Springer Theses

Recognizing Outstanding Ph.D. Research

Demetris Demetriou

The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation

Springer

Springer Theses

Recognizing Outstanding Ph.D. Research

For further volumes:
http://www.springer.com/series/8790

Aims and Scope

The series “Springer Theses” brings together a selection of the very best Ph.D. theses from around the world and across the physical sciences. Nominated and endorsed by two recognized specialists, each published volume has been selected for its scientific excellence and the high impact of its contents for the pertinent field of research. For greater accessibility to non-specialists, the published versions include an extended introduction, as well as a foreword by the student’s supervisor explaining the special relevance of the work for the field. As a whole, the series will provide a valuable resource both for newcomers to the research fields described, and for other scientists seeking detailed background information on special questions. Finally, it provides an accredited documentation of the valuable contributions made by today’s younger generation of scientists.

Theses are accepted into the series by invited nomination only and must fulfill all of the following criteria

- They must be written in good English.
- The topic should fall within the confines of Chemistry, Physics, Earth Sciences, Engineering and related interdisciplinary fields such as Materials, Nanoscience, Chemical Engineering, Complex Systems and Biophysics.
- The work reported in the thesis must represent a significant scientific advance.
- If the thesis includes previously published material, permission to reproduce this must be gained from the respective copyright holder.
- They must have been examined and passed during the 12 months prior to nomination.
- Each thesis should include a foreword by the supervisor outlining the significance of its content.
- The theses should have a clearly defined structure including an introduction accessible to scientists not expert in that particular field.

Demetris Demetriou

The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation

Doctoral Thesis accepted by
the University of Leeds, UK

Springer

Author
Dr. Demetris Demetriou
School of Geography
University of Leeds
Leeds, LS2 9JT
UK

Supervisors
Prof. Dr. John Stillwell
School of Geography
University of Leeds
Leeds, LS2 9JT
UK

Dr. Linda See
Ecosystems Services and Management Program
International Institute for Applied Systems Analysis
Schlossplatz 1, A-2361 Laxenburg
Austria

ISSN 2190-5053 ISSN 2190-5061 (electronic)
ISBN 978-3-319-02346-5 ISBN 978-3-319-02347-2 (eBook)
DOI 10.1007/978-3-319-02347-2
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013948368

© Springer International Publishing Switzerland 2014
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Parts of this thesis have been published in the following peer reviewed journal articles/conference books:

Demetriou, D., Stillwell, J., See, L., 2011. LandSpaCES: A Spatial Expert System for Land Consolidation. In: Geertman, S., Reinhardt, W., Toppen, F., (eds.), *Advancing Geo-information Science for a Changing World*, Springer-Verlag Berlin Heidelberg, 249–274. (With kind permission of Springer Science+Business Media)

Demetriou, D., Stillwell, J. and See, L., 2012a. Land consolidation in Cyprus: Why is an integrated planning and decision support system required? *Land Use Policy* 29(1), 131–142. (With the kind permission from Elsevier)

Demetriou, D., Stillwell, J. and See, L., 2012b. An Integrated Planning and Decision Support System (IPDSS) for land consolidation: theoretical framework and application of the land redistribution modules. *Environment and Planning B: Planning and Design*, 39(4), 609–628. (With kind permission of Pion Ltd, London; www.pion.co.uk and www.envplan.com)

Demetriou, D., See, L., Stillwell, J., 2012c. A spatial multi-criteria model for the evaluation of land redistribution plans. *ISPRS International Journal of Geo-Information*, 1, 272–293. doi: 10.3390/ijgi1030272

Demetriou, D., 2013. LACONISS: A Land Consolidation Integrated Support System for planning and decision making. zfv, *Journal of Geodesy, Geoinformation and Land Management*, 2, 119–131.

Demetriou, D., See, L., Stillwell, J., 2013a. A Parcel Shape Index for Use in Land Consolidation Planning. *Transactions in GIS*, doi: 10.1111/j.1467-9671.2012.01371.x. (With the kind permission of John Wiley & Sons Ltd)

Demetriou, D., Stillwell, J. and See, L., 2013b. A New Methodology for Measuring Land Fragmentation. *Computers, Environment and Urban Systems*, 39, 71–80. (With the kind permission from Elsevier)

Demetriou, D., Stillwell, J., See, L., 2013c. LACONISS: A planning support system for land consolidation. . In: Geertman, S.,Stillwell, J., Toppen, F., (eds.), *Planning Support Systems for Sustainable Urban Development*, Springer-Verlag Berlin Heidelberg, 73–90. (With kind permission of Springer Science+Business Media)

Demetriou, D., See, L., Stillwell, J., 2013d. A spatial genetic algorithm for automating land partitioning. *International Journal of Geographical Information Science* (In press), (with the kind permission from Taylor and Francis, www.tandfonline.com).

This thesis is dedicated
to my wife and children,
and to my mother and late father

Supervisors' Foreword

Land fragmentation is a major problem in many countries around the world since it may hinder rational agricultural development and sustainable rural development. Land consolidation, the popular land management approach for solving land fragmentation, is currently implemented in the majority of EU countries and in many other parts of the world. The research reported in this book focuses on the design and development of land consolidation planning support system comprised of four modules: LandFragmentS measures land fragmentation in an agricultural context; LandSpaCES Design automates land redistribution; LandSpaCES Evaluation assesses alternative land redistribution plans and; LandParcelS automates land partitioning. These four modules compose LACONISS, a prototype LAnd CONsolidation Integrated Support System for planning and decision making that integrates GIS, artificial intelligence techniques including both expert systems (ES) and genetic algorithms (GAs) and multi-criteria decision methods (MCDM) that involve many attributes and objectives. The whole system has been applied to a case study area in Cyprus.

The original contribution of this research focuses on land consolidation planning both in terms of theory and practice, by discovering new knowledge and by developing better tools and methods based on an integrated GIS platform. In terms of theory, the contribution concerns new methodologies and models for: measuring land fragmentation in a more reliable and efficient manner; automating land redistribution by successfully emulating human reasoning that easily and rapidly provides the generation of alternative solutions; evaluating land redistribution plans in a flexible way by combining a comprehensive set of criteria with varying weights; and automating land partitioning by satisfactorily optimising shape, size and the land value of parcels simultaneously. In terms of practice, LACONISS may significantly alleviate current problems apparent in the process by: reducing the time needed for carrying out land reallocation and the related operational costs through automation, efficiency and systematisation; tackling conflicts of interest via ensuring equity, transparency and standardisation of the process; and providing detailed land reallocation outputs that can be the basic inputs for *ex ante* evaluation of land consolidation projects as required by European Union rural policy.

The broader contribution of the research concerns the fields of spatial decision making, spatial optimisation, spatial systems analysis, shape analysis and space partitioning because it provides new methods and ideas that could be applied to other spatial problems that fall in these methodologies. In particular, innovations focus on: the method of integration of expert knowledge within GIS without utilising an inference engine; the method of utilising multi-attribute decision making not only in the classical way (for evaluating alternative solutions) but also for measuring the performance of an existing spatial system (land tenure system) and the quality of a spatial object (parcel shape) compared with an ideal system and an optimum object, respectively; a new formula for measuring the dispersion of spatial units represented by points in space that may be influenced by relevant policies; a new method for assigning weights to particular criteria; a new method for normalising values of a variable and the integration of a single and multi-objective genetic algorithm with a GIS for optimisation of space partitioning, guided through the use of Thiessen polygons.

Leeds, UK, July 2013

John Stillwell
Linda See

Acknowledgments

This research has been completed with the help and support of numerous people for whom I am extremely grateful. First, I would to give huge thanks from my heart to my supervisors, Prof. John Stillwell and Dr. Linda See, who trusted me to undertake this work while living in my country and tirelessly studied and edited really vast quantities of material produced over the last four years. Their feedback, advice and guidance after long discussions were invaluable and superior, which made this effort a fruitful, productive and wonderful adventure. In addition, the financial support provided to me through their research budgets, for visiting Leeds and attending training and conferences abroad to present different parts of this work was also extremely beneficial and offered me great experiences. Finally, and also important is the fact that I had the fortune to cooperate not only with two great academics but also with two wonderful people.

I also thank very much the two remaining members of my research support group, Prof. Graham Clarke and Dr. Steve Carver who always provided constructive feedback and comments during the relevant meetings. I also appreciate the help provided by Dr. Andy Evans regarding programming issues. In addition, I am grateful to Alison Manson who carefully recreated several figures presented in this thesis and the relevant papers. Thanks also are due to the administrative staff of the School of Geography who was always very kind, informative and helpful.

Further to people at Leeds, thanks are owed to my employer, i.e. the Land Consolidation Department in Cyprus, which kindly provided the data for the case study area. I would like to also thank the staff involved in preparing and discussing the case study data. In addition, thanks go to Mr. Andreas Christofis (past Senior Technical Superintendent), who developed the current land consolidation software implemented by the Department, for his useful help regarding programming issues. I would also like to thank many other land consolidation experts who participated in various discussions and interviews regarding the development of the system and who provided fruitful suggestions and advice. I am also very grateful to all those anonymous people involved in discussions regarding my questions which were addressed in relevant GIS development support forums (of ESRI and GIS Stack Exchange) that unstuck me several times from programming problems.

Finally, I am very grateful to my wife Voula and our two children Katerina and Angelos, who showed understanding and supported me with various ways during this difficult effort.

Contents

Abbreviations

AFF	Areal form factor
CAD	Computer aided design
DoP	Dispersion of parcels
DSS	Decision support system
EC	European commission
ES	Expert system
EU	European union
FAO	Food and agriculture organization
FD	Fractal dimension
FIG	International federation of surveyors
GA	Genetic algorithm
GDP	Gross domestic product
GIS	Geographic information systems
GLFI	Global land fragmentation index
IPDSS	Integrated planning and decision support system
LACONISS	Land consolidation integrated support system for planning and decision making
LandFragmentS	Land fragmentation system
LandParcelS	Land parcelling system
LandSpaCES	Land spatial consolidation expert system
LCC	Land consolidation committee
LCD	Land consolidation department (in Cyprus)
LFI	Land fragmentation index
LIS	Land information system
LVC	Land valuation committee
LSD	Land surveys department (in Cyprus)
LSR	Landowner satisfaction rate
MADM	Multi-attribute decision making
MCDM	Multi-criteria decision methods
MODM	Multi-objective decision making
mSM	Mean standardisation method
NIET	No inference engine theory
PCC	Parcel concentration coefficient
PPI	Parcel priority index

PSI	Parcel shape index
PSS	Planning support system
SA	Sensitivity analysis
SDSS	Spatial decision support system
SI	Shape index

Chapter 1
Introduction

1.1 Context

Land fragmentation involves a situation when single landholdings consist of numerous spatially separated land parcels [1–4]. It is a fundamental spatial problem in rural areas that implies a defective land tenure structure and inhibits agricultural production and rural sustainable development more generally. The main shortcomings associated with land fragmentation include the small sizes and irregular shapes of the land parcels, the large potential distances between parcels and the owner's farmsteads, and the existence of boundary lines [4–8]. There may be additional complexities due to the lack of road access to land parcels in certain areas and issues relating to unfavourable ownership rights. The main effect of land fragmentation is the increase in the cost of transport and production and hence a reduction in the income of the farmers. Fragmentation is a frequent occurrence in various parts of the world including EU27 countries where censuses [9] have shown that up to 75.7 % of all agricultural holdings were of less than five hectares (ha). In Cyprus, land fragmentation has been a problem for several decades with the average land holding size declining from 7.2 ha in 1946 to 3.5 ha in 2003 [10].

At present, there is no standard algorithm or methodology for measuring land fragmentation [5, 11] although a variety of indices have been developed in the past [12–17]. These indices have three significant drawbacks. First, they are not comprehensive since, at best, they take into account three factors which can be correlated (i.e. the number of parcels, the size of each parcel and the size of the whole ownership); hence they ignore significant spatial factors such as the dispersion of parcels per ownership and the shape of parcels and also non-spatial factors such as the type of ownership and the existence of accessibility of a parcel to a road. Second, they are not flexible because they are represented by standard mathematical equations and therefore a planner is not able to select which factors should be accounted for in a particular project. Third, they are not problem specific since the factors are equally weighted, which may not be true for all cases. As a result of these deficiencies, the existing land fragmentation indices cannot adequately represent the land fragmentation problem; hence their outcome can be

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_1, © Springer International Publishing Switzerland 2014

misleading and may lead to wrong decisions. Therefore, it is clear that there is a need for a new and more reliable methodology for measuring land fragmentation.

Land consolidation, which began in Europe in the 14th century [4, 18] is considered to be the most favoured land management response to the problem of land fragmentation. Both the European Union (EU) and the Food and Agriculture Organization (FAO) regard land consolidation schemes among the most important measures in their integrated rural development programmes [9, 19, 20]. Land consolidation consists of two main components: land reallocation (or readjustment) and agrarian spatial planning [21]. The former involves finding an optimal rearrangement of the existing land tenure structure in a given rural area based on the country's land consolidation legislation and current practices, both of which impose a series of criteria and various constraints on achieving the aims of a particular land consolidation project. The latter involves the provision of the necessary infrastructure such as roads, irrigation and drainage systems, landscaping and environmental management, village renewal and soil conservation.

Land consolidation in Cyprus, which began much later (in 1970), has resulted in significant positive changes in the land tenure structure [22] and the provision of a road network in many rural areas, which have both contributed to an improvement in the incomes of farmers. However, the implementation of land consolidation in its current form has come under criticism and these benefits have not always been recognised. The process has also experienced major problems such as the long duration of projects, the high operational costs involved in consolidation and the conflicts of interest that have arisen among stakeholders. These latter problems are associated with land reallocation, which is the most important, complex and time-consuming part of the land consolidation process [4, 23–28]. Therefore, there is a demand to support and automate land reallocation where possible so that it can be transformed into an efficient, systematic and transparent process to alleviate the problems concerned.

Land reallocation can be split into two main sub-processes: land redistribution and land partitioning [10]. Land redistribution, which involves the decision making part of the whole process, comprises the preparation of a preliminary plan to restructure ownerships and hence parcels in terms of their number, ownership, size, land value and approximate location. It is based on legislation, the existing land tenure structure, rules of thumb and the experience of the planner. In Cyprus, it involves answering the following questions: Which landowners will have property in the new plan and which will not? What are the total area, number of parcels and value of the property which each landowner will receive in the new plan? What are the area, value and approximate location of each new parcel belonging to each landowner? Land partitioning, on the other hand, involves a design process, i.e. the subdivision of land into smaller 'sub-spaces' (land parcels) in terms of parcel shape, size and land value. This is conventionally a trial-and-error procedure based on legislation, the existing land structure, empirical design criteria, constraints and rules of thumb. The outcome of this process is the final land consolidation plan.

It might be expected that a traditional process such as land reallocation in the 21st century would be adequately supported by geographical information systems (GIS) but it is clear that proprietary GIS do not have the capability to support such complex spatial planning and decision-making problems [29, 30]. In particular, although GIS provide excellent data management, visualisation and spatial analysis tools which may be utilised for investigating and formulating solutions for a spatial problem, they are too generic and hence do not have the ability to incorporate expert knowledge, produce alternative solutions or allow evaluation of these solutions without considerable programming or customisation. In addition, although research on land reallocation has been ongoing since the 1960s [31], an integrated planning and decision support system for land consolidation that truly automates the process in a systematic and efficient manner where possible has not yet been realised. Existing research focuses mainly on isolated algorithms for land redistribution, land partitioning and the evaluation of land consolidation plans.

More specifically, some previous studies have attempted to automate the problem of land redistribution by treating it as a mathematical optimisation problem (e.g. [28, 31–35]). This means that, although results are sometimes optimal in terms of efficiency, they are not necessarily realistic or operationally applicable. Other studies, focusing on land partitioning [36, 37] have produced operationally encouraging results but solutions that are different from what experts would have produced. Furthermore, land consolidation evaluation studies [38–40] have also suffered from the lack of tools capable of providing detailed land reallocation inputs for ex-ante project evaluation. The limitations of these studies emphasise the need for new and more efficient methods and techniques to model the entire land reallocation process within an integrated planning framework.

Based on the above considerations, the focus of this research can be framed as follows: how can the land fragmentation problem be better represented and both sub-processes of land reallocation (i.e. land redistribution and land partitioning) be automated and supported in a systematic and efficient manner through new algorithms and methods in the context of an integrated planning and decision making framework within a common computerised platform?

1.2 Thesis Aim and Objectives

The aim of this research is therefore to design, develop and evaluate a prototype hybrid system to support planning and decision making for land consolidation, which integrates new models for land fragmentation measurement, land re-distribution and land partitioning within a GIS environment. The new system, called LACONISS (LAnd CONsolidation Integrated Support System for planning and decision making), adopts the three phase decision making model (Intelligence-Design-Choice) proposed by Simon [41], which has been extended by Sharifi et al. [42] as a generic planning and decision-making framework and integrates GIS, expert systems (ES), genetic algorithms (GAs), multi-attribute decision making methods (MADM) and multi-objective decision making methods (MODM). This model addresses three critical questions about land consolidation. Is there a land fragmentation problem and hence a need for land consolidation? What are the alternative land re-reallocation plans? Which alternative plan is the most beneficial? Based on these considerations, the operational framework of LACONISS [43] is presented in Fig. 1.1, which shows the set of different methods utilised in each component.

LACONISS consists of three sub-systems: LandFragmentS (Land Fragmentation System) that involves a new land fragmentation module which is capable of measuring the extent of land fragmentation; LandSpaCES (Land Spatial Consolidation Expert System) that contains two modules: the Design module which automatically generate alternative land redistribution plans and the Evaluation module that is capable to evaluate these alternative plans to identify the most beneficial and; LandParcelS (Land Parcelling System) which is capable of automatically designing the new parcels in terms of shape, size and land value that constitute the final land reallocation plan.

The aim of the research will be achieved through the following objectives:

Objective 1: To critically evaluate the literature on land fragmentation, consolidation and reallocation (Chaps. 2, 3 and 4).

Objective 2: To critically evaluate the literature on the tools, methods and techniques for supporting spatial planning processes and to develop a conceptual framework for an integrated planning and decision support system for land consolidation (Chap. 5).

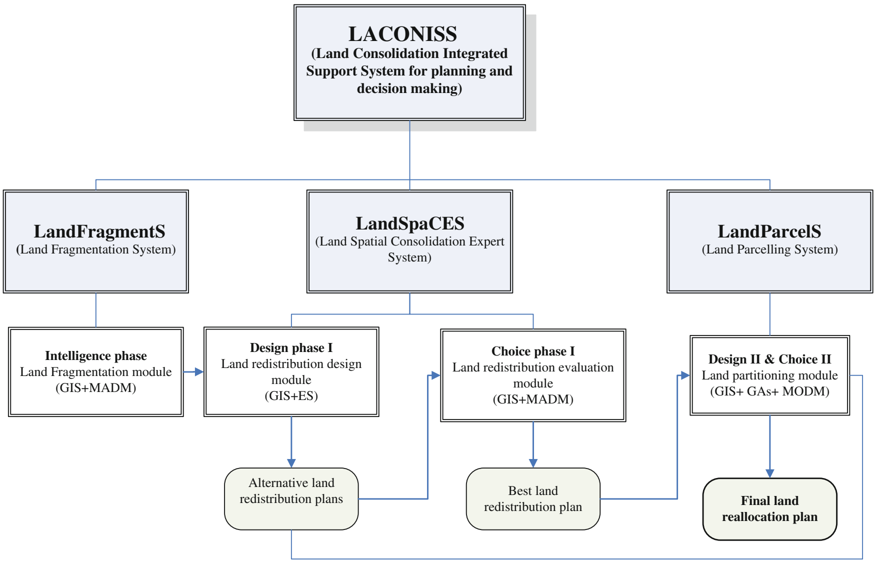


Fig. 1.1 The operational framework of LACONISS

Objective 3: To develop and test a new model for measuring the land fragmentation problem by integrating a multi-attribute decision making method with GIS (Chap. 7).

Objective 4: To develop and test a new land redistribution model that is capable of automatically generating alternative land redistribution plans by integrating expert systems with GIS (Chap. 8).

Objective 5: To develop and test a new evaluation model that is capable of evaluating alternative land redistribution plans by integrating a multi-attribute decision making method with GIS (Chap. 9).

Objective 6: To develop and test a new land partitioning model that is capable of automatically generating the new parcels in terms of shape, size and land value by integrating genetic algorithms and multi-objective decision making methods with GIS (Chap. 10).

The achievement of the above objectives represents the original contributions of this research, which focuses on land consolidation planning both in terms of theory and practice, by discovering new knowledge and by developing better tools and methods based on an integrated GIS platform. In terms of theory, the contribution concerns new methodologies and models for: measuring land fragmentation in a more reliable and efficient manner; automating land redistribution by successfully emulating human reasoning that easily and rapidly provides the generation of alternative solutions; and evaluating land redistribution plans in a flexible way by combining a comprehensive set of criteria with varying weights, and automating land partitioning by satisfactorily optimising shape, size and the land value of parcels simultaneously.

These new methodologies involve the development of several focused innovations such as: a new metric known as the *GLFI* (global land fragmentation index), that quantifies the land fragmentation problem and outperforms existing indices; a new coefficient called *PPI* (parcel priority index) that ‘predicts’ landowners’ preferences and ensures equity of land redistribution; a new index called *PSI* (parcel shape index) for measuring the shape of parcels [44] that outclasses existing metrics; a new measure called *PCC* (parcel concentration coefficient) that represents the dispersion of parcels in a more explicit way; a measure called the *LSR* (landowner satisfaction rate) that ‘predicts’ the landowners’ agreement regarding land redistribution; a new fitness function for land partitioning optimisation that may guide the process of using Thiessen polygons for generating parcels with a certain shape, size and land value; a new transformation process called the ‘mean standardisation method’ (mSM) that is better than similar existing approaches; and a new qualitative rating method for assigning weights in criteria/factors in a more realistic way than similar existing methods.

The above theoretical innovations contribute to supporting the application of a major land management approach, such as land consolidation planning, by significantly alleviating the three problems noted earlier that currently challenge the process: they reduce the time needed for carrying out the land reallocation process and the related operational costs through automation, efficiency and systematisation of the process; they tackle conflicts of interest via ensuring equity, transparency and standardisation of the process; and they provide detailed land reallocation outputs that can be the basic inputs for ex-ante evaluation land consolidation projects as required by EU rural policy. The latter, in turn, is expected to have consequent multiple benefits for the stakeholders involved including governments, local authorities, planners and landowners.

The broader contribution of the research concerns the fields of spatial decision making, spatial optimisation, spatial systems analysis, shape analysis and space partitioning because it provides new methods and ideas that could be applied to other spatial problems that fall in the noted fields. In particular, innovations focus on: the method of integration of expert knowledge within GIS without utilising an inference engine; the method of utilising multi-attribute decision making not only in the classical way (for evaluating alternative solutions) but also for measuring the performance of an existing spatial system (land tenure system) and the quality of a spatial object (parcel shape) compared with an ideal system and an optimum object respectively; a new formula for measuring the dispersion of spatial units represented by points in space that may be influenced by relevant policies; a new method for assigning weights to particular criteria; a new method for normalising values of a variable and the integration of a single and multi-objective genetic algorithm with a GIS for optimisation of space partitioning guided through the use of Thiessen polygons.

1.3 Thesis Structure

The rest of the thesis is organised as follows:

Chapter 2—Land Fragmentation contains a review of the extant literature on the land fragmentation problem, including existing descriptor indices that suggest the need for a new methodology to measure land fragmentation. The available policies for handling land fragmentation are then outlined followed by an examination of the extent of the problem at global and EU levels. Finally, an extensive analysis is provided of the land fragmentation trends in Cyprus.

Chapter 3—Land Consolidation presents the conceptual framework underpinning this research. In particular, it discusses the relevant literature on land consolidation, describes the land consolidation procedure, emphasises the importance of land consolidation in the context of EU and FAO policies, and then focuses on the way in which it is applied in Cyprus, which constitutes the case study country for demonstrating LACONISS.

Chapter 4—Land Reallocation outlines this core stage in the process of land consolidation. In particular, the land reallocation process is set out as applied in Cyprus and the relevant principles are outlined. This is followed by a critical review of existing related research and a discussion of the ex-ante EU evaluation framework for rural development programmes and existing land consolidation evaluation studies.

Chapter 5—System Development Framework concentrates on the tools, methods and techniques for system development, in particular the theoretical foundations for the spatial decision making process and a critical review of the existing tools provided to support this process. Both multi-attribute decision making methods (MADM) and multi-objective decision making methods (MODM) are examined as well as expert systems in spatial decision making and their appropriateness for solving the land redistribution problem. Similarly, genetic algorithms (GAs) and their potential for solving the land partitioning problem are also investigated. Finally, the conceptual framework of LACONISS is defined.

Chapter 6—Case Study: The four modules that comprise LACONISS are implemented and evaluated using a real world land consolidation case study, which is presented in this chapter. The study area, the types of data collected, their quality and the building of the GIS model are outlined.

Chapter 7—LandFragmentS Model discusses important model structure aspects including a methodology for developing the new index called *GLFI* (global land fragmentation index) and a new method for assigning weights to factors. In addition, it discusses the factors involved in the model and the standardisation process of these factors. This is followed by a presentation of the module interface including the calculation of existing land fragmentation indices, the generation of the land fragmentation table and its standardisation and sensitivity analysis. A new 'parcel shape index' (*PSI*) is then presented, which is compared to existing indices. Finally, the model is applied using the case study area in Chap. 6 and compares the outcomes with existing land fragmentation indices. The application of the model also involves changing the weights of factors, a sensitivity analysis of the outputs and a parcel shape analysis based on the *PSI*.

Chapter 8—LandSpaCES Design Model describes the basic steps for developing a spatial expert system, i.e. system definition, knowledge acquisition, knowledge representation, knowledge base building and the definition of the inputs and outputs. The system development issues are then considered such as the selection of the appropriate development tool and the description of the system architecture and interface. The system evaluation is then carried out both in terms of verification and validation where ten different sets of inputs are used to generate ten alternative land redistribution solutions for evaluation by the next model (Chap. 9).

Chapter 9—LandSpaCES Evaluation Model describes the design and development of the second model of LandSpaCES. Initially, the problem is defined and the selection of the evaluation criteria is outlined. In addition, two new concepts (the parcel concentration coefficient—*PCC* and the landowner satisfaction rate—*LSR*) are introduced. Thereafter, the module interface is presented along with the basic elements of the module such as the generation of the impact table, the weighting criteria, standardisation, ranking alternatives and sensitivity analysis. Finally, the model is applied to the case study area (Chap. 6) to evaluate ten alternative solutions.

Chapter 10—LandParcelS Model deals with the development of the land partitioning module, the fourth and final sub-system of LACONISS. The chapter initially focuses on modelling the land partitioning process as a single and multi-objective optimisation problem followed by the detailed design of the genetic algorithm in terms of representation and the definition of evolutionary operators. The module interface is then presented, sequenced by an application of the model for both single and multi-objective cases where the performance of the algorithm is tested using land blocks from the case study area.

Chapter 11—Conclusions and Further Research: In this chapter there are three main sections. The first section highlights the research innovations and main conclusions whilst the second section deals with the research and system limitations. The third section suggests directions for further research focusing on improvements to LACONISS. Eventually, the whole thesis is closed by stating a final remark.

References

1. Binns O (1950) *The consolidation of fragmented agricultural holdings* (Vol. 11). Washington: FAO Agricultural Studies.
2. King, R., & Burton, S. (1982). Land fragmentation: Notes on a fundamental rural spatial problem. *Progress in Human Geography, 6*(4), 475–494.
3. McPherson, M. F. (1982). *Land fragmentation: A selected literature review*. Development Discussion Paper No. 141. Harvard Institute for International Development, Harvard University.
4. Van Dijk, T. (2003). *Dealing with Central European land fragmentation*. Delft: Eburon.
5. Bentley, W. (1987). Economic and ecological approaches to land fragmentation: In defence of a much-maligned phenomenon. *Annual Review of Anthropology, 16*, 31–67.
6. Burton, S. (1988). Land consolidation in Cyprus: A vital policy for rural reconstruction. *Land Use Policy, 5*(1), 131–147.
7. Karouzis, G. (1977). *Land ownership in Cyprus: Past and present*. Nicosia: Strabo.
8. Niroula, G. S., & Thapa, G. B. (2005). Impacts and causes of land fragmentation, and lesson learned from land consolidation in South Asia. *Land Use Policy, 22*(4), 358–372.
9. European Commission. (2005). *Agricultural statistics-quarterly Bulletin: Special issue-frame structure survey 2003*. Luxemburg: Office for Official Publications of the European Communities.
10. Demetriou, D., Stillwell, J., & See, L. (2012). Land consolidation in Cyprus: Why is an integrated planning and decision support system required? *Land Use Policy, 29*(1), 131–142.
11. Van Hung, P., MacAulay, G., & Marsh, S. (2007). The economics of land fragmentation in the North Vietnam. *The Australian Journal of Agricultural and Resource Economics, 51*, 195–211.
12. Edwards, D. (1961). An economic study of small farming in Jamaica. University College of West Indices.
13. Dovring, F. (1965). *Land and labour in Europe in the twentieth century* (3rd ed.). Hague: The Nijhoff.
14. Simmons, A. J. (1964). An index of farm structure, with a Nottinghamshire example. *East Midlands Geographer, 3*, 55–261.
15. Januszewski, J. (1968). Index of land consolidation as a criterion of the degree of concentration. *Geographia Polonica, 14*, 291–296.
16. Igozurike, M. U. (1974). Land tenure, social relations and the analysis of spatial discontinuity. *Area, 6*, 132–135.

17. Schmook, G, Jr. (1976). The spontaneous evolution from farming on scattered strips to farming in severalty in Flanders between the sixteenth and twentieth centuries: A quantitative approach to the study of farm fragmentation. In R. H. Buchanan, R. A. Butlin, & D. McCourt (Eds.), *Fields, Farms and Settlement in Europe* (pp. 107–117). Belfast: Ulster Folk and Transport Museum.
18. Uimonen, M. (2004). Actual developments of land consolidation in Finland. In *Proceedings of Symposium on Modern Land Consolidation*, 10–11 Sept. Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_04_uimonen.pdf.
19. FAO. (2003). *The Design of Land Consolidation Pilot Projects in Central and Eastern Europe*. Rome: FAO.
20. FAO. (2008). *Opportunities to mainstream land consolidation in rural development programmes of the European Union*. Rome: FAO-Land Tenure Policy Series.
21. Thomas, J. (2006). What's on regarding land consolidation in Europe? In *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 Oct. Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_03_thomas_0311.pdf.
22. Land Consolidation Department (LCD). (1993). *Land consolidation in Cyprus*. Nicosia: Ministry of Agriculture and Natural Resources of Cyprus.
23. Yomralioglu, T. (1993). *A nominal asset value-based approach for land readjustment and its implementation using GIS*. PhD thesis, Department of Surveying, University of Newcastle upon Tyne.
24. Sonnenberg, J. (2002). Fundamentals of Land consolidation as an instrument to abolish fragmentation of agricultural holdings. In *Proceedings of the XXII International FIG Congress*, 19–26 Apr. Washington, USA. Available from URL: http://www.fig.net/pub/fig_2002/Ts7-4/TS7_4_sonnenberg.pdf.
25. Essadiki, M., Ettarid, M., & Robert, P. (2003). Optimisation of technical steps of a rural land consolidation using a geographic information system: Land reallocation step. In *Proceedings of FIG Working Week, Still on the Frontline*, 13–17 Apr. Paris, France. Available from URL: http://www.fig.net/pub/fig_2003/TS_13/PP13_2_Essadiki_et_al.pdf.
26. Van den Brink, A. (2004). Land consolidation and the emergence of the metropolitan landscape. In *Proceedings of Symposium on Modern Land Consolidation*, 10–11 Sept. Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_03_vandenbrink.pdf.
27. Thomas, J. (2006). Property rights, and fragmentation and the emerging structure of agriculture in Central and Eastern European countries. *Journal of Agricultural and Development Economics*, [online] *3*(2). Available from URL: ftp.fao.org/docrep/fao/009/ah757e/ah757e00.pdf.
28. Ayranci, Y. (2007). Re-allocation aspects in land consolidation: A new model and its application. Asian Network for Scientific Information. *Journal of Agronomy, 6*(2), 270–277.
29. Batty, M. (2008). Planning support systems: Progress, predictions, and speculations on the shape of things to come. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 3–30). Cambridge: Lincoln Institute of Land Policy.
30. Geertman, S., & Stillwell, J. (2009). *Planning support systems: Best practice and new methods*. Dordrecht: Springer.
31. Rosman, F. & Sonnenberg, J. (1998). New method for the design of the reallocation plan in land consolidation projects. FIG conference. In *Proceedings of the XXI FIG Congress Brighton, Developing the Profession in a Developing Word,* 19–25 July. Brighton, UK.
32. Kik, R. (1990). A method for reallotment research in land development projects in The Netherlands. *Agricultural Systems, 33*, 127–138.
33. Avci, M. (1998). A new approach oriented to new reallotment model based on block priority method in land consolidation. *Turkish Journal of Agriculture and Forestry, 23*, 451–457.
34. Yaldir, A., & Rehman, T. (2002). A methodology for constructing multi-criteria decision support systems for agricultural land consolidation using GIS and API: An illustration from Turkey. *Computers and Electronics in Agriculture, 36*, 55–78. (Retracted).

35. Cay, T., & Iscan, F. (2006). Optimisation in land consolidation. In *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 Oct. Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ps07/ps07_14_nam_kim_0406.pdf.
36. Buis, A., & Vingerhoeds, R. (1996). Knowledge-based systems in the design of a new parcelling. *Knowledge-Based Systems, 9*, 307–317.
37. Tourino, J., Boullon, M., & Gonzalez, X. (2003). A GIS-embedded system to support land consolidation plans in Galicia. *International Journal of Geographical Information Science, 17*(4), 377–396.
38. Coelho, C., Pinto, P. A., & Silva, M. (2001). A systems approach for the estimation of the effects of land consolidation projects (LCPs): A module and its application. *Agricultural Systems, 68*, 179–195.
39. Crecente, R., Alvarez, C., & Fra, U. (2002). Economic, social and environmental impact of land consolidation in Galicia. *Land Use Policy, 19*(2), 135–147.
40. Sklenicka, P. (2006). Applying evaluation criteria for the land consolidation effect to three contrasting study areas in the Czech Republic. *Land Use Policy, 23*(4), 502–510.
41. Simon, A. (1960). *The new science of management decision*. New York: Harper & Row.
42. Sharifi, A., Herwijnen, M., Toorn, W. (2004). *Spatial Decision Support Systems*. Lecture Notes, ITC, International Institute for Geo-Information Science and Earth Observation, The Netherlands.
43. Demetriou, D., Stillwell, J., & See, L. (2012). An integrated planning and decision support system (IPDSS) for land consolidation: Theoretical framework and application of the land redistribution modules. *Environment and Planning B: Planning and Design, 39*(4), 609–628.
44. Demetriou, D., See, L., Stillwell, J., (2013). A Parcel Shape Index for Use in Land Consolidation Planning. *Transactions in GIS*, doi: 10.1111/j.1467-9671.2012.01371.x.

Chapter 2
Land Fragmentation

2.1 Introduction

The core topic of this research is the support of land consolidation through an Integrated Planning and Decision Support System (IPDSS). However, land consolidation has been traditionally an approach for solving the land fragmentation problem and hence it is considered necessary to firstly review the conceptual framework of this background problem. In particular, Sect. 2.2 presents and discusses land fragmentation definitions, the associated problems, causes of the problem, advantages/disadvantages of this phenomenon and indicators used for measuring land fragmentation. Section 2.2.3 then discusses three categories of available policies used to control land fragmentation. This is followed by Sect. 2.4, which explores and discusses the extent of the problem at both a global and EU level providing relevant statistics for each country. Finally, Sect. 2.2.5 focuses on the country case study, i.e. Cyprus. It begins with the historical evolution of the Cypriot land tenure system followed by the causes of the land fragmentation problem and the current land tenure trends based on agricultural censuses from 1946 to 2003. The associated land tenure problems are then examined in depth.

2.2 Land Fragmentation Review

2.2.1 Definitions

Fragmentation derives from the word 'fragment' which, according to the Oxford Dictionary, refers to a small or incomplete part or piece broken off, i.e. separated from the whole to which it originally belongs. Land fragmentation, which is also known as pulverization, parcellization or scattering [1], is defined in the literature as the situation in which a single farm consists of numerous spatially separated parcels [2–5]. King and Burton [3] characterise land fragmentation as a fundamental rural spatial problem concerned with farms which are poorly organised at locations across space.

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_2, © Springer International Publishing Switzerland 2014

Van Dijk [5, 6] distinguishes four types of land fragmentation: fragmentation of land ownership; land use; within a farm (or internal fragmentation); and separation of ownership and use. Fragmentation of land ownership refers to the number of landowners who use a given piece of land. Fragmentation of land use refers to the number of users that are also tenants of the land. Internal fragmentation emphasises the number of parcels exploited by each user and considers parcel size, shape and distance as the main issues. Separation of ownership and use involves the situation where there is a discrepancy between ownership and use. It appears that Western Europe has addressed only the second and third types of fragmentation since the other two types can be regarded as problem specific to central European countries, as a result of the privatisation process after the collapse of communism in 1990. This chapter focuses on internal fragmentation.

There are contradictory considerations regarding whether land fragmentation is a problem or not which have stimulated multidisciplinary debate. This has been reviewed comprehensively by Bentley [1] who points out that land fragmentation is considered by agricultural policy makers as the source of ineffective agriculture and thus it must be prevented by legislative actions. Similarly, economists, although believing that land fragmentation can be adaptive under certain conditions, recognise that this phenomenon gradually becomes non-adaptive as technology improves and the relevant costs change [7, 8]. European geographers tend to agree with economists since they support the idea that land fragmentation is not well-suited to the twentieth century machinery and labour costs.

In contrast, non-European geographers suggest that land fragmentation can be really adaptive although some of them recognise a series of advantages and disadvantages. Anthropologists, on the other hand, see land fragmentation as a positive situation under which farmers can cultivate many environmental zones, minimise production risk and optimise the schedule for cropping activities. Many environmentalists consider that any intervention to land tenure structure to remove land fragmentation may have serious environmental effects in nature and even social effects on landowners. Those ethnographers who have made reference to land fragmentation consider it neither a problem nor an adaptation.

These contrary views are not unreasonable since numerous studies showed contrary results. For instance, Karouzis [9] and Blaikie and Sadeque [10] argue that land fragmentation is a serious constraint preventing productivity whilst other authors [11–14] support the view that land fragmentation has not had negative effects on productivity. However, these studies focused on certain regions. Therefore, Van Dijk [5, 6] and Bentley [1] provide a balanced view by pointing out that land fragmentation has advantages and disadvantages with consequent favoured and adverse effects for different contexts. Thus, these effects should be evaluated separately for each community by considering the local economic, social and environmental conditions before decisions for relevant policies are undertaken.

2.2.2 Problems Associated with Fragmentation

The main problems associated with land fragmentation can be outlined as follows: distance between parcels and the farmstead; many boundary lines; small size and irregular shape of parcels; and lack of access. In particular, when parcels are spatially dispersed, travel time and hence costs in moving labour, machines etc. from one parcel to another, are increased [1, 9, 15, 16]. A consequent drawback is that parcels at a greater distance are cultivated less intensively [5]. Many case studies have proven the consequences of this problem in practice: for instance, Thompson [17] for Greek farms, Karouzis [18] for Cypriot landholdings, DeLisle [19], who demonstrated that distance has a relationship to intra-farm cropping patterns in Manitoba (Canada), and Blaikie [20, 21] for four Indian villages.

In addition, land fragmentation involves a complicated boundary network among parcels (hedges, stone walls, ditches, etc.) which cause land wastage [1, 9, 15] because a part of a holding (especially in small parcels) remains uncultivated at the margins of the parcels. Moreover, the cost of fencing and neighbouring conflicts between landowners increases due to this problem. Furthermore, the small size and irregular shape of parcels is another dominant problem associated with land fragmentation [22]. The use of modern machinery is difficult or may be impossible in tiny parcels and may require an excessive amount of manual work in the corners and along the boundaries [1, 9, 15, 23]. Specifically, irregular parcel shape prevents the proper cultivation of land, especially for some crops (e.g. vines, olives) which need to be cultivated in series. Also, the implementation of soil conservation work is harder, the construction costs are higher, more fencing is needed and roads, which are usually adjusted to the shape of parcels, have low geometrical standards.

As a result of these problems, productivity decreases and hence the income of farmers also declines. Thus, this situation emphasises the need for agricultural commercialization via large farm sizes to attain economies of scale. However, although these arguments may seem logical, and many authors have revealed the positive relationship between farm size, productivity and net income [24, 25], other authors [26] have supported an inverse relationship between farm size and productivity. Niroula and Thapa [16], for example, argue that this situation was a reality in the past but not at the present time.

In addition to the classical land fragmentation problems, the lack of a road network providing access to a parcel is a primary factor favouring abandonment or for parcels to remained uncultivated [9]. Small fields often have no road access [17, 20–22, 27]. Furthermore, the lack of a road network to access the land parcels prevents the introduction of other agricultural infrastructure such as irrigation and drainage systems. Moreover, this problem causes conflicts among neighbouring landowners which may clog up the local courts because a part of a 'front' parcel may be used as a road access or a path to the 'back' parcel.

It is generally accepted that all the above problems associated with land fragmentation usually act as an obstacle to rational agricultural development. At present, this situation, which is even more intense because of the high agricultural market competition and the high industrialization of the agricultural sector, reduces farmers' net income considerably.

2.2.3 Causes

Even though causes of land fragmentation may vary from country to country and from region to region, authors [1, 3, 16, 28, 29] tend to agree that the four main factors triggering this situation are inheritance; population growth; land markets; and historical/cultural perspectives. These are briefly described below.

It is accepted that inheritance is the primary cause of land fragmentation. Inheritance laws applied in most countries facilitate or demand the subdivision of holdings into equal parts among all heirs or in some countries among only sons. This tradition has deep historical roots in old world countries' laws (e.g. the Napoleonic and Islamic inheritance laws) where the equal distribution of patrimony among heirs was a requirement [3]. As a result, land fragmentation has become a continuous process with land holdings and land parcels getting smaller and smaller as they have been dispersed to successive generations [30]. There is empirical evidence that inheritance is the prominent factor for land fragmentation in many places such as in medieval England [31], in the Netherlands [32] and in Cyprus [33]. This strong relationship between inheritance and land fragmentation has also been demonstrated in a Portuguese study (Silva 1983; cited in [1]).

Population growth, which is linked with inheritance [2, 8, 34–36], involves increasing demand for land acquisition. However, there are some contradictory views about this issue. In particular, [37–39] claim that population increase is a contributing factor towards better land management and increasing agricultural production. Similar views have been expressed also by Homans [40]. These views contest those of the majority of other scholars causing some confusion.

Since land is a multi-purpose resource, land markets play an important role in the whole process of ownership restructuring, because people wish to acquire a piece of land not only for agricultural activities, but also for other reasons such as investments, enhancing personal prestige and status, and having secure current and future living conditions for the family. Grigg [41] notes that acquiring land is among the most important aims of many people in different societies all over the world. In principle, land markets contribute to further fragmentation of the existing holdings since, in most cases, farmers purchase land which is not continuous to their existing holdings or they (or other people) may purchase pieces of land as shares in other parcels. However, in some cases, land purchase may reduce land fragmentation when farmers acquire neighbourhood pieces of land to expand their holdings.

Historical and cultural perspectives, which prevailed in old communities (such as in Europe), were inevitably the cause of land fragmentation. Some authors consider that the current problem of land fragmentation is a result of the historical legacy of an ancient field structure [1]. In those times, land fragmentation was adaptive to the prevailing conditions, i.e. small fields for acquiring a family's subsistence, manual or animal cultivation, cheap labour, small production, etc. However, these conditions are not well suited to current modern agricultural mechanization demands.

2.2.4 Disadvantages and Advantages

Although land fragmentation is generally considered as a fundamental rural spatial problem due to many disadvantages and its impacts, it is not a problem by definition in all cases because it can also be beneficial. In particular, the most prominent disadvantage is the increase of economic costs because it hinders mechanisation, causes inefficiencies in production and involves large costs to alleviate its effects. As a result, agricultural productivity and hence income are reduced. Namely, Karouzis [42] found that farmers (in a region in Cyprus with an average of 22 parcels per holding) needed to travel almost 4,000 km annually to visit their scattered parcels. Another economic drawback is that fragmentation limits the desire of a farmer to modernize or rationalise his/her holding by introducing new agricultural techniques such as machinery, irrigation systems and fencing while also preventing the introduction of new crops, disease controls, etc. This is due to small parcel size; a remarkable statistic is that a tractor may spend up to one third of its time turning round on a one hectare parcel [43].

In addition to the economic impacts, King and Burton [44] support the view that fragmentation may have social and psychological impacts with consequently wider repercussions across the agricultural sector or within a certain community as a whole. More specifically, an organised land tenure structure in a rural community may raise the status of certain farmers and improve communication and cooperation among them. Also, it may reduce inequalities among farmers which have less agricultural problems due to fragmentation. King and Burton [3] also emphasise the social tension caused by disputes over ownership, especially in the case of shared and multiple ownerships. As a result, litigation sometimes leads to serious conflicts and court settlement.

While most studies tend to focus on the negative impacts of land fragmentation in agriculture, sometimes land fragmentation offers benefits and sometimes may be desirable or even necessary [3]. Namely, literature concentrates on three main benefits: risk management; crop scheduling; and ecological variety. In particular, risk management may minimise the potential risk due to climatic and natural disasters (e.g. storms, frosts, fire, floods, etc.) because risk is spread spatially [1, 3, 28, 45, 29]. Also, risk management involves the logical reduction of risk by giving a farmer a variety of soils, crops and growing conditions, by virtue of the spatial dispersion of parcels [29]. This situation is especially a reality in Alpine and monsoon areas.

In addition, crop scheduling may be favoured when parcels are scattered between various locations at different altitudes because crops ripen at different times. Thus, a farmer may adjust his labour force according to a schedule so as to avoid labour bottlenecks. For example, crop scheduling through altitude zones was very important in some villages in the Swiss Alps, for the mowing of hay. Also, crop scheduling is possible on the island of Pantelleria (Italy) since grapes ripen at different times; a household with scattered parcels may harvest all of its grapes without extra labour [46]. The advantages of crop scheduling is not limited to mountainous areas; [47], for example, indicates that crop scheduling has allowed farmers in England to maximise their self-employment and minimise the amount of hired labour needed.

Furthermore, fragmentation may also offer ecological benefits by formulating a natural mosaic of parcel shapes and crops. In contrast, regular parcel shapes, especially in semi-mountainous and mountainous areas are not so harmonious with the landscape and they may create a 'foreign' aesthetic value. In addition, small parcels are less exposed to winds and hence to crop diseases and to soil erosion. Moreover, some non-economic and social benefits of fragmentation are offered by the fact that scattered parcels will be distributed more easily to the heirs of a holding. Also, in some communities in which cultivation is still subsistence based, then fragmentation really offers the advantages mentioned above.

2.2.5 Indicators

Land fragmentation is a spatial problem which depends on many parameters. King and Burton [3] cite the following six relevant factors: holding size; number of parcels belonging to the holding; size of each parcel; shape of each parcel; the spatial distribution of parcels; and the size distribution of parcels. In Cyprus, land fragmentation has additional complexities including the lack of road access to land parcels and problematic ownership rights [48]. For example, a parcel may be owned in undivided shares, i.e. it may belong to more than one landowner; or a parcel may have dual or multiple ownership, i.e. the land is owned by one person whilst the trees growing on the land are owned by someone else and a third party has ownership rights to the water. In addition, a land parcel may not have a title deed. The existence of all these different factors highlights the complexity of representing and measuring land fragmentation.

There appears to be no standard measurement of land fragmentation [1, 29] and no index takes into account all of the above mentioned factors [49]. Shuhao [50] distinguished single indicators of land fragmentation from indices based on integrated indicators that utilise more than one variable. Most authors who tried to measure fragmentation have used a simple average of the number of parcels per holding (either regional or national), an average of holding size and an average of parcel size. Some others developed more complicated descriptors. In particular, Edwards [51] calculated a fragmentation index as the percentage of a holding's land which is not adjacent to the farmstead. In addition, Simmons [52] proposed a land fragmentation index which took into account the number of parcels in a holding and the relative size of each parcel. The formula for Simmons's land fragmentation index is as follows:

$$FI = \frac{\sum_{i=1}^{n} a_i^2}{A^2} \tag{2.1}$$

where FI is the fragmentation index, n is the number of parcels belong to a holding, a is the size of a parcel and A is the total holding size. An FI value of 1 means that a holding consists of only one parcel and values closer to zero mean higher fragmentation. The Simmons index becomes the Simpson index if it is subtracted from 1 [50].

Furthermore, Dovring [53] computed fragmentation by measuring the distance which a farmer would have to travel to reach each of his parcels, returning back to his farmstead after each visit although it ignores the number of actual visits per year and the potential that any parcel could be visited without returning back to the farmstead. Moreover, Januszewski [54] developed a similar fragmentation index to Simmons, combining the number of parcels per holding and their size distribution into a K index as follows:

$$K = \frac{\sqrt{\sum_{i=1}^{n} a_i}}{\sum_{i=1}^{n} \sqrt{a_i}} \tag{2.2}$$

where n is the number of parcels and a is the parcel size. The K values range from 0 to 1. As values tend to zero, K indicates a high degree of fragmentation. This index has three main properties: the degree of fragmentation increases proportionally with the number of parcels; fragmentation increases when the range of parcel sizes is small and fragmentation decreases as the area of large parcels increases and that of small parcels decreases. Blarel et al. [55] note that Januszewski and Simmons indices are the most popular.

Igozurike [56] suggested a 'relative index of land parcellization'. In contrast to the above indexes, this measure is based on the average size of the parcels and the distance travelled by a farmer to visit all his parcels sequentially (i.e. in one round trip). This index is given by the following equation:

$$P_i = \frac{1}{\frac{\bar{S}_i}{100}} Dt \tag{2.3}$$

where P_i is the fragmentation (or parcellization) index of holding i, $\bar{S}_i$ is the size of each parcel and Dt is the total round-trip distance covering all parcels. King and Burton [3] criticized this index because distance has not been clearly defined by the researcher and is overemphasized, without taking into account the number of parcels. An example is quoted based on a holding with two parcels with size $\bar{S}_i$ and a distance of 10 km apart, which would give a P_i twice as high as a holding with 10 parcels of size S, each 1 km from its neighbours.

Schmook [57] defined a fragmentation index called P_0, which is the ratio between the area of a polygon which circumscribes all the parcels of a holding, to the area of that holding. Values of this index are always above 1; a high P_0 value indicates intense fragmentation. Schmook also suggested another fragmentation coefficient which is calculated by dividing the average distance to parcels by the mean parcel size.

The above presentation of current indices indicates that all have three significant disadvantages [58, 59]. First, they are not comprehensive since, at best, they take into account three factors which can be correlated (i.e. the number of parcels, the size of each parcel and the size of the whole ownership); hence they ignore significant spatial factors such as the dispersion of parcels per ownership and the shape of parcels and also non-spatial factors such as the type of ownership and the existence of accessibility of a parcel to a road. Second, they are not flexible because they are represented by standard mathematical equations and hence therefore a planner is not able to select which factors should be accounted for in a particular project. Third, they are not problem specific since the factors are equally weighted, which may not be true for all cases. As a result of these deficiencies, the existing land fragmentation indices cannot adequately represent the land fragmentation problem; hence their outcome can be misleading and may lead to wrong decisions. Therefore, it is clear that there is a need for a new methodology for measuring land fragmentation that will be able to overcome the noted deficiencies and hence be more reliable and accurate. This demand is addressed by objective 3 of this research which is elaborated in Chap. 7.

2.3 Policies to Control Land Fragmentation

Once a Government assesses that land fragmentation constitutes a problem for rational agricultural development, there are three strategies to be followed. The first strategy is to promote legislation regarding aspects that affect land fragmentation so as to prevent a worsening of the problem. In particular, legal provisions, most of which are restrictions, involve changing legislation regarding inheritance, minimum size of parcel division, absentee landowners, prevention of transfer to non-farmers, leasing, imposing a maximum limit on the size of a holding etc. Some of these legal restrictions that have been applied in EU countries in the past, or they are currently applied in non-European countries such as India and Nepal, could be considered as non-democratic and unconstitutional according to the current institutional framework of the EU.

The second strategy is to apply specific land management approaches to tackle certain problems in particular agricultural areas. The main land management approaches used to battle land fragmentation in agriculture are: land consolidation; land funds and land banking; voluntary parcel exchange; and cooperative farming.

Namely, land consolidation is the prominent land management measure applied as a solution to land fragmentation that involves the reorganisation of space by reconfiguring the land tenure structure in terms of parcels and landowners and the provision of appropriate infrastructure according to the aims of a scheme. As a result, production and hence the income of farmers are increased. Extensive analysis of land consolidation follows in the next chapter.

Land funds and land banking is the process when a landowner is not interested in extending his landholding but in distributing it to other established farms. Thus, in such a case, his land may be used as a land buffer. More specifically, a land buffer is available for the improvement of other farms and the construction of agricultural infrastructure such as roads, irrigation and drainage systems. The land buffer itself is a land fund which can be used as an agricultural policy tool, and its use is referred to as land banking [5]. Land funds and land banking have mainly been used in Western Central European countries such as Germany and the Netherlands.

Voluntary parcel exchange involves the exchange of parcels among three or more landowners resulting in a more efficient spatial layout since the aim is to group adjacent parcels of each landowner. Some Western European countries such as Germany and the Netherlands have used this measure for a long time. Cooperative farming involves the joint cultivation of land by a group of households. It was considered by some Asian countries such as India and Nepal until 1970 as an effective solution to land fragmentation, through the creation of economically operational farm units. However, according to Niroula and Thapa [16], the practical experience has shown negative results, mainly because of the reluctance of landowners to participate in these programmes. Reluctance is due to conflicting interests and perceptions among landowners and the fear of losing their rights. As a result, the whole attempt has collapsed.

The third strategy is to apply specific land protection policies/programmes to prevent agricultural land from being developed for housing or commercial use. This strategy has been applied in the United States in regions/zones where there is a mixed land use, i.e. agricultural and housing [60]. In particular, these policies, i.e. a purchase of development rights (PDR) programme; a clustering programme; and a transfer of development rights (TDR) programme, aim to prevent agricultural land fragmentation because of urban sprawl. The PDR programme involves the use of public funds for purchasing and funding to eliminate the development rights on agricultural land. It is a farmland conservation tool which is considered very effective, is fair to landowners and provides a permanent solution. The most common disadvantage is its high cost of implementation.

A TDR programme, which is applied at a regional scale, concerns a specific area to be protected from development (i.e. the sending area) and an area where development will be allowed to occur (i.e. the receiving area). The programme involves the transfer of the development rights of a parcel located in the sending area to another parcel of the receiving area. This program, which is mandatory, is considered to be the most aggressive in terms of preserving farmland. In contrast to the PDR and TDR policies, which refer to a regional scale, cluster development programmes focus on development on a site by site basis. Cluster programmes work with the zoning density, reducing minimum parcel sizes and ensuring that a part of the site remains as open space. Despite this strategy being popular among various communities, it is not regarded as a very effective tool to protect agricultural land bases.

A study carried out by Brabec and Smith [60] showed that TDR and PDR programmes are the most successful in terms of the total area of land protected. The clustering program proved unable to achieve the protection of a large amount of land. On the other hand, TDR and PDR programmes have achieved better results regarding an increase in the size and the continuity of parcels than the clustering programme.

A very important point emphasised by Van Dijk [5] is the fact that any land policy applied in one country may not be able to be applied in the same way in another country. Thus, a Government, before considering the adoption of a land policy, should be aware of the prevailing conditions and circumstances of its country; otherwise many problems can arise and failure will be inevitable.

2.4 The Extent of the Problem at the Global and EU Level

Land fragmentation is evident in many areas throughout the world. The following sections consider the current situation regarding land fragmentation in 113 countries in six continents, followed by a deeper analysis for EU countries. The data have originated from the most recent agricultural censuses published by FAO and the European Commission [61–63], respectively. It should be noted that these figures refer to averages for a country. However, it is known that land fragmentation may differ significantly from these figures from region to region within a country.

2.4.1 Land Fragmentation at a Global Level

Even though land fragmentation has been closely associated with Europe and Mediterranean countries, it has been studied in many other countries and regions all over the world: for example, in South Asia [16]; Bangladesh [64]; Vietnam [29], China [13, 28, 50, 65]; Taiwan [66]; Turkey [67]; USA [60, 68, 69, 70]; Nepal [71]; India [72, 73]; Ethiopia [55, 74]; Ghana and Rwanda [55]; Israel [75]; South Asian countries South Asian countries [76]; Jordan [77]; Peru [78]; and Syria [79].

The FAO publishes National Agricultural Census results referring to the 1980, 1990 and 2000 rounds. Countries are grouped in six continents (Africa, Asia, Europe, North and Central America, South America and Oceania). Table A.1.1 in Appendix A shows by continent, the average holding size and average number of parcels per holding for 113 countries based on the latest available data provided by FAO from 1986 to 2004. In particular, it is indicated that the smallest average holding size is found in Asian and African countries where in 20 out of 24 and 16 out of 20 countries, respectively, it is less than 5 ha. In almost half of the Central American and Oceania countries, the average holding size is less than 5 ha. In contrast, the situation is completely different in South American and European countries where 10 out of 10 and 23 out of 28 countries respectively have an average holding size higher than 5 ha. In the case of European countries, this figure is due to the extensive adoption of appropriate policies to control land fragmentation and particularly the implementation of land consolidation schemes in all European countries (at least in some period). As a result, the average size of holdings in Europe presents an almost normal distribution since 10 countries have more than 40 ha, 10 countries have between 10–40 ha and 8 countries have less than 10 ha.

It is also remarkable that some countries have an even smaller average land holding size which indicates serious land fragmentation; six Asian and four African countries have an average land holding size of less than 1 ha. The Asian countries and the corresponding values are: Bangladesh (0.35 ha), Sri Lanka (0.5 ha), China (0.67 ha), Vietnam (0.71 ha), Nepal (0.79 ha) and Indonesia (0.79 ha). Not only are these land holdings extremely small, but each land holding consists of about 1.8 parcels, a fact that exaggerates the problem. The African countries are: Congo (0.5 ha), Comoros (0.6 ha), Malawi (0.7 ha) and Egypt (0.82 ha). Some of these countries are among the most densely populated countries of the world, which is a factor strongly related to land fragmentation; Bangladesh is ranked 9th, China 14th, Comoros 27th, Sri Lanka 38th, Vietnam 48th and Nepal 59th among the 238 countries of the world.

At the other end of the scale, five countries have much higher average land holding size. Australia has a figure of 3,243.21 ha, which is the highest of all countries. Other countries with high figures are: Brazil (582.45 ha), Uruguay (287.40 ha), Canada (273.38 ha) and the USA (178.35 ha). According to the data provided by the European Commission which are more recent than FAO data, the highest figure for EU countries is for Slovakia (172.1 ha). Undoubtedly, the data in Table A.1.1 have a strong relation with the size of each country since Canada (2nd), USA (4th), Brazil (5th) and Australia (6th) are among the six largest countries in the world. Population density is also another factor justifying the figures. In particular, Australia (232nd), Canada (227th), Brazil (189th) and the USA (177th) are among the least densely populated countries in the world. On the other hand, all EU countries (except Finland, 198th, Sweden, 192nd and Estonia, 179th) are more densely populated than the last ranked country (i.e. USA) of the previous group.

2.4.2 Land Fragmentation in the European Union

The problem of land fragmentation in Europe and particularly in Mediterranean countries has been identified a long time ago [45, 66]. Further to these general studies about land fragmentation in Europe, other studies focused on particular EU countries such as Cyprus [18, 33]; Portugal [80]; Greece [81]; Czech Republic [82]; Romania [83]; Bulgaria, Germany, Hungary, Romania and Slovenia [84, 85].

The European Commission carries out statistical agricultural analyses and prepares relevant reports about farm structure in EU countries. These reports, which are based on the national agricultural censuses of each member state, include some specific sections about land fragmentation. There are three dominant reports which cover farm structure statistics for the period 1966–2003. The first was published in 2000 for the period from 1966/1967 to 1997; the second one was published in 2003 covering the period 1999/2000 and the last one was published in 2005 and refers to a survey of 2003 about the EU-27 countries. Data were extracted from these reports and (after some processing) are presented as basic land fragmentation statistics as described below.

Table 2.1 shows the average agricultural area per holding (in hectares) in EU countries for the decade 1993–2003. It shows a linear rising trend in the average agricultural area per holding for all the countries during the whole period of the study. This finding is also revealed in the results for EU-12 and EU-15. It is remarkable that a significant rise in this measure has been observed in some countries such as Portugal (67.90 %), Germany (54.09 %), Italy (50.85 %), Luxemburg (48.13 %), Sweden (47.96 %), Denmark (47.43 %), the Netherlands (39.88 %), France (39.32 %) and Finland (39.17 %). Smaller increases are evident in other countries.

In terms of numbers, the reason for this increase over time is the general decline in the number of holdings and the rather stable level in the total agricultural area. In reality, this increase is the result of the agricultural policies adopted by the EU for improving farm structure conditions for more effective and productive agriculture. While before 1999/2000 the UK had the highest average agricultural area per holding since its accession to the European Community in 1975, Slovakia, which joined the EU on 1 May 2004, has now gained this position based on the 2003 agricultural census with 172.1 ha. The Czech Republic follows with 143.8 ha and then the UK with 85.2. The phenomenon in Slovakia and the Czech Republic is due to the fact that, although after the collapse of communism 70 % of the agricultural land (in Czech Republic) passed to private landowners, the former have united their land in bigger enterprises. A similar situation exists in Slovenia [5]. Other countries with relatively high figures are Luxembourg (55.4 ha), Denmark (54.7 ha), Sweden (50.9 ha), France (48.9 ha) and Germany (43.3 ha). In contrast, the average area per holding is less than 10 ha in Malta (1.3 ha), Cyprus (5.2 ha), Greece (5.9 ha), Slovenia (7.3 ha) and Italy (8.9 ha). Figures for the other countries range in the middle, i.e. between 12 and 34 ha.

Table 2.1 Average agricultural area per holding in EU countries, 1993–2003

	1993	1995	1997	1999/2000	2003
EU-25	–	–	–	–	22.6
NMS-10	–	–	–	–	17.9
EU-15		17.4	18.4	22.2	24
EU-12	16.4	17.2	18.2	18.4	–
Belgium	17.6	19.1	20.6	23.7	26.4
Czech Republic	–	–	–	–	143.8
Denmark	37.1	39.6	42.6	45.8	54.7
Germany	28.1	30.3	32.1	37.6	43.3
Estonia	–	–	–	–	48.3
Greece	4.3	4.5	4.3	5.3	5.9
Spain	17.9	19.7	21.2	21.7	23.2
France	35.1	38.5	41.7	45.8	48.9
Ireland	26.8	28.2	29.4	32.9	33.8
Italy	5.9	5.9	6.4	8.2	8.9
Cyprus	–	–	–	–	5.2
Latvia	–	–	–	20.5	22.8
Lithuania	–	–	–	–	20.4
Luxembourg	37.4	39.9	42.5	48.2	55.4
Hungary	–	–	–	22.7	25.3
Malta	–	–	:	:	1.3
Netherlands	16.8	17.7	18.6	20	23.5
Austria		15.4	16.3	17.1	19.3
Poland	–	–	–	–	12.2
Portugal	8.1	8.7	9.2	11.9	13.6
Slovenia	–	–	–	6.8	7.3
Slovakia	–	–	–	171.4	172.1
Finland	–	21.7	23.7	28.3	30.2
Sweden	–	34.4	34.7	40.5	50.9
United Kingdom	67.3	70.1	69.3	84.6	85.2

Source European Commission [63]

The distribution by size class (Table A.2.1 in Appendix) indicates that the large majority of European holdings are relatively small in size since 75.7 % (EU-27 in 2003) of all holdings use less than 5 ha. It is noticeable that there was a continuous increase in the proportion of small parcels with every EU enlargement. Namely, for EU-15 and EU-25, the percentage of small parcels was 60.4 and 63.1, respectively. It is also remarkable that this percentage increased significantly by 12.6 % in the last EU enlargement (1 January 2007) when only two new state members joined, i.e. Bulgaria and Romania. This is due to the fact that 95.6 % and 98.8 % of their holdings, correspondingly, are less than 5 ha. The highest shares in the number of holdings with a size of less than 5 ha are found in Romania (98.8 %), Malta and Hungary (97 %), Slovakia (96.2 %), Bulgaria (95.62 %), Cyprus (87.6 %), Italy (87.3 %) and Portugal (85 %). Three of these countries, i.e. Malta, Cyprus and Italy are Mediterranean countries, a region for which early evidence exists for land fragmentation. Shaw [45] and Burton and King [33] note that there is an excessive land fragmentation in the Mediterranean region, mainly because they contain long-settled peasant communities.

The other four countries, i.e. Romania, Hungary, Slovakia and Bulgaria are ex-Communist Central European countries which, after 1989 and the collapse of the iron curtain, passed into a privatisation process (in terms of land as well). By then, agricultural land was under the control of the state in the form of 'state' and 'collective' farms. State farms were owned absolutely by the state. Collective farms involved transferring only part of the rights to land from the landowners to the collective: the right to use and alienate. According to Swinnen et al. (1997), 78.4 and 21.1 % of agricultural land in Bulgaria was in collective and state farms respectively. The figures for Hungary and Romania were: 71.4 and 14.9 %, and 54.7 and 28.9 %, respectively. After the transition of the political systems to a free market, total land tenure restructuring took place. As a result, the figures on the land fragmentation in these countries show quite a varied pattern. In the case of the countries mentioned above, a large number of small farms use a relatively modest share of the total agricultural land [5].

A different situation, i.e. where the proportion of small holdings is limited to around 10 %, occurs in Denmark (3.7 %), Ireland (6.5 %), Sweden (9.3 %) and Finland (10.5 %). Three out of four are Scandinavian countries. This may be due to the fact that these countries have a very long tradition of land consolidation projects (i.e. the first land consolidation act was prepared in Denmark in 1781). At the other end of the spectrum, holdings with more than 50 ha account for some 4.65 % for EU-27. Among the member states, based on the 2003 census, Luxembourg presents the largest proportion of such holdings with 45.9 %, followed by France and Denmark (35.65 %), UK (26.3 %), Sweden (25.4 %) and Germany (21.4 %). Also, these countries (except for the UK which has applied a form of land consolidation since the 15th century and there is no evidence after that) has a long tradition of land consolidation projects.

The above analysis suggests that agricultural land is still fragmented in most EU countries. However as noted, this is not a problem in principle. Thus, every country should be aware of this potential problem and its consequences so as to adopt the proper land policies noted earlier based on its distinct conditions.

2.5 Land Tenure in Cyprus and its Problems

2.5.1 Historical Evolution of the Cypriot Land Tenure System

The land tenure system of a country plays an important role in its socio-economic development since it defines the framework for managing one of the most important resources, i.e. land. Thus, land tenure has always had a dominant and multi-dimensional role in Cypriot society [86] due to: the importance of the island because of its strategic location i.e. it is among three continents: Europe, Africa and Asia; the small size of the island (its extent is 9,250 km^2); and the strong relationship of Cypriots with land that extends beyond its economic value. The present land tenure system is a result of a long historical evolution which started in the Neolithic era around 7000 BC and the numerous conquests of the island [15]. In particular, each of the long list of colonisers, i.e. Greeks, Romans, Byzantines, Lusignans, Venetians, Ottomans and British left a contribution to the evolving agrarian land structure [33].

In particular, the most significant historical periods that influenced the land tenure structure are the following: the Neolithic age (7000–3900 BC), for which there is archaeological evidence that from the 6th millennium B.C. Cypriots practiced agriculture on a communal basis (Land and Surveys Department 2008); the Bronze Age (2500–1050 BC) during which the idea of individual ownership in Cyprus had arisen by the Greek settlers in about 1400 BC [15]; the historical periods (1050 BC–330 AD) when the 'idalio' inscription was excavated (5th century BC) at Dali village, which can be described as a 'title to land', indicating the development of private ownership in ancient Cyprus; and the Hellenistic period (325–58BC) when private ownership, even at a small scale, consisted of houses, vineyards and gardens or else emerged from the hereditary leasing of land to royal peasants.

In addition, during the Ottoman period (1571–1878), all the land belonged to the Sultan, although for practical reasons, the peasants were the owners of the land they cultivated. It was actually a kind of feudalism. As in other parts of the Ottoman Empire, taxes were very heavy and unbearable for most people. Thus, many pious people donated and granted their land to the Church to avoid taxes and the possibility of seizure by officials, while they could cultivate their land and gain the benefits from it. Furthermore, once the property passed to the Church (monasteries), it was safe, since the Church had certain privileges. Feudalism was abolished when the new Ottoman Land Code of 1850 was introduced [33]. The most important provision of the code was that land was grouped into five categories which led to the registration system. Thus, private rights spread, rights of possession were registered and land inheritance and transfer via sale became possible. The aim of all these measures was to increase revenue from taxes. This Ottoman Code was in force until 1946, i.e. far after the termination of the Ottoman Empire in Cyprus. Afterwards, during the British period (1878–1960), a general survey carried out from 1909 to 1929 attempted to put order into the cadastral chaos and the introduction of the Immovable Property Law in 1946 aimed at reducing land fragmentation.

Eventually, Cyprus became an independent country in 1960 and its constitution safeguarded private and ownership rights. Despite the fact that the British left a well-organised cadastral situation in terms of the land administration system and an excellent (for those times) geodetic and cartographic infrastructure, land fragmentation gradually extended to become a serious problem which hampered agricultural development. Therefore, in March 1969, a Land Consolidation Act was established in Cyprus as a result of a long effort begun before independence aiming at controlling land fragmentation. Thereafter, in December 1970, the first land consolidation project began, in the Kissonerga village in Pafos District.

It is also worthwhile to note that further to the conventional land fragmentation problems in Cyprus there was the physical fragmentation of people from their properties and their places of origin, imposed by Turkey and its troops following the invasion of Cyprus in 1974. As a result, 38 % of the whole island (the northern part) is occupied by Turkey and it is still not under the control of the Republic. Cyprus (as a whole country) joined the EU on 1 May 2004 when many new political, economic, and social prospects appeared. However, heavy competition in the agricultural sector in the EU and the continuous decline of this sector in Cyprus, required integrated rural programmes, a part of which can be land consolidation.

2.5.2 Causes of Land Fragmentation

Generally, causes of land fragmentation in Cyprus follow the common reasons referred to in Sect. 2.2.3. However, every country has its own, distinct circumstances. Thus, a series of reasons are associated with land fragmentation in Cyprus. In particular, according to Inheritance Law, upon the death of an owner, his/her property is divided among his/her heirs unless there is a different agreement among them. In most cases, particularly in the past, all parcels of the deceased were fragmented and divided between all the heirs. However, with the introduction of the Immovable Property Law in 1946 during the British colonisation, parcels cannot be sub-divided among all heirs but only the holding. As a result, parcels are split in undivided shares. Separate entire parcels can be obtained by the heirs only if they have a size beyond a limit defined by the Immovable Property Law.

Furthermore, according to the Immovable property (Tenure, Registration and Valuation) Law, any vineyard, orchard, grove or land irrigated or capable of being irrigated from a seasonal source of water can be divided into holdings of up to one donum (0.13 ha) in extent. Also land used for agricultural purposes which is not irrigated either from a permanent or a seasonal source of water, can be divided into separate holdings of not less than five donums (0.67 ha) in extent. These very low figures, coupled with the Inheritance Law, permit the fragmentation of the property and its subdivision into tiny parcels of land.

In addition, the increase in population is another cause of fragmentation. Namely, the population of the Republic of Cyprus (only the free part) was 789,258 inhabitants in 2008, which has increased by 16.9 % from 1998. Also, the percentage of the most active and largest age group, i.e. those aged 25–49, rose from 35.7 % of the total population in 1997 to 37.4 % in 2008. As a result, the pressure on the land and particularly the need for land ownership rose as well. People living in agricultural areas or employed in towns or abroad, continue to own land and eventually they pass it over to their children.

Another reason for the existence of land fragmentation is the fact that sometimes it is desirable, e.g. to reduce crop risk as noted earlier. In addition, morphological and parcel sub-division may render the creation of small parcels inevitable. Also, the strong relation of Cypriots with land has made land ownership very popular for social, economic, emotional, cultural and other reasons. Furthermore, the fact that a limited housing development (in most cases just the building of one house) is permitted in agricultural land if a parcel fulfils certain criteria (e.g. access to a registered road, etc.) favours investments by non-farmers and hence further fragmentation. Moreover, the fact that land can be easily, quickly and trustworthily transferred from person to person via the Department of Lands and Surveys (one of the oldest and largest departments of the Republic of Cyprus) creates a plethora of owners, a process that automatically leads to fragmentation.

2.5.3 Land Tenure Trends

The major land tenure types encountered in Cyprus based on the last four agricultural censuses carried out in 1977, 1985, 1994 and 2003 are shown in Table 2.2. Private land, i.e. the land that belongs to private individuals or households accounts for about 97–99 % of the total number of holdings and for 85–93 % of the total area enumerated in the censuses. It constitutes the prominent type of land ownership in Cyprus. The total number of agricultural holdings increased from 1977 to 1985 and from 1985 to 1994 (7.71 and 7.11 % respectively) but a considerable decrease has occurred from 1994 to 2003 (11.57 %). On the other hand, the total cultivated area shows a continuous decline for all the censuses; this ranges from 2.75 to 7.48 %. The last result is in accordance with the gradual and continuous drop of the agricultural sector after 1970. In particular, the agricultural sector's share to the GDP has been decreasing: from 18 % in 1970 to 10 % in 1980 to 7.2 % in 1990 to 6.3 % in 1998 to 3.8 % in 2004 and 2.7 % in 2007. This evolution is attributed to the relatively low-income elasticity of demand for agricultural products, the urbanisation trend and the reallocation of productive resources from agriculture to other more profitable economic activities such as light manufacturing and services.

Joint land holders or partnerships refer to land which is held by or rented jointly by two or more individuals. The number of these holdings decreased from 325 in 1977 to 270 in 1985 and significantly increased to 554 in 1994. This constitutes a small portion of the total number of holdings, ranging from 0.56 to 1.06 %. This land category has not been recorded in the 2003 census. The number of holdings possessed by companies presents a stable increase for the first three censuses and a small decrease in 2003. It is remarkable that the number of holdings owned by companies rose significantly from 95 in 1977 to 303 in 1985 and 526 in 1994. This is due to the fact that agriculture began around the 1970s, developing (despite its decline in terms of its contribution to the GDP share) a more organised base, so

Table 2.2 The major land tenure trends in Cyprus, 1977–2003

Year/Land tenure type	Holdings		Area	
	Number	%	Hectares	%
1977				
Private land	43,867	98.53	172,003.73	85.68
Joint holders land	325	0.73	2,905	1.45
Company land	95	0.21	6,617.99	3.30
Co-operatives land	4	0.01	33.18	0.02
State land	24	0.05	1,259.65	0.63
Community land	16	0.04	94.31	0.05
Church land	163	0.37	6,705.35	3.34
Other	28	0.06	11,140.9	5.55
Total	44,522	100.00	200,760	100.00
1985				
Private land	47,251	98.35	159131.87	88.85
Joint holders land	270	0.56	2429.14	1.36
Company land	303	0.63	6693.98	3.74
Co-operatives land	11	0.02	862.6	0.48
State land	15	0.03	632.64	0.35
Community land	16	0.03	1213.9	0.68
Church land	168	0.35	7661.6	4.28
Other	12	0.02	473.44	0.26
Total	48,046	100.00	179,099.17	100.00
1994				
Private land	50,610	97.16	154751.45	87.07
Joint holders land	554	1.06	5541.75	3.12
Company land	526	1.01	8950.95	5.04
Co-operatives land	14	0.03	313.98	0.18
State land	145	0.28	1,675.84	0.94
Community land	29	0.06	1,053.5	0.59
Church land	176	0.34	4,988.58	2.81
Other	35	0.07	454.58	0.26
Total	52,089	100.00	177,730.63	100.00
2003				
Private land	44,752	99.01	145,341.7	92.94
Companies	381	0.84	8,719.2	5.58
Public or government	45	0.10	1,866.4	1.19
Other	21	0.05	452.4	0.29
Total	45,199	100.00	156,379.7	100.00

Source Republic of Cyprus, Censuses of Agriculture 1977, 1985, 1994 and 2003
Notes 1 The above figures refer only to the free part of Cyprus which is under the control of the Republic of Cyprus and not to the occupied part
Notes 2 The figures for 2003 are grouped in four land categories instead of eight as in the previous censuses

many companies acquired agricultural land and they began to operate as agricultural units. The Church, for historical reasons mentioned above, has always been a landowner, owning on average 0.35 % of the total number of agricultural holdings, while it actually holds a greater percentage that is not recorded as agricultural land. Also, a noticeable figure in Table 2.2 is the significant increase in the number of state land holdings enumerated in 1994 (145) compared to previous censuses, i.e. in 1977 (24) and in 1985 (15).

2.5.4 Land Tenure Problems

Burton and King [33], Burton [15], Karouzis [86] and Demetriou et al. [48] point out that the land tenure structure in Cyprus is defective. A brief updated analysis of the main land tenure problems met in Cyprus, which comprises land fragmentation, follows. In particular, the average holding size based on the last six agricultural censuses is shown in Table 2.3.

It is obvious that the average holding size steadily diminished from 1946 to 1994 and then it remained stable until 2003. The fall in mean size from 1946 to 1994 is 51.74 %. It is the second smallest figure (2003 census) among the 27 EU countries (just after Malta, 1.3 ha) and the 46th among the 113 countries of the world. However, the figure varies significantly among the various regions of Cyprus and between dry and irrigated parcels [9].

Another useful figure regarding holding size is the distribution of holdings by size of area in fifteen classes, based on the 2003 census (Table 2.4). The direct comparison with the figures of the previous censuses is not possible since the area unit used was a donum (1 donum equals 1,337.78 m^2 or 0.133778 hectares) and a different class aggregation was used, so a simple conversion is not useful. The distribution by size class indicates that the large majority of holdings are relatively small in size since 87.4 % of all holdings use less than 5 ha and 54.2 % of this proportion refers to holdings with a smaller size than 1 ha. This figure classifies Cyprus as the sixth country among the EU-27 with the highest percentage of holdings with less area than 5 ha. In contrast, at the other end of the spectrum, only

Table 2.3 The average holding size, 1946–2003

Census year	Average holding size (ha)
1946	7.17
1960	6.23
1977	4.59
1985	3.79
1994	3.46
2003	3.50

Source Republic of Cyprus, Census of Agriculture 1946–2003

Table 2.4 Distribution of holdings by size, 2003

Size class (ha)	Number	Percentage	Cumulative percentage
<0.5	15,561	34.88	34.88
0.5–1	8,631	19.35	54.23
1–2	7,544	16.91	71.14
2–3	3,741	8.39	79.53
3–5	3,499	7.84	87.37
5–8	2,156	4.83	92.20
8–10	696	1.56	93.76
10–15	1,011	2.27	96.03
15–20	511	1.15	97.17
20–25	260	0.58	97.76
25–30	213	0.48	98.23
30–40	231	0.52	98.75
40–50	141	0.32	99.07
50–100	256	0.57	99.64
>100	160	0.36	100.00

Source Republic of Cyprus, Census of Agriculture 2003

2.8 % of the holdings have a size larger than 20 ha. Only 9.8 % of the holdings fall in the middle-sized class, i.e. from 5 to 20 ha.

Table 2.5 shows land tenure trends by size of holding from 1946 to 1994 for four classes: small holdings (0–5 donums), medium holdings (5–20 donums), large holdings (20–60) and very large holdings (more than 60 donums).It is apparent that there is a continuous increasing trend in the proportion of small and medium-sized holdings from 5.3 to 29.1 % and 27.1 to 38.7 % respectively, throughout the 8-year period. In contrast, the share of the large-sized holdings presents a continuous decreasing trend from 37.5 to 23.93 % during the study period. The percentage of very large holdings shows a dramatic fall from 30.1 to only 8.26 %. These figures clearly indicate a gradual increase in the problem of land fragmentation.

Table 2.6 presents the mean number of parcels per holding and the mean size per parcel from 1946 to 2003. The mean number of parcels per holding falls over the years from 1946 to 1994 with the exception of a slight increase in 2003. In accordance with this, the mean parcel size gradually increases over the period 1946-1994 and slightly reduces between 1994 and 2003.

Table 2.5 Percentage of holdings by size class, 1946–1994

Size class (in donums)	1946	1960	1977	1985	1994
0–5	5.3	11.7	18.0	24.4	29.07
5–20	27.1	29.3	34.8	37.38	38.74
20–60	37.5	35.3	34.8	28.29	23.93
>60	30.1	23.7	12.4	9.93	8.26

Note 1 donum = 0.133778 ha
Source Republic of Cyprus, Census of Agriculture 1977–1994

Table 2.6 Mean number and mean size of parcels, 1946–2003

Census year	Mean number of Parcels per holding	Mean size per parcel (ha)
1946	12.7	0.56
1960	9.5	0.65
1977	6.4	0.71
1985	5.2	0.73
1994	4.5	0.77
2003	5.0	0.69

Source Republic of Cyprus, Census of Agriculture 1977–2003
Note Censuses of 1946 and 1960 refer to the whole of Cyprus. The other censuses refer only to the free part of Cyprus (and not to the northern part occupied by Turkish troops since 1974,) which is under the control of the Republic of Cyprus

Although land consolidation projects began in 1970 and land fragmentation then reduced significantly, in particular in the consolidated areas (which by 2008 constituted only 8.87 % of the total agricultural area enumerated in the 2003 census), the trend may not represent an actual reduction of fragmentation since it is potentially due to the significant growth of the smaller holding classes (i.e. 0–5 donums), a result that agrees with the findings of Karouzis [86] and Burton [15]. Karouzis [9] points out that the overall figure of the mean parcel size for the whole of Cyprus could be misleading since on a regional basis there are considerable differences. For example, regarding the 1960 census, he shows that the average parcel size for six regions ranges from 0.29 ha (in mountainous regions) to 2.1 ha (in coastal plain regions). It is clear that a large range and the existence of extreme values may give unreliable statistical results. In these cases, the median may provide a better representation of data than the mean.

Table 2.7 shows the percentage of holdings for six classes of number of parcels. It is clear that there is an upward trend in the proportion of holdings consisting of 1–3 parcels, a levelling out of holdings consisting of 4–5 parcels, a slight fall of holdings consisting of 6-9 parcels and a slump of the share of holdings with over 10 parcels. Despite this finding leading to the conclusion that land fragmentation reduced over time, it may be a misleading interpretation since results are in accordance with a continuous reduction of the cultivated area and the mean

Table 2.7 Percentage of holdings and number of parcels, 1977–2003

Number of parcels	1977	1985	1994	2003
1 parcel	20.0	26.5	30.3	34.8
2–3 parcels	23.7	27.5	30.1	31.5
4–5 parcels	16.2	15.3	15.3	13.8
6–9 parcels	18.8	16.1	13.9	10.8
10–15 parcels	21.3	9.2	6.5	5.0[a]
16 and over	0.0	5.4	3.9	4.1[a]

Source Republic of Cyprus, Census of Agriculture 1977–2003
Note [a] These figures are based on rough estimations since the aggregation of the number of parcels for the 2003 census was different than the previous ones

holding size (Tables 2.2 and 2.3). Robust results could only be obtained if the cultivated area was stable over time.

Further to the size and number of parcels per ownership, parcels are spatially dispersed all over village areas in neighbouring villages and in distant villages. As a result, a farmer has to travel long distances to carry out agricultural activities, hence the cost of production is increased and the income is decreased. Karouzis [23, 42] carried out a survey about the time wasted and distance travelled by the average Cypriot farmer in order to visit his scattered and fragmented agricultural holdings. He found that, on average, a farmer travels 1,357 km every year which absorbs 337 h or 15 % of the total working time. Burton and King [33] note that although someone may criticise Karouzis' methodology, the results are highly indicative of the irrational effects of land fragmentation.

Another problem is ownership in undivided shares that refers to a parcel which is owned by more than one landowner. Karouzis [9] notes that about 30 % of the agricultural land is owned in undivided shares. Also, Karouzis [23] found that the smaller the size of a plot is, the higher the number of plots held in undivided shares and the smaller the area occupied. He pointed out that the problem is prevalent in parcels with a size below 3 donums (0.4 ha). Some of the problems associated with parcels of this type include landowner disagreements regarding exploitation of a parcel, i.e. the kind of cultivation; execution of development works such as soil conservation, drainage, irrigation, etc. This form of ownership is not preferred by land purchasers, developers, etc. and landowners consider it as an ownership of secondary importance. Nevertheless, peasants very often find ways and means to operate the land and minimise the potential conflicts with their co-landowners.

Similarly to the previous problem are dual or multiple ownerships. Specifically, they refer to ownership for which the piece of land, the trees or even the water contained within it are owned by different landowners. Karouzis [9] and Burton [15] point out that the origin of this kind of ownership is in the Ottoman legislation. It is realised that this is an anachronistic and undesirable system of ownership with very negative effects on agriculture. Data from four land consolidation areas revealed that the portion of dual/multiple ownership ranges from 9.4 to 23.2 %.

Another significant problem is parcels having irregular shape. According to Karouzis [9, 23], regularly-shaped parcels for Cypriot conditions are considered to be the ones that fulfill the following five prerequisites: parcels that have parallel lines; parcels that have a distance between their sides of at least 30 m; parcels with no pointed edges; parcels of odd shape hindering cultivation; and parcels with an area of at least two donums (i.e. 0.27 ha). Parcels with irregular shapes are met in areas with intense relief whilst parcels with regular shapes are found in areas with low relief. This thesis examines this issue in detail and develops a new index for evaluating shapes called the parcel shape index (*PSI*) in Chap. 7.

Furthermore, the lack of road access of parcels also constitutes a prominent problem. Namely, the random lay-out of parcels, their irregular shape, small size and relevant costs make the provision of road access to every parcel an impossible task. Thus, most parcels are 'enclosed' and the only way they can be reached is by traversing other parcels or by moving along the boundaries of nearby parcels. But such arrangements lead to frequent disputes between the neighbouring owners. In addition, considerable areas of land are left unexploited just because of the lack of a proper road network. Thus, the existence of registered road access for a parcel constitutes a privilege, which considerably increases its value.

All the above land tenure problems are considered in the new methodology for measuring land fragmentation discussed in Chap. 7.

2.6 Conclusions

Although land fragmentation is not a problem by definition, it is considered by most commentators to be a serious obstacle which prevents rational agricultural development and in general rural sustainable development. Its main disadvantages are that it hinders mechanisation, causes inefficiencies in production and hence reduces the income of farmers. Land fragmentation is a universal phenomenon in the EU and other continents. Cyprus has been confronted by this problem for a long time ago and hence it has applied land consolidation measures since 1970 to eliminate land fragmentation. Planners and decision makers need a reliable metric for quantifying land fragmentation on which to base their decisions. However, existing land fragmentation indices presented in the literature suffer from significant weaknesses that may be misleading and support wrong decisions regarding adopting appropriate land management measures. As a result, there is a need for developing a new methodology for quantifying land fragmentation which is addressed by objective 3 of this research that is elaborated in Chap. 7. The next chapter deals with the most effective land management approach for tackling the land fragmentation problem i.e. land consolidation.

References

1. Bentley, W. (1987). Economic and ecological approaches to land fragmentation: In defence of a much-maligned phenomenon. *Annual Review of Anthropology, 16*, 31–67.
2. Binns, O. (1950). *The consolidation of fragmented agricultural holdings* (Vol. 11). Washington DC: FAO Agricultural Studies.
3. King, R., & Burton, S. (1982). Land fragmentation: Notes on a fundamental rural spatial problem. *Progress in Human Geography, 6*(4), 475–494.
4. McPherson, M. F. (1982). *Land fragmentation: a selected literature review*. Development Discussion Paper No. 141. Harvard Institute for International Development, Harvard University.
5. Van Dijk, T. (2003). *Dealing with Central European land fragmentation*. Delft: Eburon.
6. Van Dijk, T. (2004). Land consolidation as Central Europe's Panacea reassessed. In: *Proceedings of Symposium on Modern Land Consolidation,* September 10–11, Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_01_vandijk.pdf

7. Johnson, E. G. (1970). A note on the economics of fragmentation. *The Nigerian journal of economic and social studies, 12*, 175–184.
8. McCloskey, D. N. (1975). The persistence of english open fields. In W. N. Parker & E. L. Jones (Eds.), *European peasants and their markets: Essays in agrarian economic history* (pp. 73–122). Princeton: Princeton University Press.
9. Karouzis, G. (1977). *Land ownership in Cyprus: Past and present*. Nicosia: Strabo.
10. Blaikie, P., & Sadeque, A. (2000). *Policy in the high Himalayas: Environment and development in the Himalayan region*. Kathmandu: ICIMOD.
11. Hooi, T. S. (1978). Fragmentation of paddy farms, its determinants and impact in the Muda area, Kedah, West Malaysia. MSc thesis, Asian Institute of Technology, Bangkok.
12. Wong, S. T., & Geronimo, E. D. R. (1983). Determinants and impact of Rice farm fragmentation in Ilocos region. Philippines HSD monograph No. 4. Asian Institute of Technology, Bangkok.
13. Wan, G. H., & Cheng, E. J. (2001). Effects of land fragmentation and returns to scale in the Chinese farming sector. *Applied Economics, 33*(2), 183–194.
14. Wu, Z., Liu, M., & Davis, J. (2005). Land consolidation and productivity in Chinese household crop production. *China Economic Review, 16*, 28–49.
15. Burton, S. (1988). Land consolidation in Cyprus: A vital policy for rural reconstruction. *Land Use Policy, 5*(1), 131–147.
16. Niroula, G. S., & Thapa, G. B. (2005). Impacts and causes of land fragmentation, and lesson learned from land consolidation in South Asia. *Land Use Policy, 22*(4), 358–372.
17. Thompson, K. (1963). Farm fragmentation in Greece. Centre of Economic Research, Monograph Series 5, Athens.
18. Karouzis, G. (1971). Land tenure in Cyprus: A powerful typological criterion. In: *Proceedings of the Symposium of agricultural typology and agricultural settlements*. *European Regional Conference*. International Geographic Union. SZEGEZ-PEGS, Hungary.
19. DeLisle, D. (1982). Effects of distance on cropping patters internal of the farm. *Annals of Association of American Geographers, 72*(1), 88–98.
20. Blaikie, P. (1971). Spatial organization of agriculture in some north Indian villages: Part 1. *Transactions of the Institute of British Geographers, 52*, 1–40.
21. Blaikie, P. (1971). Spatial organization of agriculture in some north Indian villages Part 2. *Transactions of the Institute of British Geographers, 53*, 15–30.
22. Yates, P. (1960). *Food land and manpower in western Europe*. New York: Macmillan.
23. Karouzis, G. (1980). Report on aspects of land tenure in Cyprus. Ministry of Agriculture and Natural Resources of Cyprus, Nicosia.
24. Wattanutchariya, S., & Jitsanguan, T. (1992). *Increasing the scale of Small-farm operations in Thailand*. Food & Fertilizer Technology Center. Available from URL:http://www.agnet.org/library.php?func=view&id=20110726143050&type_id=4.
25. Jian-Ming, Z. (1997). *A new proposal for land consolidation and expansion in Japan and other economies*. European University Institute, Florence, Italy. Available from URL: http://www.fao.org/sd/LTdirect/LTan0018.htm.
26. Schultz, T. W. (1964). *Transforming traditional agriculture*. New Haven: Yale University Press.
27. Morgan, W. B. (1978). *Agriculture in the third world: A spatial analysis*. Colorado: The Westview Press.
28. Tan, S., Heerink, N., & Qu, F. (2006). Land fragmentation and its driving forces in China. *Land Use Policy, 23*(3), 272–285.
29. Van Hung, P., MacAulay, G., & Marsh, S. (2007). The economics of land fragmentation in the North Vietnam. *The Australian Journal of Agricultural and Resource Economics, 51*, 195–211.
30. Mearns, R., & Sinha, S. (1999). Social exclusion and land administration in Orissa, India. Policy Research Working Paper 2124, World Bank, Washington DC.
31. Houston, J. M. (1953). *A social geography of Europe*. London: Gerald Duckworth.

32. Vanderpol, P. R. (1956). Reallocations of land in the Netherlands. In K. H. Parsons, J. Penn, & P. M. Raup (Eds.), *Land tenure* (pp. 548–553). Madison: Univesty of Wisconsin Press.
33. Burton, S., & King, R. (1982). Land fragmentation and consolidation in Cyprus: A descriptive evaluation. *Agricultural Administration, 11*(3), 183–200.
34. Papageorgiou, E. (1956). Fragmentation of land holdings and measures for consolidation in Greece. In K. H. Parsons, J. Penn, & P. M. Raup (Eds.), *Land tenure* (pp. 543–547). Madison: University of Wisconsin Press.
35. O'Riordan, T. (1976). *Environmentalism*. London: Pion Limited.
36. Smith, C. T. (1978). *An historical geography of western Europe before 1800*. New York: Longman Press.
37. Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure*. London: Earthscan Publications.
38. Geertz, C. (1963). *Agricultural Involution: The process of ecological change in Indonesia*. Berkeley: University of California Press.
39. Tiffen, M., Motimore, M., & Gichuki, F. (1994). *More people, less erosion: Environmental recovery in Kenya*. West Sussex: Wiley.
40. Homans, G. (1941). *English villages of the Thirteenth Century*. Cambridge: Harvard Univesrity Press.
41. Grigg, D. (1980). *Population growth and agrarian change: A historical perspective*. Cambridge: Cambridge Univesrity Press.
42. Karouzis, G. (1971). Time-wasted and distance travelled by the average Cypriot farmer in order to visit his scattered and fragmented agricultural holding. *Geographical Chronicles: Bulletin of the Cyprus Geographical Association, 1*(1), 39–58.
43. Naylon, T. (1959). Land consolidation in Spain. *Annals of the Association of American Geographers, 49*(4), 361–373.
44. King, R., & Burton, S. (1989). Land ownership values and rural structural change in Cyprus. *Journal of Rural Studies, 5*(3), 267–277.
45. Shaw, D. (1963). The problem of land fragmentation in the Mediterranean area. A case study. *Geographical Review, 53*(1), 40–51.
46. Galt, A. H. (1979). Exploring the cultural ecology of field fragmentation and scattering in the island of Pantellaria. *Journal of Anthropological Research, 35*, 93–108.
47. Fenoaltea, S. (1976). Risk, transaction costs and the origin of medieval agriculture. *Exploring Economic History, 13*, 129–151.
48. Demetriou, D., Stillwell, J., & See, L. (2012). Land consolidation in Cyprus: Why is an integrated planning and decision support system required? *Land Use Policy, 29*(1), 131–142.
49. Monchuk, D., Deininger, K., & Nagarajan, H. (2010). Does land fragmentation reduce efficiency: Micro evidence from India. In: *Proceedings of Agricultural and Applied Economics Association.* Joint Annual Meeting, July 25–27, Colorado, USA. Available from URL: http://ageconsearch.umn.edu/bitstream/61652/2/WB-land-frag-alt_measures-AAEA.pdf.
50. Shuhao, T. (2005). Land fragmentation and rice production: a case study of small farms in Jiangxi Province, P.R. China. PhD thesis, Wageningen University.
51. Edwards, D. (1961). An economic study of small farming in Jamaica. University College, West Indices.
52. Simmons, A. J. (1964). An index of farm structure, with a Nottingahmsire example. *East Midlands Geographer, 3*, 255–261.
53. Dovring, F. (1965). *Land and labour in Europe in the twentieth century* (3rd ed.). Hague: The Nijhoff.
54. Januszewski, J. (1968). Index of land consolidation as a criterion of the degree of concentration. *Geographia Polonica, 14*, 291–296.
55. Blarel, B., Hazell, P., Place, F., & Guiggin, J. (1992). The economics of farm fragmentation—evidence from Ghana and Rwanda. *World Bank Economic Review, 6*(2), 233–254.

56. Igozurike, M. U. (1974). Land tenure, social relations and the analysis of spatial discontinuity. *Area, 6*, 132–135.
57. Schmook, G, Jr. (1976). The spontaneous evolution from farming on scattered strips to farming in severalty in Flanders between the sixteenth and twentieth centuries: A quantitative approach to the study of farm fragmentation. In R. H. Buchanan, R. A. Butlin, & D. McCourt (Eds.), *Fields, farms and settlement in Europe* (pp. 107–117). Belfast: Ulster Folk and Transport Museum.
58. Demetriou, D., Stillwell, J., & See, L. (2011). The development and evaluation of a new model for measuring land fragmentation. Working Paper 11/05. School of Geography, University of Leeds, pp. 57. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/11-05.pdf.
59. Demetriou, D., Stillwell, J. and See, L., (2013). A New Methodology for Measuring Land Fragmentation. *Computers, Environment and Urban Systems*, *39*, 71–80.
60. Brabec, E., & Smith, C. (2002). Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States. *Landscape and Urban Planning, 58*(2–4), 255–268.
61. European Commission, (2000). Farm *structure: Historical results-surveys from 1966/1967 to 1997*. Office for Official Publications of the European Communities. Luxemburg.
62. European Commission, (2003). *Farm structure: 1999/2000 Survey*. Office for Official Publications of the European Communities. Luxemburg.
63. European Commission, (2005). *Agricultural statistics-quarterly bulletin: Special Issue-frame structure survey 2003*. Office for Official Publications of the European Communities. Luxemburg.
64. Rahman, S., & Rahman, M. (2009). Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. *Land Use Policy, 26*(1), 95–103.
65. Nguyen, T., Cheng, E. J. And, & Findlay, C. (1996). Land fragmentation and farm productivity in China in the 1990s. *China Economic Review, 7*(2), 169–180.
66. Vander Meer, P. (1975). Land consolidation through land fragmentation: Case studies from Taiwan. *Land Economics, 51*(3), 275–283.
67. Yaslioglu, E., Aslan, S. T., Kirmikil, M., Gundogdu, K. S., & Arici, I. (2009). Changes in farm management and agricultural activities and their effect on farmers' satisfaction from land consolidation: The case of Bursa-Karacabey, Turkey. *European Planning Studies, 17*(2), 327–340.
68. Kjelland, M., Kreuter, U., Clendenin, G., Wilkins, R., Ben, X., Afanador, G., et al. (2007). Factors related to spatial patterns of rural land fragmentation in Texas. *Environmental Management, 40*(2), 231–244.
69. Soltow, L. (1983). Land fragmentation as an index of history in the Virginia military district of Ohio. *Explorations in Economic History, 20*(3), 263–273.
70. Verry, E. S. (2001). Land Fragmentation and Impacts to streams and fish in the central and upper midwest. In: *Proceedings, Society of American Foresters, 2000 national convention* (pp. 38–44), November 16–20, Washington DC.
71. Niroula, G. S., & Thapa, G. B. (2007). Impacts of land fragmentation on input use, crop yield and production efficiency in the mountains of Nepal. *Land Degradation and Development, 18*(3), 237–248.
72. Ram, K. A., Tsunekawa, A., Sahad, D. K., & Miyazaki, T. (1999). Subdivision and fragmentation of land holdings and their implication in desertification in the Thar Desert, India. *Journal of Arid Environments, 41*(4), 463–477.
73. Sengupta, N. (2006). Fragmented landholding, productivity, and resilience management. *Environment and Development Economics, 11*(4), 507–532.
74. Belay, K., & Manig, W. (2004). Access to rural land in Eastern Ethiopia: Mismatch between policy and reality. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 105*(2), 123–138.

75. Falah, G. (1992). Land fragmentation and spatial control in the Nazareth metropolitan-area. *Professional Geographer, 44*(1), 30–44.
76. Heston, A., & Kumar, D. (1983). The persistence of land fragmentation in peasant agriculture—An analysis of south asian cases. *Explorations in Economic History, 20*(2), 199–220.
77. Jabarin, A. S., & Epplin, F. M. (1994). Impacts of land fragmentation on the cost of producing wheat in the rain-fed region of northern Jordan. *Agricultural Economics, 11*(2–3), 191–196.
78. Goland, C. (1993). Field scattering as agricultural risk management—A case-study from Cuyo–Cuyo.
79. Abdelali-Martini, M., Goldey, P., Jones, G. E., & Bailey, E. (2003). Towards a feminization of agricultural labour in northwest Syria. *Journal of Peasant Studies, 30*(2), 71–94.
80. Bentley, W. (1990). Wouldn't you like to have all of your land in one place—land fragmentation in northwest Portugal? *Human Ecology, 18*(1), 51–79.
81. Keeler, M., & Skuras, D. G. (1990). Land fragmentation and consolidation policies in Greek agriculture. *Geography, 75*(1), 73–76.
82. Sklenicka, P., & Salek, M. (2008). Ownership and soil quality as sources of agricultural land fragmentation in highly fragmented ownership patterns. *Landscape Ecology, 23*(3), 299–311.
83. Rusu, M. (2002). Land fragmentation and land consolidation in Romania. In: *Proceedings of the International Symposium on Land Fragmentation and Land Consolidation in Central Easter European Countries (CEEC): A gate towards sustainable rural development in the new millennium,* Munich, February 25–28. Available from URL:http://www.landentwicklung-muenchen.de/cd_ceec_conference/case_studies/romania/os_n_rusu_formatiert.pdf.
84. Thomas, J. (2006). What's on regarding land consolidation in Europe? In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* October 8–13, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_03_thomas_0311.pdf.
85. Thomas, J. (2006). Property rights, and fragmentation and the emerging structure of agriculture in central and eastern European countries. *Journal of Agricultural and Development Economics, 3*(2), 325.
86. Karouzis, G. (1993). The land tenure structure in Cyprus and related problems. In: Land Consolidation Department, (eds.), *Land consolidation in Cyprus* (pp. 5–17), Ministry of Agriculture and Natural Resources of Cyprus.
87. Swinnen, J.F.M., Mathijs, E., and Buckwell, A., (1997). Agricultural Privatisation, *Land Reform and Farm Restructuring in Europ*e. Aldershot, Ashgate.
88. Land Surveys Department (LSD), (2008). Historical Background. [online]. Accessed on 20 May 2009 at URL:http://www.moi.gov.cy/moi/DLS/dls.nsf/dmlhistory_en/dmlhistory_en?OpenDocument

Chapter 3
Land Consolidation

3.1 Introduction

This chapter provides a broad review of approaches to land consolidation, which is the problem domain of this research. Specifically, the chapter is divided into four primary sections. Section 3.2 provides a brief historical evolution of land consolidation, sets outs its definitions, objectives and principles, identifies its advantages and disadvantages and defines different types including implementation approaches. Section 3.3 explores the main aspects of the land consolidation procedure based on international practices: the main stages of the procedure, the ways a decision is taken for project implementation, the administrative and executive organisations involved and the information needed. Crucial matters, such as public participation and land valuation are also discussed. The role of land consolidation in the framework of EU policies and FAO activities is investigated in Sect. 3.4. More specifically, the extent of land consolidation implementation in an international context is identified and the importance of land consolidation in EU rural development policies is considered with special reference to the current Rural Development Programme 2007–2013. The traditional involvement of FAO in land consolidation activities is briefly identified. Thereafter, Sect. 3.5 focuses on the Cypriot land consolidation framework by defining the aims and the available measures, the organisations that execute land consolidation and the procedures involved. This section ends with an evaluation of project results so far and a summary of current problems associated with the process and some recommendations.

3.2 Land Consolidation Review

3.2.1 Historical Evolution

Land consolidation is a kind of land reform although its objectives are different. In particular, land reform involves the redistribution of land in a national or regional level to achieve social equity in terms of landownership, whereas traditionally,

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_3, © Springer International Publishing Switzerland 2014

land consolidation involves the redistribution of land in a particular locality, aiming to achieve an optimum land tenure structure to facilitate rational agricultural development [1]. According to Van Dijk [2], the first conception of land consolidation began in 1343, in the region of Bavaria in Germany, when monks spontaneously exchanged parcels in the village of Oberalteich. Uimonen [3] suggests that the first land rearrangement began in the fourteenth century in Finland in response to the King's taxation system. The idea was adopted a century later (in 1435) in the Netherlands, when members of the Agnieten monastery in the city of Zwolle consolidated the land parcels into a 50 ha area. Some years later, in 1450, the concept emerged in Italy. Afterwards, the concept spread to other European countries: in Denmark (1650); in France (1702); in Switzerland (1808); in Spain (1850); and in Norway (1859). Although the concept of land consolidation began early in the fourteenth century, legislation was only adopted some centuries later.

The first land consolidation legislation emerged in the middle of the eighteenth century. In particular, in Sweden, a land consolidation law was promulgated in 1749 [4] while the first land consolidation began in 1757 covering most of the agricultural land [5]. In Denmark, the first Consolidation Act was introduced in 1781 [6] although it was not completed until 1805 (Meuser 1992; cited in [2]). Germany established land consolidation legislation in 1856 (in the region of Baden) and this was applied later to other regions (in 1861 in Bayern and in 1862 in Wurttemb). Other countries followed thereafter: Austria in1883; Switzerland in 1893; Italy in 1896; Belgium in 1900; France in 1918; and the Netherlands in 1924. As noted in Chap. 2, Cyprus acquired land consolidation legislation in 1969. In Britain, land consolidation took place so long ago, that many writers and even experts, tend to forget that it took place at all [7]. The 'enclosure' that started in the fifteenth and sixteenth centuries, was the action of the lord of the manor to enclose common land. The wholesale action of enclosure took place in the eighteenth and nineteenth centuries, supported by the Enclosure (Consolidation) Act of 1801 (Sayce et al. 1992; cited in [8]; Dixon-Gough et al. [9]). This Act, together with others that followed, continued until 1862 when attempts at the registration of title were first introduced, which effectively ended the process of enclosure.

Traditionally, land consolidation has always been regarded as a primary land management approach for rural development. The reason is because early concepts of rural development were virtually the same as agricultural development, due to the predominant role of agriculture in rural areas at that time. Thus, what was good for the farmers was also good for rural areas. Consequently, the primary aim of land consolidation focused on the creation of competitive agricultural production arrangements, by enabling farmers to have farms with fewer parcels, to have larger and better shaped fields and to expand the size of their holdings [10–12]. In other words, it was a technique for solving or limiting land fragmentation.

However, initially in the 1960s and more intensively in the 1980s, it was realised that rural space cannot be regarded for agricultural production purposes alone. The concept of rural development became broader and expanded to include other aims than agriculture, such as environmental protection, landscape, nature conservation, recreation, village renewal, regional projects and generally concepts that affect the living and working conditions of rural areas' residents [10]. This expanding of rural development concepts led to a proportional shift from traditional land consolidation to modern land consolidation, i.e. to a powerful land management instrument with multi-functional goals. A plethora of land consolidation experts provide evidence about the shift of land consolidation aims [8, 12–17]. Originally, Austria and Switzerland in 1951, followed by Belgium in 1970, Spain in 1973 and Germany 1976 modified their legislation to include these broader aims. Other countries followed suit later, e.g. Denmark in the 1980s and the Netherlands in 1985. However, in some countries, land consolidation still remains an agricultural oriented instrument [2]. It is also remarkable that in some cases, land consolidation was employed for the transition from a socialist control-economy to a market economy [2, 18].

3.2.2 Definitions and Principles

Many definitions have been used to cover the content of land consolidation, depending on the objectives concerned, which have varied from country to country [2, 15]. Basically, some of the definitions have a narrow concept which is closer to the traditional form of land consolidation while others have a broader concept which refers to the modern form of land consolidation. Recently, the FAO [19] clarified the whole matter by combining the two prevailing concepts of land consolidation into the following statement:

> land consolidation is a term traditionally used to refer to measures to remove the effects of fragmentation by adjusting farm structures. But the term goes well beyond the narrow, yet important, actions of the reparcelling of land to remove fragmentation. Land consolidation has long been associated with broader social, economic and environmental changes. As a result land consolidation has shifted from a narrow focus on agricultural structures to a broader focus of integrated rural development.

Thus, land consolidation consists of two main components: land reallocation (or land readjustment) and agrarian special planning [15]. Land reallocation involves the rearrangement of the land tenure structure in terms of parcels (size, shape and location) and landowners (rights) and is the core issue of each land consolidation approach. Agrarian special planning involves the provision of the necessary infrastructure such as roads, irrigation systems, drainage systems, landscaping, environmental management, village renewal, soil conservation, etc. for the land development of a certain land use(s).

FAO [10] suggests the following basic principles which should rule modern land consolidation approaches:

> the objective should be to improve rural livelihoods rather than to improve only the primary production of agricultural products; the end result should be community renewal through sustainable economic and social development of the whole community, and the

protection and sustainable management of natural resources; the process should be participatory, democratic and community-driven in practice and not only in concept; The intervention should be to assist the community to define new uses for its resources and then to reorganize the spatial components accordingly; The approach should be comprehensive and cross-sectoral, integrating elements of rural and broader regional development including the rural–urban linkages

All these principles emphasise the multi-dimensional role of land consolidation aimed at rural sustainable development, which is associated with regional planning through a democratic, participatory and community driven approach. The relationship between land management and sustainable development is directly related to the types of efforts conducted in this direction; namely, to maximise resource use, reduce environmental impacts, avoid/improve social impacts, promote the use of renewable and green technologies and enforce democratic decision processes. Land management, which has a vital role to play in the achievement of these efforts [20, 21], emphasises the substantial evidence for the shift of land consolidation from its traditional form to a modern form with broader economic, environmental and social aims. Consequently, the role of land consolidation, which is among the primary and most effective land management instruments, to rural sustainable development is crucial and it has been emphasised many times in the literature [14, 15, 21–24].

3.2.3 Objectives of Modern Land Consolidation

As noted earlier, the evolution from the traditional form of land consolidation to a modern form involves a shift of the fundamental land consolidation aims to a broader spectrum of goals which focus on aspects such as: agriculture, environment, rural landscape, village renewal, rural infrastructure, etc. Vitikainen [12] points out that the objectives of land consolidation may vary from country to country because of different political, social, economic and historical conditions and as a result, different approaches and different legislation are applied in each country [23] despite the fact that there are many common characteristics of the whole process between different countries [16].

Thomas [14] grouped the land consolidation objectives into seven categories with objectives related to: agriculture/forestry; regional transport; regional water management [25]; communal development [26]; environmental protection/supply-waste disposal; nature protection/landscape [27, 28]; and leisure/recovery. Similarly, Vitikainen [12] operationally grouped the objectives of land consolidation into four categories with objectives concerning: agriculture and forestry; the development of other industries; the housing and living environment; and other land-use needs. Regarding the goal setters, the objectives of land consolidation can be considered from the viewpoint of the landowners, other interested parties, society and other interest groups. Thus, the objectives of land consolidation may have a different importance for different interested parties and groups. For instance, it is reasonable that farmers identify their prominent aim being to reduce their production costs and increase their income. On the other hand, non-farmers in a village may emphasise the need for adjusting agricultural production to other land use needs of the village community. In terms of the national economy, the importance of each aim is defined by market demand.

The various land consolidation objectives may have impacts in the community at several levels. The FAO [19] classifies land consolidation impacts at three levels: first, there is the *micro-level*, where land consolidation aims focus on changing the farm structure and their direct environment so as to enable farmers to become more competitive. Secondly, there is the *meso-level*, where land consolidation has broader aims for changing rural communities by improving infrastructure (roads, irrigation and drainage systems, water and disposal installations, etc.), the natural environment, management of natural resources, landscape and, consequently, the spatial distribution of economic activities. Finally, there is the *macro-level*, where the focus is on changes which can positively affect the whole country, by reducing the disparities between rural and urban areas, by ensuring a more efficient and multiple use of rural space, by improving the overall competitiveness of the agricultural and rural sector, by building trust between governments and inhabitants of rural areas and by enhancing the land market.

3.2.4 Advantages and Disadvantages

FAO [10] recognises that land consolidation has four major capabilities. First, it can lead to improvements in agriculture via an effective restructuring of land tenure systems that results in rational agricultural development and thus in benefits to farmers' income. Secondly, it can promote improved management of natural resources since land tenure restructuring may have a substantial influence on the geo-ecological and bio-ecological resources. Also, better land-use planning and land management of natural resources can be achieved through solving public–private conflicts. Thirdly, it can improve rural development through project-oriented land consolidation schemes which may facilitate the efficiency and cost effectiveness of public and private investments in transportation and communication networks, utilities and irrigation systems.

Also, potential conflicts for acquiring the necessary space for these developments may be reduced via the use of land consolidation procedures and tools. Land consolidation projects may be at the heart of integrated rural development programmes by providing the means and the infrastructure to support the provisions/measures/aims of these programmes. Fourthly, it can improve land administration systems since it provides an opportunity to clarify and update ownership records. Thus, better quality land information systems facilitate the reliability and hence the development of land markets and the management of land conflicts. It also supports the social and political stability in developing countries or the smooth transition to the free market economy of ex-communist countries.

Despite the fact that the capabilities/achievements of land consolidation are recognised by many national governments, international organisations and commissions, such as the FAO and UNECE (United Nations Economical Commission for Europe), not all experts or landowners agree on a need for land consolidation [8]. Indeed, some authors disagree with the idea of land consolidation, emphasising the potential benefits of land fragmentation [29, 30]. Similarly, other authors view land consolidation with scepticism [2, 11, 31]. Thus, despite the recognised advantages and capabilities provided by land consolidation, some disadvantages are evident. In particular, land consolidation causes negative effects when it is applied in areas where land fragmentation is beneficial and it does not constitute a serious problem. Such effects focus on agriculture and natural ecosystems as well. These matters have been discussed in Sect. 2.2.4. Thus, land consolidation cannot be considered as a panacea for all rural areas and their problems. Bentley [31] identifies some criteria for when national policy should favour land consolidation. In summary, areas that should be left fragmented are those which have dramatic micro environmental contrasts or are important ecological micro zones, these being high risk in terms of production.

Furthermore, as with any infrastructure project, land consolidation causes some impacts on the natural environment. Many authors point out the potential impacts of land consolidation on the natural environment and the rural landscape in general ([32], [8, 15, 33]). Bullard [8] summarises some of them: increasing field size and area of cultivation which destroys the scene variety provided by land fragmentation; removing hedges and physical parcel boundaries which are used as 'green fencing' and provide habitats for wildlife; increasing wind and water erosion by removing the barriers created by boundaries; bringing abandoned land back into production; standardising tree species in forest consolidation; adding extra infrastructure which destroys land and creates pollution; providing access to locations where before accessibility was only on foot or by animal. Lisec et al. [33] highlight that one of the primary causes of the decline of biodiversity is the fragmentation of natural ecosystems as a result of inappropriate land consolidation. These concerns were a core reason for the shift of land consolidation aims to include environmental protection and generally sustainable development within its primary aim. In practice, an environmental impact assessment study must be undertaken before applying a land consolidation project further to carrying out a feasibility study.

Moreover, a social impact of land consolidation is the generation of landless people (at least as applied in Cyprus). Bullard [8] notes that land consolidation processes generate landless people because when landowners hold insufficient land to create a minimum economic unit, they are displaced, i.e. their land is ceded to other landowners and as a result, they become landless. This is an inevitable outcome of the land consolidation process. However, the legislation in each country usually provides some ways to limit this situation. The view of FAO [10] is to avoid this process without the agreement of the people concerned. On the other hand, the effectiveness of land consolidation is considerably reduced when landowners with small holdings (under certain area/value limits) receive them back as part of the new land consolidation plan.

3.2.5 Types and Implementation Approaches

Land consolidation projects may differ significantly according to their objectives and the needs of the national, regional and local community. Based on the author's perceptions and depending on the objectives of a project, land consolidation can be divided into five types: *rural, forestry, urban, regional* and *environmental*. Some types can be combined under a common project. These terms could be used as a prefix of the general term 'land consolidation'. In particular, rural land consolidation refers to both the traditional and the modern form of land consolidation. Both forms have already been discussed. This research focuses on this type of land consolidation. Forestry land consolidation focuses on improving the production and working conditions in a forest area. Special regulations concerning woodland are applied [34]. It includes land allocation, road construction and landscape development measures and sometimes it is applied in combination with rural land consolidation.

Urban land consolidation is that used as a land development technique for urban areas in many countries around the world including Australia, Germany, Indonesia, Japan, the Netherlands, Sweden and Taiwan. Germany and Japan have a long tradition in applying this approach. In particular, 30 % of the urban area of Japan has been developed using this technique [35]. It involves the implementation of a master plan in a new or even existing urban area combined with land reallocation. The aim is to balance public and private benefits. These projects are funded by the surplus value of land created as a result of the new development. Namely, this surplus value of land provides the funding for construction costs and the profit of the landowners involved. Further information can be found in books by Doebele [36], Minerbi et al. [37] and Hong and Needham [38] and Ph.D. theses by Yomralioglu [39] and Sorensen [35].

Regional land consolidation is usually applied when land is required for the construction of major public projects such as roads, airports, railways or dams. In this case, a well-planned and implemented consolidation scheme can greatly improve the yields of agriculture in an area, in addition to providing a major restructuring of the land. The core aims are to mitigate the effects on farmers and others in the communities [19] and reduce the conflicts between landowners and the Government arising from the necessary acquisition of land. In this way, the procedure of expropriation is avoided and the impacts on land are minimised and equally distributed to the landowners of a broader area. This type of land consolidation, which is applied in Belgium, France, Germany and the Netherlands, solves expropriation problems in the context of public infrastructure intentions [15]. Furthermore, environmental land consolidation is implemented with the specific objective of improving and protecting the environment, landscape and nature generally. For example, a land consolidation project can be applied to protect/restore a lake or a river by reorganising land tenure structure or to create a national park (e.g. in combination with NATURA programmes). In countries like Denmark, Germany and the Netherlands, many nature and environmental projects are implemented through a land consolidation procedure.

Independently, different types of land consolidation implementation approach can be utilised. Implementation approaches involve the legal aspects of the land consolidation process. For example, Germany has five different procedures [14], the Netherlands has four and France has seven [8]. FAO [10] suggests four implementation approaches for land consolidation projects. The most effective consolidation approach to rural development is *comprehensive land consolidation* but there are also other approaches such as *simplified consolidation, voluntary group consolidation* and *individual consolidation* initiatives which can bring benefits. The differentiation between these approaches is due to legal aspects and the procedures followed.

Specifically, complex or comprehensive land consolidation includes the re-allocation of parcels together with a broad range of other measures to promote rural development. It is the most appropriate approach for integrated rural development programmes since it provides a long-term solution to agrarian structures [14]. Examples of such activities include village renewal, support to community-based agro-processing, construction of rural roads, construction and rehabilitation of irrigation and drainage systems, erosion control measures, environmental protection and improvements including the designation of nature reserves and the creation of social infrastructure including sports grounds and other public facilities. This is the most popular approach. In addition, simplified land consolidation optimises conditions in the agricultural sector through the re-allocation or exchange of parcels and the provision of additional lands from land banks. These simplified projects are often combined with the rehabilitation of infrastructure through public projects and sometimes the provision of minor facilities but they do not include the construction of major public works although they can provide the framework for their construction at a later stage. Procedures for simplified land consolidation projects tend to follow those of comprehensive projects but some of the requirements may be relaxed.

Another approach is voluntary group consolidation that occurs in some countries where there is mutual agreement with no element of compulsion. As consolidation is entirely voluntary, all participants must agree fully with the proposed project. As a result, voluntary projects tend to be small and are best suited to address minor and localised problems. In some countries, voluntary projects usually have fewer than ten participants. It is worthwhile mentioning that in Denmark almost all land consolidation projects are carried out in a completely voluntary way and are typically based on negotiations with about 50–100 landowners. Based on Wilden [34] this kind of land consolidation is the simplest, fastest and most inexpensive. Moreover, individual consolidation of holdings can take place on an informal and sporadic basis. The state is not directly involved so these initiatives do not include the provision of public facilities. However, the state can play a significant role in encouraging consolidations that improve agriculture by promoting policies such as joint land-use agreements, leasing and retirement schemes.

3.3 Land Consolidation Procedure

The land consolidation procedure is based on legislation, which varies from country to country and regulates, authorises and ensures the transparency of the whole process. Some important aspects of land consolidation procedures are discussed in the following sections.

3.3.1 Stages

Land consolidation procedures involve several tasks and processes which can be grouped into stages. The main stages are similar in all countries, although the sequence of the processes and tasks in each stage may differ or may be classified in another stage. Zhou [40] and Vitikainen [12] recognise three main stages: the preparation stage (or administrative preparation); the inventory and planning stage (or technical preparations); and the implementation stage which is followed by a monitoring procedure to establish the benefits and impacts of a project. Namely, the preparation stage involves the following processes: the initial request for applying land consolidation in an area; the education of the farmers about the processes, benefits and costs of the project; the setting-up of the executive body for the project, e.g. the ‘executive committee’, or appointment of a ‘cadastral surveyor’; the delimitation of the study area and the decision by the apposite public body to promote the project, which is usually based on feasibility and environmental assessment studies.

This is followed by an inventory and planning stage, which involves obtaining an updated inventory of all cadastral information for the consolidated area; the decision by landowners for implementing the project; beginning the survey engineering works; land valuation; infrastructure planning (e.g. road, irrigation and drainage network); preparation of the land consolidation plan; and appeals of landowners for plans and construction works. Finally, the implementation stage involves the demarcation of the boundaries of new parcels; complementary construction works; calculation of the compensation to landowners and the cost of the project corresponding to each landowner; registration of the new parcels; and the issuing of the new cadastral titles.

3.3.2 Decision for Project Implementation

Generally, there are three ways in which the decision taken for applying a land consolidation project can be applied, i.e. land consolidation may be *voluntary, compulsory* or *partly voluntary*. In particular, voluntary land consolidation is the case when all of the landowners of an area agree to carry out land consolidation.

It could be via spontaneous efforts of landowners in the form of cooperatives or personal exchanges and should be promoted and encouraged by governments [40]. However, such operations are usually slow and ineffective, have many problems and usually fail. There is evidence that voluntary land consolidation efforts in Denmark, France, Switzerland, India and the Netherlands failed or were too slow and hence unsatisfactory [40, 41].

In contrast, compulsory land consolidation is imposed by governments. This approach may also result in many problems due to the lack of cooperation and resistance shown by landowners. Although this approach might have been successful in older and not so democratic times or in areas where it is easier to apply land consolidation, it may not be accepted in many countries nowadays. As Zhou [40] notes, in India (1950) and in Slovenia (1996), landowners resisted their Governments' decisions to proceed with compulsory land consolidation. However, the German Land Consolidation Law ensures that the Higher Land Consolidation Authority has the power to decide whether to begin a project only if it is convinced of the 'willingness' of the landowners [2]. Despite this provision, land consolidation has a long successful tradition in Germany.

The third approach is a combination of the above two, i.e. partly voluntary consolidation means that when a certain percentage of landowners agree with the implementation of the project, then the others should follow. This percentage varies from more than 1/3 or 1/2 or 2/3 of the number of landowners. Furthermore, usually, those landowners in favour of land consolidation should hold a certain amount of land in terms of area or value. Thus, a project may proceed with a simple minority, simple majority and a substantial majority, respectively [40].

Most of the countries apply the latter approach, although the percentage of the landowners' consent that is necessary will vary from place to place. For example, in Japan, legislation requires agreement from 2/3 of the landowners involved before the project can be carried out. Similarly, in Turkey, a project can be initiated with the consent of 2/3 of the landowners who own more than 1/2 of the area of the scheme being proposed [8]. In Cyprus, China, Greece, Netherlands, Portugal and Sweden, a simple majority agreement (i.e. more than 50 %) combined with a land size/value majority is sufficient to initiate a project. Despite the above practices, many countries have legislation that allows them to apply compulsory land consolidation in special cases, usually when it should be part of an integrated rural programme.

3.3.3 Administrative and Executive Organisation

In most countries, there are special bodies which are responsible for the implementation and administration of land consolidation schemes. Usually, they are separate land consolidation authorities (or government departments) consisting of professional experts such as surveying/geodetic engineers, land surveyors, rural/agricultural engineers, agriculturalists/agronomists, environmentalists, lawyers, economists, geographers, civil engineers, urban planners and others. Whilst land consolidation is carried out in terms of organisation/administration by the responsible authority, in some countries (e.g. in Germany), the authority may authorize another competent and entitled institution/agency/bureau to implement some service and/or legally defined processing stage [14].

According to Van der Molen et al. [16], there are two main alternative models regarding the execution responsibility of the land consolidation procedure: *'the cadastral surveyor model'* and *'the committee model'*. In the former, which is applied in Austria, Finland, Germany and Sweden, the land consolidation authority appoints a 'registered' or 'chartered' surveyor to carry out the project. However, the surveyor may be assisted in decision making by trustees appointed by the municipality or another public body. In the latter case, which is applied in Belgium, Cyprus, France, the Netherlands, Portugal and Switzerland, the responsibility is concentrated in a panel or committee which may consist of government experts and farmers' representatives.

Even in countries which follow the 'committee model' (e.g. in France or the Netherlands), a 'chartered' surveyor dominates the whole process in terms of execution. Also, it is noted that in the case of the 'cadastral surveyor model', decisions are not taken by a person but by a panel or a local body. For example, in Germany, legislation gives the power to the so called 'Body of Participants' which in turn elects a Board. This Board, which is chaired by a land consolidation official, has far reaching authority within the project such as taking decisions about public facilities, distributing costs among participants, designing the relocation plan and land valuation. In Cyprus, such a Board with these powers is the Land Consolidation Committee.

3.3.4 Public Participation

Public participation is recognised as a basic characteristic of good governance [42]. Although public participation has only been part of the planning process during the last few decades, it has a long tradition in land consolidation. Basically, it is an integral part of the process for two reasons; firstly, land consolidation is a 'bottom-up' planning approach, i.e. it usually begins with the favoured decision (via voting) of the majority of landowners concerned and its success depends strongly on the acceptance by the landowners of the decisions taken. Secondly, the land consolidation process cannot be carried out without the participation of the landowners concerned, because it directly involves handling of their properties. The strong relationship of most people with land is well-known and goes beyond economic value [10, 11, 43] with conflicts emerging from highly interventional such as land consolidation. The need for public participation in land consolidation procedures has been identified by Backman [44], FAO [10] and Thomas [15].

Namely, public participation in land consolidation includes four levels: Firstly, in the case of partly voluntary schemes, which are the most common in the EU, they decide via voting in favour of or against the implementation of a project. Secondly, they have representatives on the 'Execution Committee' or in any other local committee (e.g. in the Land Valuation Committee, or in the Body of Participants as it is called in Germany). Thirdly, they participate in the so called 'preference or wish sessions' in which every landowner has a personal conversation (with the local committee or with the staff of the land consolidation authority) to express his/her thoughts about the parcelling problems in the area in general and his/her holdings in particular. Fourthly, landowners have the right to appeal against the decisions/plans at certain important stages of the process. In particular, they may submit objections against the land consolidation plan, the land valuation plan, the road network plan and so forth. These appeals against plans can be examined usually at three levels of justice which gradually increase in power. Firstly, an objection is examined by the local committee or the land consolidation authority. The next level is a central government authority and the final level is a court. It is remarkable that Norway is the only country that has established specific 'land consolidation courts' since 1882, which handle land disputes and planning issues [45].

It is worth noting that although the land consolidation process has been interactive and participatory, the process still remains mostly traditional, with face to face meetings and workshops. Thus, it is the time to use the technology as a complementary mean providing an interactive/participatory land consolidation process in addition to the traditional procedures. Such tools are PPGIS (public participation GIS), Web-GIS and the GIS portals.

3.3.5 Land Valuation

Land valuation is a process of assigning values to land locations. In particular, land valuation in land consolidation projects is a process of assigning values (monetary or other units, e.g. soil quality) to all parcels of the consolidated area and to all of the contents, i.e. trees, wells, buildings etc. It is among the most important and critical tasks of the land consolidation process since the land reallocation relies on the principle that each landowner should receive, after land consolidation, a land holding with approximately the same land value as that of the original holding before land consolidation [10]. If the value of the holding is smaller after consolidation, equivalency can be achieved by paying financial compensation. In other words, land value is the crucial factor for the land reallocation process and hence for the final land consolidation plan [12, 23, 40, 46, 47].

Yomralioglu [39] identifies 40 factors that may affect the land parcel value for the land readjustment (urban land consolidation) process. Some factors could be also used for land valuation in rural land consolidation: topography; parcel shape; location and size; soil condition; land use; environment; and access to a road. In addition, land productivity, soil quality and depth, source of irrigation, distance from homestead and village and capital improvements (e.g. buildings, wells) are also important factors. A critical question regarding land valuation in consolidated areas is: should land appraisal be based on market value or on soil quality/land productivity units?

FAO [10] and Thomas [15] note that two types of land appraisal should be used in combination with land consolidation projects: appraisal of soil quality and of market values. On the other hand, Van Dijk [2] argues that the actual market value is not appropriate for land consolidation projects. Instead, he suggests that soil production potential is more suitable. This is correct when the permitted land use is limited only to agricultural purposes. However, in cases such as Cyprus, where housing land use is possible in land consolidation areas, agricultural appraisal alone is not appropriate and may lead to serious reallocation problems. Thus, in such cases, the soil productivity of a parcel is only just one important factor among many taken into account for the estimation of a broader market value. Land valuation for land consolidation projects is usually carried out by the committee implementing the project (e.g. in the Netherlands,), by a specific Land Valuation Committee in which landowners participate (e.g. in Cyprus), by agricultural experts (e.g. in Germany), and by a surveying engineer and two trustees (e.g. in Finland and Sweden). The comparable sales method is employed in the case of Cyprus. However, it is interesting that German et al. [48] present traditional and new approaches of land valuation that could be also considered for land consolidation. The new approaches involve the utilisation of GIS [49].

3.4 Land Consolidation in the Context of EU and FAO Policies

3.4.1 The Extent of Implementation

A review of the literature reveals that currently land consolidation is applied or is under an implementation process (e.g. pilot projects being executed) in 26 out of 28 EU countries. It is not evident in the UK and Ireland. Some EU countries have a long tradition in land consolidation and they have extensively applied such schemes. These countries are: Austria, Denmark, Finland, France, Germany, the Netherlands, Spain and Sweden. In addition to EU countries, the literature provides evidence that land consolidation is widely applied (or is under an implementation process) in many countries in all continents such as: in Europe (Albania, Armenia, Croatia, Georgia, Kosovo, Moldova, Montenegro, Norway, Serbia, Switzerland, Russia); in Asia (China, India, Indonesia, Japan, Nepal, North Korea, South Korea, Taiwan, Thailand, Turkey, Pakistan); in Africa (Egypt, Kenya, Morocco, Zimbabwe); in North and Central America (Canada, Mexico, United States); in South America (Chile, Colombia);and in Australia.

Regarding the UK, it seems that land consolidation projects have been abandoned despite the fact that considerable progress was made before 1900 [43] due largely to the enclosure movement which began in the fifteenth century. This is possibly due to the fact that UK agriculture does not suffer from land fragmentation problems. A related analysis has been presented in Sect. 2.4.2. Nevertheless, according to Farmer [50], the scattering of holdings is still a problem in several parts of the UK.

3.4.2 The Role of Land Consolidation in EU Policies

A broad aim of EU policies has been to reduce disparities between urban and rural areas by improving rural conditions of its member states [19]. This aim requires sustained programmes and projects that lead to the development of farms, villages and small towns, and the rural space in which they exist [10]. Land consolidation, as an integral part of rural development, has a great role to play towards the success and sustainability of these programmes through its powerful capabilities as noted earlier. The EU, following this declared policy, has always included land consolidation as a measure within its overall rural development policy.

Initially, EU policy regarding rural development was focused on agricultural development. This approach changed around the 1970s, when the EU and its predecessor (the European Community) extended the concept of rural development beyond agricultural development. Despite this broadening of focus, until recently, the emphasis of EU programmes was limited to investments in farms, farm products and marketing. Broader rural development activities such as rural infrastructure, road construction and village renewal were omitted.

This situation really changed in 2000 with the coming into force of the Council Regulation (EC) No 1257/1999 of 17, May 1999 that established the European Agricultural Guidance and Guarantee Fund (EAGGF) and certain regulations amended to include social, environmental and other requirements of rural communities. Within this context, Article 33 of the regulation listed a number of measures aimed at promoting the adaptation and development of rural areas among which was land consolidation. Several other measures were also relevant to comprehensive land consolidation [19].

Furthermore, the 'Leader approach' was introduced, aiming at encouraging the emergence and testing of new approaches, such as integrated and sustainable development, as the main parts of the rural development policy. The Leader approach was a part of the policy for three programming periods: 1988–1994; 1994–2000; and 2000–2006. The Leader+, which was established in 2000, could be used to support the formulation and implementation of integrated territorial development strategies, through a truly bottom-up approach. Among the territorial strategies, land consolidation was also included.

In addition, EU policy not only pertained to member states but also countries with pre-accession status. Two relevant programmes were introduced in 1999: the SAPARD (Special Accession Program for Agriculture and Rural Development) and ISPA (Instrument for Structural Policies for Pre-accession) programmes. Land consolidation was mostly associated with SAPARD. The SAPARD measure regarding the 'adaptation and development of rural areas', was strongly relevant to land consolidation since it included sub-measures such as reparcelling, land improvement, basic services for the rural economy and population, renovation and development of villages, protection and conservation of cultural heritage, as well as development and improvement of infrastructure. With the enlargement of the EU in 2004, SAPARD was replaced by EAGGF (European Agricultural Guidance and Guarantee Fund) and Leader+ until the end of 2006.

These EU programmes, which they were in force for the period before 2007, were evaluated in depth and lessons were learned. As a result, the need for a more simplified rural development policy was revealed which was taken into account for the preparation of the new programming period of 2007–2013. At present, in each EU country, a Rural Development Programme 2007–2013 is in force. The EU Council Regulation No.1698/2005 of 20 September 2005 established the European Agricultural Fund for Rural Development (EAFRD) programmes to finance rural development policy in member states for the period 2007–2013. The main focus of EAFRD is solely in the 'second pillar' of the CAP (Common Agricultural Policy), i.e. rural development. The EAFRD has the following three primary objectives corresponding to three thematic axes and a fourth axis representing the Leader approach: improving the competitiveness of agriculture and forestry sectors by means of support for restructuring; improving the environment and the countryside by means of support for land management; and improving the quality of life in rural areas and encouragement of diversification of economic activities.

These objectives are directly related to the aims of comprehensive land consolidation as an instrument of rural development. It is remarkable that the measures of EAFRD can provide support for land consolidation activities to an extent not previously possible within the EU context, since article 30 of the relevant regulation clearly defines land consolidation as one of the actions that can be supported. In particular, land consolidation is supported in a different grade by the three main axes-objectives of the EAFRD program. Axes 1 to 3 consist of a number of groups of measures, each group constituting of a series of sub-measures. EAFRD has four thematic axes. In addition, land consolidation can also be supported by Axis 4, i.e. Leader, since it is a useful instrument to implement projects with multiple purposes.

3.4.3 FAO Support to Land Consolidation

The Food and Agriculture Organization (FAO) has a long tradition of involvement in land consolidation activities [51]. In particular, since its inception in October 1945, it has assisted member nations in addressing the land fragmentation and land consolidation issues in various ways, i.e. funding land consolidation initiatives/programmes, publishing relevant technical manuals/documents, organising workshops and seminars, elaborating studies etc. After a long gap, land consolidation came back onto the FAO's agenda in 2000 among the highest priorities for its Sustainable Development Division and its specialized services, both Land Tenure and Rural Development in Central and Eastern European Countries (CEEC) and Commonwealth of Independent States (CIS)countries [52]. Specifically, in recent years, the FAO has promoted initiatives and programmes for land consolidation in CEEC such as Armenia, Bulgaria, Czech Republic, Hungary, Romania, Serbia, Lithuania, Moldova and Kosovo. Thus, the FAO, which focuses on the agricultural/rural development sphere, has played a crucial role since its foundation in promoting land consolidation projects worldwide.

Furthermore, since 2002, the FAO has organized or co-organized six workshops/symposiums about land consolidation and published many related documents. Among the workshops that have been organized, the [53] in which participation involved representatives from 23 countries, mainly from Central and Eastern Europe and the CIS, was considered as a benchmark for land consolidation experts. The Munich statement [53] recognizes land consolidation as a gate towards sustainable rural development. Among other findings, the following statement can be found:

> new methodologies should be introduced savings in costs and time by using simple and advanced tools and methods (GIS, remote sensing, spatial data infrastructure) as appropriate so as to reduce cost and time related to land consolidation schemes

This recommendation is in a full accordance with the primary aim of this research.

3.5 Land Consolidation in Cyprus

As noted in the previous chapter, Cyprus acquired the legislative instrument to initiate land consolidation in March 1969 after about a thirty year period [54] since the beginning of relevant studies [55–58], discussions and preparation; the first project began in December 1970. Since then, the LCD has skilfully implemented the provisions of the Land Consolidation Law by applying land consolidation measures in rural areas, at village level, focusing mainly on agricultural development. Because this research focuses on the land consolidation process as it is applied in Cyprus, a review of the process is essential.

3.5.1 Aims and Available Measures

The Department's policy and objectives constitute part of the overall rural and agricultural policy of the Government, which aims at raising the agricultural income and creating a better working and living environment for the farmers and the rural population in general. The two primary aims of land consolidation are: the creation of as great a number of 'economically viable holdings' as possible and the improvement of the defective land tenure structure"[59]. Regarding the first aim, the term 'economically viable holding' is defined annually in monetary values by the Director of the Department. It represents the necessary income that should be derived by a holding so as to sufficiently support a farmer's family economically based on the standard prevailing living conditions in Cyprus. Thus, for the years 2010 and 2011, an 'economically viable holding' should produce an annual income equal to €38,550 (approximately £31,000 in Great Britain). Regarding the second aim, i.e. solving the problems of the land tenure structure in Cyprus, these have been extensively analysed in Sect. 2.5.

In order to accomplish the two primary aims, land consolidation uses the following five basic measures [59]: grouping of the fragmented and scattered land parcels into compact holdings; construction of a new rural road network providing access to all new parcels; enlargement of small holdings by purchasing private, church, state land and re-distributing it to the farmers; creation of regularly-shaped land parcels; and elimination of dual/multiple ownerships and of ownerships held in undivided shares.

A graphical illustration of the capabilities of available land consolidation measures, by comparing the situation before and after land consolidation, in the area of Monagroulli village (District of Limassol), is shown in Figs. 3.1 and 3.2, respectively. In particular, in Fig. 3.1, it is apparent that there is a defective cadastral status with many small parcels which have irregular shapes and no access (the only existing roads are marked in red). In addition to these problems, many landowners hold parcels and shares that are scattered across various locations. For example, one landowner owns the 19 parcels marked in black shading and also holds eight shares in other parcels shown in hatched black. Further to these visible cadastral problems, the land tenure is also subject to some other problems, including dual/multiple ownership and parcels with no-deeds which are not visible on a map. In contrast, the situation in Monagroulli after land consolidation, which is illustrated in Fig. 3.2, is completely different. There is a spatially organised cadastral plan with larger parcels which have regular shapes and access to roads. The owner with the 19 parcels and the eight shares received only three parcels after land consolidation (marked in green) which have approximately the same land value as the original area.

Thus, the land consolidation approach may solve land tenure problems and its measures directly aim at providing the following six main benefits, related to rational agricultural development [60]: better organisation and operation of the agricultural holdings via minimising land fragmentation; reduction in the cost of construction of soil improvement, irrigation and other infra-structural works through the reorganisation of space and the construction of a new rural network; utilisation of abandoned agricultural land, by clarifying the ownership rights or by redistributing it to other farmers; restructuring of cultivation through a complete spatial re-arrangement of ownerships in terms of boundaries, soil classes and parcel orientation; mechanisation of agricultural activities via increasing parcel size and improving parcel shape; and increase of production with simultaneous reduction in the costs and a consequent increase in productivity, as a result of the whole land consolidation scheme.

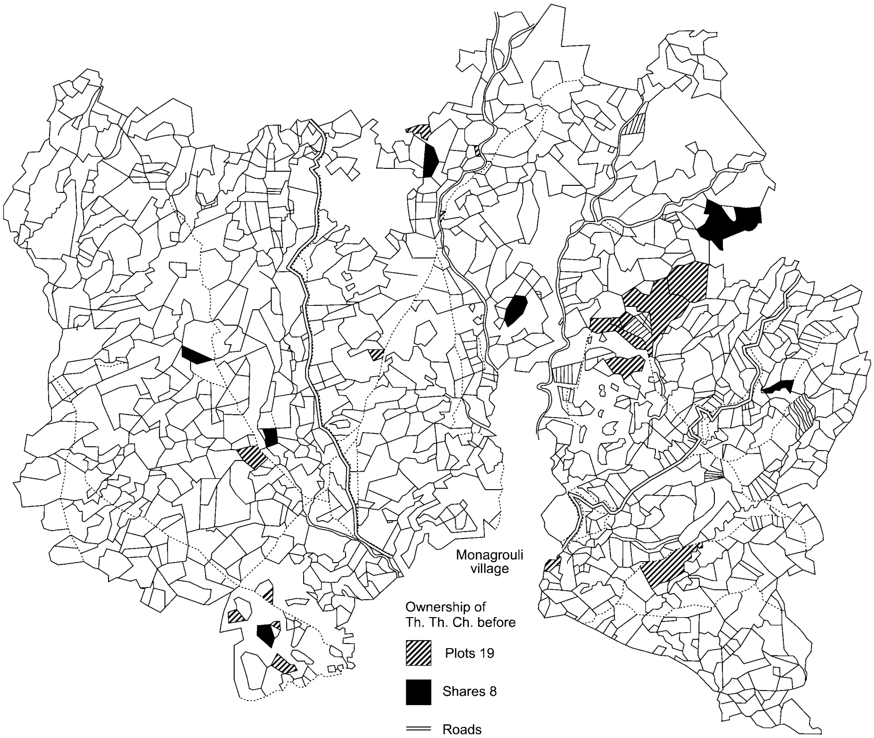


Fig. 3.1 A cadastral plan before land consolidation

3.5.2 Execution Organisations

The main organisations involved in implementing the land consolidation projects are: the *Land Consolidation Department*; the *Land Consolidation Committee*; and the *Land Valuation Committee*. With the enactment of the land consolidation legislation in March 1969, a Central Land Consolidation Authority (a semi-governmental organisation) was established with responsibility for the central direction, organisation and co-ordination of all land consolidation related activities in the country. In August 1985, the Land Consolidation Authority was replaced by the Land Consolidation Department (a purely governmental organisation) under the Ministry of Agriculture, Natural Resources and Environment. The Land Consolidation Department is responsible for the co-ordination, administration and execution of all the land consolidation measures. Furthermore, it may buy, sell, exchange and mortgage immovable properties and has the power to advance money and make loans for the accomplishment of its objectives.

Further to the LCD, a Land Consolidation Committee (LCC) is established for each land consolidation area/project and has a crucial role for project implementation, since it decides and approves almost all the main matters of the process.

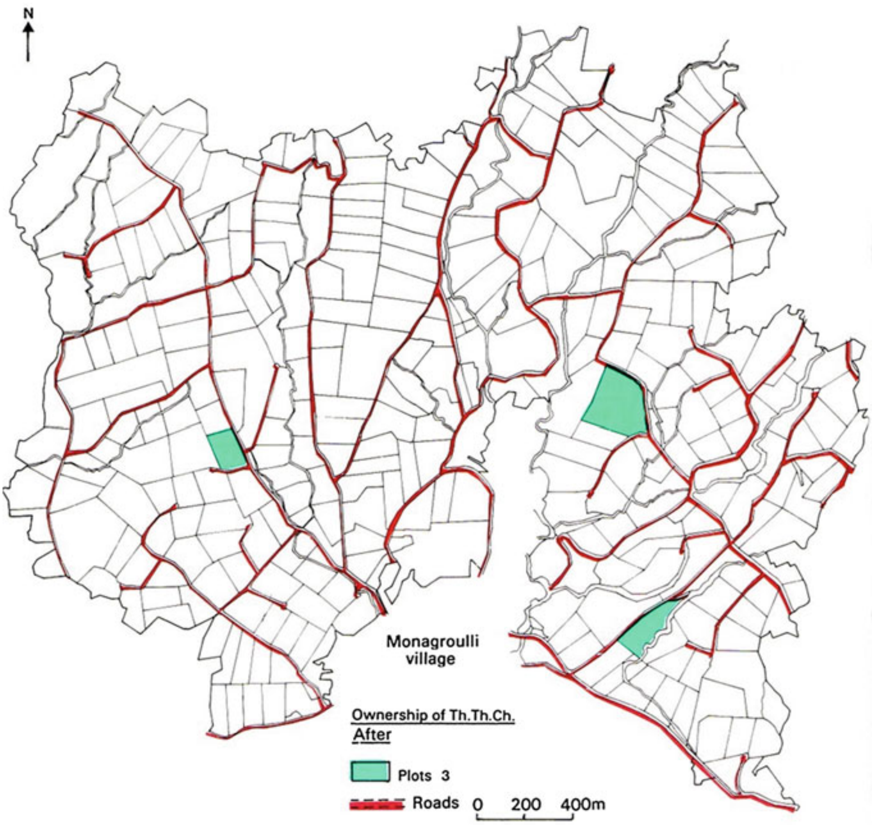


Fig. 3.2 A cadastral plan after land consolidation

A LCC consists of eight members: three elected among the landowners of the project area and five governmental officers from the Land Consolidation Department, the District Administration, the Department of Agriculture, the Land Surveys Department and the Water Development Department. Each LCC is chaired by the District Land Consolidation Officer and is responsible for organising, monitoring and administering the affairs of the Land Consolidation Association of the particular project area. Its main power is decision making in relation to all the matters affecting the Association, including the approval of all plans prepared by the LCD. It is also responsible for examining (at a first level) the objections of landowners against the land consolidation plan, the road network plan and the distribution of road network construction costs.

Moreover, a Land Valuation Committee (LVC) is also established for each land consolidation area/project consisting of five members: two elected among the landowners of the project area and three governmental officers from the LCD, the District Administration and the Land Surveys Department. The Committee is chaired by the District Land Surveys Department Officer. It carries out the valuation of any property (e.g. land, trees, buildings, wells) within the consolidated area based on the market values. The LVC examines (at a first level) the objections made by landowners against the land valuation plan/list. Its role is very important since land value is the fundamental factor for land reallocation. Namely, each landowner should receive after the project, a holding of approximately equal land value to that of his/her land before consolidation.

3.5.3 Procedure

Legislation allows for the application of three different land consolidation approaches: on a voluntary basis by agreement among the landowners; on a compulsory basis by resolution of the majority of the landowners concerned which is a part-compulsory method; and on a compulsory basis by governmental order. To date, only the second method has been used to implement land consolidation in Cyprus (positive voting of landowners in favour of land consolidation implementation, ranged from 60 to 92 % for the forty years implementation in Cyprus) and the procedure is both complex and time-consuming. It involves many processes and tasks, and normally takes from 7 to 10 years.

The whole procedure can be organised into 21 main processes/tasks which can be grouped into four main stages: *planning; preparation; implementation;* and *post-implementation* Demetriou et al. [61]. A graphical representation of the procedure is shown in Fig. 3.3.

It is remarkable that public participation takes place in 13 out of 21 processes which are marked in black shaded rectangles. The process may be terminated in four critical points marked with Yes/No, which means a decision to proceed or not, is taken. The central process of the implementation stage is land reallocation, which is the main problem domain of the system development. Land reallocation is extensively discussed in the next chapter.

3.5.4 Projects Outputs

According to the annual report of the Land Consolidation Department [62], from the beginning of land consolidation in Cyprus, i.e. 1970 up to 2011, 76 land consolidation projects were completed covering an area of 18,081 ha, which corresponds to 11.56 % of the total agricultural area enumerated in the 2003 agricultural census. Furthermore, 12 projects are currently running and 31 projects are under study. A comparative analysis of the land tenure structure before and after land consolidation, based on the completed projects so far, is shown in Table 3.1.

The above results demonstrate the improvement of the land tenure structure in the rural areas in Cyprus, which constitute a vital structural change for about the

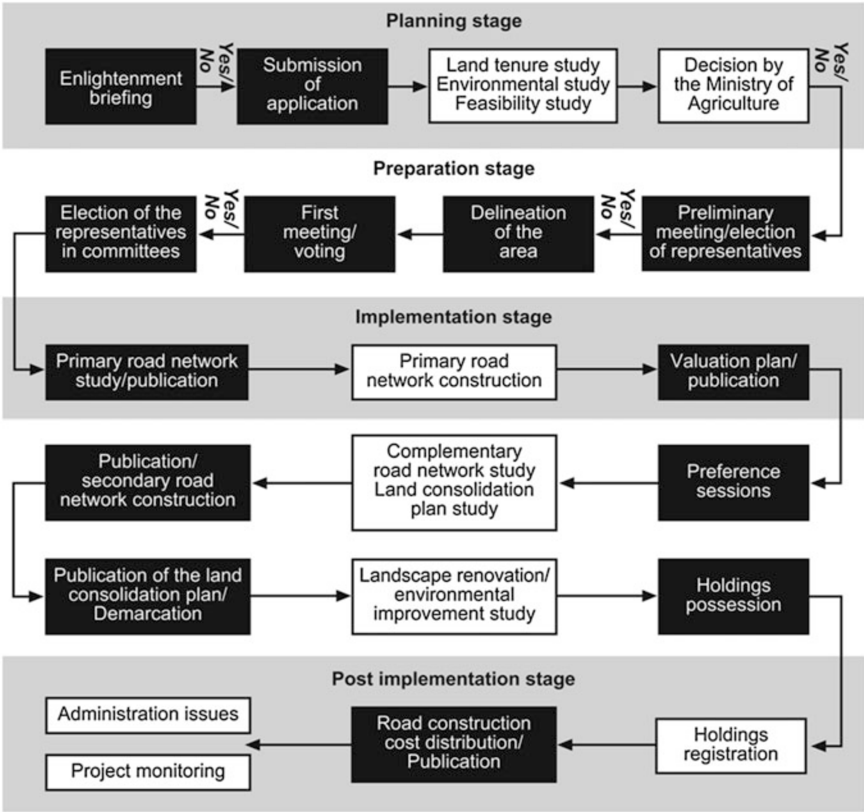


Fig. 3.3 Land consolidation procedure in Cyprus

last 40 years. In land consolidation areas, the number of landowners decreased by 28.1 %, the number of parcels/shares fell dramatically by 54.4 % and the average number of parcels/shares per landowners was reduced by 36.7 %. Conversely, the average size of parcels/share saw a considerable increase by 111.8 % and the average size of ownership resulted in a smaller rise of 31.6 %. The increase of the parcel/ownership size is because the Department acquired about 1,000 ha of land through purchases and expropriations and allocated these, through the schemes, to those farmers who were interested in increasing their ownership. Moreover, the percentage of the area and the number of parcels held in undivided shares sharply decreased by 89.5 %. Further to land tenure indicators, the length of roads has increased by 194.8 %. These roads provide access to almost all (98.1 %) of the new parcels. These figures indicate the effectiveness of the land consolidation measures to limit the land fragmentation and hence to create the conditions for rational agricultural development and generally for enhancing rural areas.

Table 3.1 Overall statistics of land consolidation implementation

	Before	After	Change (%)
No. of owners	24,928	17,954	−27.98
No. of parcels/shares	54,435	24,839	−54.37
Average no. of parcels/shares per owner	2.18	1.38	−36.70
Average size of parcel/share (ha)	0.34	0.72	+111.76
Average size of ownership (ha)	0.76	1.00	+31.58
% area in undivided form	27.40	2.88	−89.48
% of parcels in undivided form	22.05	2.31	−89.53
% of parcels served by farm roads	33.28	98.14	+194.84
Road length (Km),(for 80 schemes)	439	1330	+203.21

Source LCD [62]

According to the same report (based on sample surveys), the above land tenure changes resulted in an improvement of agriculture and eventually in farmers' income. In particular, capital productivity rose by 45 %, both labour productivity and production increased by 100 %, the agricultural income rose by up to 300 %, the number of economically viable holdings was increased by 16 % and the internal rate of return in 15 completed schemes was found to range between 10 and 22 %.

Despite the above successful outputs, Burton and King [63] criticise the fact that a comprehensive evaluation of land consolidation in Cyprus has never been undertaken in terms of the wider social and environmental effects, which is still valid today since they are based only on land tenure efficiency indicators and the consequent economic effects. However, a relevant study carried out by Burton [64] showed that land consolidation, in addition to considerable positive economic effects, also resulted in positive social changes, namely, some land consolidation projects prompted a change in lifestyle.

3.5.5 Problems and Recommendations

Today, the application of the traditional form of land consolidation, with its focus on agricultural development, faces some criticism due to the decline of the broader agricultural sector and drought. Namely, as noted in the previous chapter, the contribution of the agricultural sector in terms of GDP has dropped dramatically, from 18 % in 1970 to 2.7 % in 2007. As a result, the benefits of land consolidation implementation are increasingly controversial. Also, urban planning and environmental decision makers criticise the contribution of land consolidation to scattered housing development. Therefore, any new land consolidation implementation must handle with care the selection of appropriate areas so as to really benefit agriculture without causing negative environmental impacts. With the above controversy, the need to re-establish the role of land consolidation in Cyprus may be strengthened, which suggests a shift from the traditional/agricultural form of land consolidation to a modern form, including the aforementioned types of urban, regional and environmental land consolidation. A promising step towards this direction is the fact that during the last few years, the application of land readjustment (i.e. urban land consolidation) is under consideration and currently new legislation has been submitted in the House of Representatives for approval.

Further to the external criticism about the usefulness of land consolidation, the process confronts three main problems itself: the long duration of projects, the high operational costs of each project and the conflicts between the stakeholders involved [61]. The long duration of projects is a common problem encountered in many countries that apply land consolidation programmes. Vitikainen [12] provides some figures on duration, e.g. land consolidation projects in Germany last about 16–17 years and, in their simplest form, from 8 to 14 years. Similarly, in the Netherlands, the duration is about 10 to 12 years, in Finland from 8 to 12 years, in Sweden (in the case of forestry land consolidation) from 5 to 7 years, while in Norway this process takes only 2–4 years on average. Similarly, Choi and Usery [65] provide duration information for Korea, where 2–3 years is the average period of a project. In Cyprus, the average duration is 6–10 years although in earlier projects carried out in the 1970s, the duration was about 4–5 years. Project duration is strongly related to the land consolidation type and approach, the size of the consolidated area, the number of landowners, the current activities of an authority, and the available resources. Other factors include waiting times as a result of the interdependencies between various tasks, the lack of cadastral inventories, the increased planning needs due to the rapid structural change in agriculture (e.g. subsidies, retirement of farmers) and the increasing tendency towards wanting consensus in decision making [12].

The problem of project duration has considerable impacts on the achievement of the strategic aims of land consolidation. For instance, socioeconomic changes (e.g. the boom in land values after the accession of Cyprus to the EU in 2004) diverted the interest of people to sectors other than agriculture, such as housing development and tourism. In addition, the compensation of people who lose their properties (when their size and land value is under specific limits) is smaller than the current market value of land or vice versa. Furthermore, many landowners (especially farmers) may be of an age such that a potential delay in a project may negate the benefits expected to them.

High operational costs are associated with the long duration of projects. Some of the planning tasks shown in Fig. 3.3 are currently undertaken in a semi-computerised manner while others are undertaken in a completely manual way. For example, the valuation of properties is carried out by visiting all the properties and public participation is implemented using traditional face-to-face methods. The costs of land consolidation projects in Cyprus or elsewhere are not available from the literature. However, in practice, the main tasks involved in the implementation phase of all projects, i.e. a road network study, land valuation, preference sessions with landowners, followed by a land reallocation study and demarcation of new parcels, involve a large number of individuals over a considerable period of time so it is evident that the overall costs involved are high.

The third main problem associated with current land consolidation practice is the potential conflicts between the stakeholders involved, i.e. mainly between the LCD, and/or the LCC and the landowners whose parcels are being consolidated. These conflicts, which may number from tens to a couple of hundred cases depending on the number of landowners involved in the project, may be expressed either unofficially or officially via the submission of objections. These conflicts are often created by the mechanical nature of the legislation and the desire for optimising plan efficiency, which often ignores or overrides the human element [63]. In particular, the creation of landless people and the separation of people from a piece of land that has been cultivated and passed down through generations for many years are possible situations that cause serious conflict. The treatment of such people during the process needs to be more considered so as to minimise conflicts even though this may reduce the quality of the land reallocation plan.

Generally, legislation and the current practices need to be remodelled in many respects, producing a more flexible and effective process which is beyond the aims of this research. In addition, the introduction of new sophisticated technologies, such as the system developed in this research which is aimed at automating and supporting the land reallocation process, may effectively limit these problems as discussed in the chapters that follow.

3.6 Conclusions

Land consolidation, which begun around the 14th century in Europe, is a traditional approach involving land tenure restructuring (land reallocation) and the provision of appropriate infrastructure aimed at rural development (spatial agrarian planning). It is considered as the most effective land management approach for solving the land fragmentation problem. Whilst initially land consolidation was focused solely on agricultural development, it expanded later in the 1980s as a multi-function instrument supporting sustainable rural development. It is currently implemented in almost all EU countries and in many other countries all over the world and thus it is included in EU policies and FAO programmes. Land consolidation in Cyprus, which began in 1970, has resulted in significant positive changes in the land tenure structure and the provision of a road network in many rural areas, both of which have contributed to an improvement in the incomes of farmers. However, the process has also experienced major problems such as the long duration of projects, the high operational costs involved in consolidation and the conflicts of interest that have arisen among stakeholders. These latter problems are associated with land reallocation, which is the most important, complex and time-consuming part of the land consolidation process. Therefore, there is a demand to support and automate land reallocation where possible so that it can be transformed into an efficient, systematic and transparent process to alleviate the problems concerned. This requirement is addressed by objectives 4, 5 and 6 of this thesis and then further elaborated in Chaps. 8, 9 and 10, respectively. Land reallocation is the topic of the next chapter.

References

1. King, R., & Burton, S. (1983). Structural change in agriculture: the geography of land consolidation. *Progress in Human Geography, 7*(4), 471–501.
2. Van Dijk, T. (2003). *Dealing with central European land fragmentation*. Delft: Eburon.
3. Uimonen, M. (2004). Actual developments of land consolidation in Finland. In: *Proceedings of Symposium on Modern Land Consolidation*. 10–11 September 2004, Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_04_uimonen.pdf.
4. Meha, M. (2004). Land Consolidation in Kosovo and its Impact on Rural Development. In: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 September 2004, Volvic (Clermont-Ferrand), France.
5. Backman, M. & Osterberg, T. (2004). Land consolidation in Sweden. In: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 September 2004, Volvic (Clermont-Ferrand), France.
6. Binns, O. (1950). The consolidation of fragmented agricultural holdings. FAO Agricultural Studies 11, Washington DC.
7. Simpson, S. R. (1976). *Land law and registration*. Oxford: Oxford University Press.
8. Bullard, R. (2007). *Land Consolidation and Rural Development*. Papers in Land Management. Anglia Ruskin University.
9. Dixon-Gough, R. W., Mansberger, R., & Seher, W. (2000). A comparative analysis of land registration and agrarian reform in Austria and Great Britain. *Transactions in International Land Management, 1*, 73–104.
10. FAO. (2003). *The design of land consolidation pilot projects in Central and Eastern Europe*. Rome: FAO.
11. Van Dijk, T. (2004). Land consolidation as Central Europe's Panacea reassessed. In: *Proceedings of Symposium on Modern Land Consolidation,* 10–11 September, 2004, Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_01_vandijk.pdf.
12. Vitikainen, A. (2004). An overview of land consolidation in Europe. *Nordic Journal of Surveying and Real Estate Research, 1*, 25–43.
13. Van Dijk, T. (2007). Complications for traditional land consolidation in Central Europe. *Geoforum, 38*, 505–511.
14. Thomas, J. (2004). Modern land consolidation: recent trends on land consolidation in Germany. In: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 September 2004, Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_03_thomas.pdf.
15. Thomas, J. (2006) What's on regarding land consolidation in Europe? In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_03_thomas_0311.pdf.
16. Van der Molen, P., Lemmen, C., & Uimonen, M. (2005). Modern land consolidation: Multipurpose approach for sustainable development. *GIM International: The Global Magazine for Geomatics, 19*(1), 51–53.
17. Pasakarnis, G., & Maliene, V. (2010). Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy, 27*(2), 545–549.
18. Ravallion, M., & Van de Walle, D. (2006). Land reallocation in an agrarian transition. *The Economic Journal, 116*, 924–942.
19. FAO. (2008). *Opportunities to Mainstream Land Consolidation in Rural Development Programmes of the European Union*. Rome: FAO-Land Tenure Policy Series.
20. Hopfer, A. (2006). Property development and land management in Poland. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts75/ts75_02_hopfer_0817.pdf.

21. Derlich, F. (2002). Land consolidation: A key for sustainable development French experience. In: *Proceedings of the XXII International FIG Congress*, 19–26 April, 2002, Washington, D.C., USA. Available from URL: http://www.fig.net/pub/fig_2002/Ts7-4/TS7_4_derlich.pdf.
22. Gur, M., Cagdas, V. & Demirel, Z. (2003). Land Consolidation as a Tool for Sustainable Development. *FIG conference*. Accessed on 1st September 2007 at http://www.fig.net/pub/morocco/proceedings/TS4/TS4_3_gur_et_al.pdf.
23. Thomas, J. (2006). Property rights, and fragmentation and the emerging structure of agriculture in Central and Eastern European countries. *Journal of Agricultural and Development Economics* [online] *3*(2). Available from URL: ftp://ftp.fao.org/docrep/fao/009/ah757e/ah757e00.pdf.
24. Magel, H. (2003). Land policy and land management in Germany. Public Lecture in Melbourne, 6 February, 2003. Available from URL: http://www.fig.net/council/council_2003_2006/magel-papers/magel_melbourne_feb_2003.pdf.
25. Drees, A. & Sunderhauf, R. (2006). Land consolidation as a tool for flood prevention. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_01_drees_sunderhauft_0853.pdf.
26. Merten, R. (2006). Land consolidation as a tool to balance private and public requests on land use: A German example in the Rhenish Lignite mining district. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_05_merten_0314.pdf.
27. Pulecka, A. (2004). Land consolidation considered as a tool of rural landscape development in Poland. In: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 September, 2004, Volvic (Clermont-Ferrand), France. Available from URL: http://www.fig.net/commission7/france_2004/papers_symp/ts_04_pulecka.pdf.
28. Kovandova, M. (2006). Could land consolidation process be an effective tool for nature and environmental protection in the Czech Republic? In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts70/ts70_05_kovandova_0825.pdf.
29. Simpson, E.S. (1987). *The Developing World: An Introduction*. Longman, Harlow, U.K.
30. Siddiqui, K. (1997). *Land management in South Asia.: A comparative study*. Karachi: Oxford University Press, 484 pp.
31. Bentley, W. (1987). Economic and ecological approaches to land fragmentation: in defence of a much-maligned phenomenon. *Annual Review of Anthropology, 16*, 31–67.
32. Van Dijk, T. (2004). Land Consolidation as Central Europe's Panacea Reassessed.*Proceedings of Symposium on Modern Land Consolidation*, 10–11 September 2004, Volvic, France
33. Lisec, A., Cerjak, M. & Pintar, M. (2005). The influence of the land consolidation on the ecological elements in the rural landscape. In: *Proceedings of the 6th International Conference Environmental Engineering*, 26–27 May, 2005, Vilnius, Lithuania. Available from URL: http://uni-lj.academia.edu/AnkaLisec/Papers/761088/The_influence_of_the_land_consolidation_on_the_ecological_elements_in_the_rural_landscape.
34. Wilden, R. (2006). Land consolidation in Forest Areas: The German approach in terms of sustainability. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts80/ts80_04_wilden_0313.pdf.
35. Sorensen, A. (2000). Land readjustment and metropolitan growth: an examination of suburban land development and urban sprawl in the Tokyo metropolitan area. Ph.D. Thesis, University of Tokyo, Department of Urban Engineering, Japan.
36. Doebele, W. (1982). *Land readjustment: a different approach to financing urbanisation*. Canada: Lexington Books.
37. Minerbi, L., Nakamura, P., Nitz, K., & Yanai, J. (1986). *Land readjustment: the Japanese system*. Boston: Lincoln Institute of Land Policy.

38. Hong, Y., & Needham, B. (1997). *Analysing Land Readjustment*. Lincoln Institute of Land Policy, Toronto, 203 pp.
39. Yomralioglu, T. (1993). *A nominal asset value-based approach for land readjustment and its implementation using GIS*. PhD thesis, Department of Surveying, University of Newcastle upon Tyne.
40. Zhou, J.M., (1999). *How to carry out land consolidation an international comparison*. European University Institute, Department of Economics, Italy. Available from URL: http://cadmus.eui.eu/bitstream/handle/1814/686/ECO99-1.pdf?sequence=1.
41. Niroula, G. S., & Thapa, G. B. (2005). Impacts and causes of land fragmentation, and lesson learned from land consolidation in South Asia. *Land Use Policy, 22*(4), 358–372.
42. Hennemann, A. (2002). Sustainable Development by Land Consolidation in Bavaria from the point of view of Good Governance. In: *Proceedings of the XXII International FIG Congress*, 19–26 Apri, 2002, Washington, D.C., USA. Available from URL:http://www.fig.net/pub/fig_2002/Ts8-2/TS8_2_hennemann.pdf.
43. King, R., & Burton, S. (1982). Land fragmentation: notes on a fundamental rural spatial problem. *Progress in Human Geography, 6*(4), 475–494.
44. Backman, M. (2002). Rural development by land consolidation in Sweden. In: *Proceedings of the XXII International FIG Congress,* 19–26 April, 2002, Washington, D.C., USA. Available from URL: http://www.fig.net/pub/fig_2002/TS7-16/TS7_16_backman.pdf.
45. Falkgard, S. & Sky, P. (2002). Mediation as a component in land consolidation. In: *Proceedings of the XXII International FIG Congress*, 19–26 April, 2002, Washington, D.C., USA. Available from URL: http://www.fig.net/pub/fig_2002/Ts7-4/TS7_4_falkgard_sky.pdf.
46. Kovacs, E. & Ossko, A. (2004). Land consolidation in Hungary, dream or reality. In: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 September, 2004, Volvic (Clermont-Ferrand), France. Available from URL:http://www.fig.net/commission7/france_2004/papers_symp/ts_03_ossko.pdf.
47. Yomralioglu, T., Nisanci, R. & Yildirim, V. (2007). An implementation of nominal asset based land readjustment. In: *Proceedings of tne FIG Working week, Strategic Integration of Surveying Services,* 13–17 May, 2007, Hong Kong, China. Available from URL:http://www.fig.net/pub/fig2007/papers/ts_5c/ts05c_04_yomralioglu_etal_1426.pdf.
48. German, J., Robinson, D. & Youngman, J. (2000). *Traditional methods and new approaches to land valuation*. Lincoln Institute of Land Policy. LandLines, **12**(4).
49. Roos, H. (2006). The use of Geographic Information System for Property Valuation and Tax Assessment. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* 8–13 October, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts07/ts07_02_roos_0400.pdf.
50. Farmer, B. (1960). Land consolidation in Europe. *The Geographical Journal, 126*(4), 514–515.
51. Hartvigsen, M. (2006). Land Consolidation in Central and Eastern European Countries. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* October 8–13, 2006, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts71/ts71_04_hartvigsen_0882.pdf.
52. Riddell, J. & Rembold, F. (2002). Farm Land Rationalization and Land Consolidation: Strategies for Multifunctional Use of Rural Space in Eastern and Central Europe. *International Symposium on Land Fragmentation and Land Consolidation in CEEC: A Gate Towards Sustainable Rural Development in the New Millennium*, Munich, 25–28 February.
53. Munich Symposium (2002). The Munich statement on land consolidation as a tool for rural development in CEE/CIS Countries. *International Symposium on Land Fragmentation and Land Consolidation in CEEC: A Gate Towards Sustainable Rural Development in the NewMillennium*, Munich, 25–28 February, 2002.
54. Karouzis, G. (1993). An outline of the history of Land Consolidation in Cyprus. In: Land Consolidation Department, (eds.) *Land Consolidation in Cyprus,* Ministry of Agriculture and Natural Resources of Cyprus, 17–21.

55. Lanitis, N. (1944). *Rural Indebtedness and Agricultural Co-operation in Cyprus*. Limassol.
56. Government of Cyprus. (1946). *Report of the Land Utilisation Committee*. Nicosia: Government Printing Office.
57. Van den Zaken, D. (1963). *Land Consolidation Report to the Government of Cyprus*. Rome: FAO.
58. Georgiades, C. (1967). *Village Plan of Anayia (Cyprus): a study in rural improvement and consolidation of holdings*. Nicosia: Land Registration and Surveys Department.
59. Land Consolidation Department (LCD). (1993). *Land consolidation in Cyprus*. Nicosia: Ministry of Agriculture and Natural Resources of Cyprus.
60. Ioannides, P. (2007). Land consolidation in Cyprus: past, present and future. *UNECE WPLA Workshop*, 24–25 May, 2007, Munich, Germany.
61. Demetriou, D., Stillwell, J., & See, L. (2012). Land consolidation in Cyprus: Why is an integrated planning and decision support system required? *Land Use Policy, 29*(1), 131–142.
62. Land Consolidation Department (LCD). (2011). *Annual Report*. Cyprus, Nicosia: LCD.
63. Burton, S., & King, R. (1982). Land fragmentation and consolidation in Cyprus: a descriptive evaluation. *Agricultural Administration, 11*(3), 183–200.
64 Burton, S. (1988). Land consolidation in Cyprus: a vital policy for rural reconstruction. *Land Use Policy, 5*(1), 131–147.
65. Choi, J., & Usery, E. (2004). System integration of GIS and a rule-based expert system for urban mapping. *Photogrammetric Engineering and Remote Sensing*, *70*(2), 217–224.

Chapter 4
Land Reallocation

4.1 Introduction

This chapter focuses on land reallocation, the core stage in the process of land consolidation and the central focus of this research since the system that has been developed automates and supports this process. Namely, this chapter is split into six main sections. Section 4.2 sets out the land reallocation process by defining the problem, the conventional approach followed in the case study country, the modelling approach adopted in this research and the data requirements of the process. Section 4.3 establishes a series of land reallocation principles, which are separated into fundamentals and complementary associated with the application of the land reallocation process in Cyprus. Section 4.4 critically discusses existing research aimed at automating and/or supporting the process. Finally, in Sect. 4.5, the ex-ante EU evaluation framework associated with land reallocation and current land consolidation evaluation studies are considered.

4.2 The Land Reallocation Process

4.2.1 The Problem

Land reallocation, sometimes referred to as land readjustment or reallotment or reparcelling, is inherently a spatial planning process and in particular, is a very complex spatial allocation problem. The problem can be defined as follows: how to optimally rearrange the existing land tenure structure in a certain rural area, based on the country's existing land consolidation legislation, (which together with the current practices imposes a series of criteria and constraints) so as to fulfil the aims of the particular land consolidation project.

In particular, the process of land reallocation involves the assembly of all properties belonging to different landowners in a certain area, followed by a new subdivision of land into parcels and redistribution of the land to the same

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_4, © Springer International Publishing Switzerland 2014

Table 4.1 Criteria for land consolidation

Criterion group	Criteria
Parcel related	Market and/or agricultural land value, area, location, shape, soil class, access, view, distance from other parcels of a landowner, proximity to important elements (village centre, residential zone, highways, etc.), cadastral (form of ownership, rights, encumbrances, etc.), land use and existence of buildings or other constructions (e.g. drills, wells, fencing, etc.)
Landowner related	Number of parcels owned, total area owned, preference, age, occupation (i.e. farmer or not), residence (in the village or not) and socioeconomic factors (e.g. income, number of children, etc.)
Legislative/ authoritative	Law provisions, land consolidation authority's circulars and regulations, legal advice, processes and practices followed
Economic	Economic efficiency (costs and benefits), land market trends and national economic conditions
Social	Equity, equality, community benefits, local attitudes/culture/customs, emotional values and ethics
Environmental	Ecosystem (biotopes, forests, ecological boundary lines, streams, rivers, lakes, hills, canyons, etc.) landscape (topography, geomorphology) and cultural elements (e.g. churches, old mills, etc.)
Local	Land availability and hierarchy of the road network

landowners, based on the share (in terms of a holding's area and land value) of each individual's land in the whole area [1]. It is accepted as the most critical and complex process of land consolidation [1–10, Cay and Iscan 2004], given the many criteria that should be considered, the great importance of land in all societies and the comprehensive restructuring of land tenure generated after land consolidation. Van den Brink [6, p. 3] characterises land reallocation as the 'crowning glory' of land consolidation. Thus, sometimes, the terms land consolidation and land reallocation are used synonymously. A list of the main criteria which need to be taken into account in the land reallocation process, grouped into seven categories, is shown in Table 4.1.

The importance of each criterion in the process may vary from country to country, project to project and planner to planner, depending on the land reallocation approach used. However, whatever approach is employed, these criteria drive the whole process.

4.2.2 The Conventional Approach

In general, the land reallocation process can be split into five main stages: data collection; preliminary calculations; preliminary land reallocation; definitive land reallocation; and implementation [4]. Although many similarities exist, the process varies from country to country. The Cypriot land reallocation workflow involves nine main stages shown in Table 4.2.

Table 4.2 The Cypriot land reallocation workflow

• Data collection
• Preparation of a preliminary land reallocation plan
• Conducting the landowners' preference sessions
• Receiving relevant decisions by the Government, the Head of the Department and the Land Consolidation Committee
• Preparation of the final land reallocation plan by the District Land Consolidation Office
• Audit of the plan by the Central Land Consolidation Department
• Approval of the plan by the Land Consolidation Committee
• Publication of the plan
• Plan implementation

Initially, data collection involves a great volume of data from various resources, as listed in Sect. 4.2.4 later. Then, the preparation of a preliminary land reallocation plan (which is also called the global or temporary plan) can be carried out. In particular, such a plan is the first version of the definitive allocation plan. Usually it does not include the exact shape and location of the new parcels. It is used as an initial base for the following steps (i.e. landowners' preference sessions and the preparation of the final reallocation plan). The process of undertaking this plan is more or less similar with that used for the final land reallocation plan, which is discussed later in more detail.

Once this plan is ready, landowners' preference sessions are conducted. Such sessions involve members of the planning team meeting with each landowner. Each meeting takes about 30 min. Although the discussion has a free form regarding how each landowner wishes to receive his/her reallocated property, a formal questionnaire is completed and signed by the landowner which, however, does not bind either party. The questionnaire comprises the following five questions. How many parcels do you wish to receive after land consolidation? In which location(s) do you wish to receive the new parcels? Do you wish to receive your new parcels close to another person's parcels; and if so, who? Do you have a special preference for any one of your current parcels? Do you prefer to receive more land with less land value or less land with higher land value?

In the meantime, relevant decisions regarding land reallocation should be taken by the Government, the Head of the Department and the Land Consolidation Committee (LCC). Specifically, when there is state land in the land consolidation area, then the Government, and in particular the Minister of Interior, should provide approval for applying land consolidation measures to it and also decide (after a proposal from the Ministry of Agriculture, Natural Resources and Environment) the percentage of state land that will be allocated to the landowners so as to facilitate the aims of the project. The price of state land is paid by the landowners to the Government, based on the land values defined by the Land Valuation Committee (LVC), in a maximum of eight annual instalments with interest lower than the current rate. In this case, the allocation of state land is a kind of land fund or land bank noted in Sect. 2.3.

In addition, the Head of the LCD should define the size of a ‘small-medium-large holding’ (defined in Sect. 4.3.1) and the annual revenue of an ‘economically viable holding’ (defined in Sect. 3.5.1). Afterwards, the LCC should decide, after a proposal by the Head of the Department, regarding: which holdings (which are voluntarily offered by the landowners for selling in the Committee) are useful to be purchased so as to facilitate the aims of the project; the minimum area and limits on the land value of holdings in order to allocate or not allocate a property to a landowner in the new plan; and which parcels will be exempted from land reallocation. As noted in the previous chapter, ‘exempted’ parcels remain in the same location, allocated to the same landowners and only their boundaries and size may change slightly, if this is necessary.

Once all the data and relevant decisions are available, the preliminary plan is then worked out in order to prepare the final land reallocation plan. The process is currently carried out by two land consolidation planners normally using a CAD system and/or GIS. In particular, this process involves the following nine major steps:

1. Subdivision of the consolidated area in land blocks where each land block is enclosed by roads, streams, canals and the external boundaries of the study area. Roads include those constructed by the LCD in the implementation stage as the primary road network (Fig. 3.3).
2. Calculation of the total area and land value of each land block.
3. Definition of which landowners will not be granted property in the new plan, based on the minimum area and land value limits established by the Land Consolidation Committee. The parcels (or shares) of these landowners can be shown on a map.
4. Definition of which parcels will be exempt from reallocation, based on the relevant decision of the LCC. These parcels can be shown on a map.
5. Calculation of the contribution coefficient of landowners for the value of land occupied by public facilities, i.e. roads, canals, etc. This coefficient is calculated as follows:

$$CC = \frac{\sum_{i=1}^{n} V_i - \sum_{i=1}^{n'} V'_i}{\sum_{i=1}^{n'} V'_i} \tag{4.1}$$

where CC is the contribution coefficient which is common for all landowners, in terms of land value, for the land provided for the construction of public facilities.

$\sum_{i=1}^{n} V_i$ is the aggregate land value of parcels ($i = 1$ to n) before land consolidation. The value of any building or any construction included in a parcel is not taken into account.

$\sum_{i=1}^{n} V_i'$ is the aggregate land value of reallocated parcels ($i = 1$ to n′) after land consolidation.

6. Calculation of the land value that should be allocated to each landowner after the subtraction of the land value calculated by the contribution coefficient.
7. Definition of the maximum number of parcels that can be allocated to each landowner based on the rule of a 'small-medium-large holding' as defined by the Head of the Department.
8. Calculation of the initial available land (in terms of size and value) for reallocation in each block.
9. Reallocation of properties. This is an iterative, trial and error process, which proceeds block by block by considering how to reallocate the properties in a certain block. Firstly, the property in the block owned by the landowners is considered, followed by the potential to transfer the property of other landowners in that block. The aim of the planner is to produce an optimum plan based on the criteria listed in Table 4.1. In particular, for each land block, planners attempt to create a predefined number of parcels (as a result of the preliminary plan), each with as regular a shape as possible, approximating a desired land value (because the latter is the basic land reallocation criterion according to legislation) and size, subject to the limitation that the latter exceeds the minimum limits noted later in Sect. 4.3.1 and that a parcel should have access to a road. The land value of a parcel is calculated by overlaying a layer of parcel shapes with the land valuation thematic map that consists of various categories. The processes can be semi-structured and formulated as an algorithm as shown in Table 4.3.

Table 4.3 The algorithm for land reallocation followed in practice

Step	Action
1	Begin reallocation for block *i* for landowner *k* who owns land located within block *i*
2	Consider if the property of landowner *k* should be reallocated to block *i* and if it is possible to do that
3	Consider other ownership attributes, i.e. parcels/shares of the landowner *k* owned in other blocks
4	Decide how to reallocate his/her property based on the previous steps (1–8 outlined above), using the reallocation principles which were discussed in Sect. 4.3 and the criteria listed in Table 4.1. The decision refers to the number of parcels, their size, the land value, the location of each parcel and the aggregate size and land value
5	Design the new parcel(s) in block *i*, which involves the exact definition of its/their shape and location. The design should take into account the criteria listed in Table 4.1 such as existing boundaries, environmental protection, etc
6	Calculate the remaining available land in terms of size and value for reallocation in block *i*
7	Move to the next landowner in block *i* and execute steps 2–5 and reconsider (if necessary) the reallocation decisions that have already been made, for potential appropriate modifications
8	Once land reallocation is completed for block *i*, go to the next block and repeat steps 1–6
9	Once all the landowners have been granted the property in question, then a new version of the land reallocation plan is ready

It is recognised that the process may lead to some unassigned land in certain locations in certain blocks. These lands, the so called 'non-allocated space', which in some cases may form separated new parcels, may be kept until just before the end of the process, to solve reallocation problems derived from the disagreement of some landowners about how their property is reallocated. In addition, in the situation where these spaces may form new parcels, they may also be kept after the completion of the projects under the ownership of the LCD, in order to confront potential appeals from some landowners in court.

10. New discussions and 'negotiation' with some landowners will follow, in order to solve problematic and complex reallocation cases. This process involves some new modifications and a new version of the plan.

During the preparation of the reallocation plan by the District Office planning team, it is checked by the Departmental Audit team. Plan checking refers to all the aspects of the plan that are related to the criteria in Table 4.1. Special attention is paid to the accordance of the plan with legislation and the relevant economic, social and environmental assessment criteria. Then, a presentation and discussion about the plan is carried out with the three elected representatives of the landowners who are members of the LCC. This procedure takes place for some days and involves intense visits to the consolidation area. It may also involve some new modifications and a new version of the plan, which in turn is discussed with the audit Departmental team. Afterwards, the plan is officially sent out to the LCC for discussion and approval. This procedure may lead to some new modifications and a new version of the plan as well.

Eventually, the LCC gives its permission and hence the plan is published for inspection by the landowners, who may then lodge an objection with the LCC, within 21 days of publication. Once the objections have been examined, the amended plan is republished and finalized. If a landowner is not satisfied by a decision of the LCC, then he/she may appeal to the Minister of Agriculture, Natural Resources and Environment, (who appoints an *ad hoc* Committee) within 21 days from the date of the notice of the decision being issued to him/her. In the case that any landowner is not satisfied by the decision of the Minister, he/she may then appeal to the Court within 21 days from the date of notice to him/her of the decision. Finally, plan implementation is carried out, which involves the demarcation of the final plan on the ground and the indication of the new boundary markers for each landowner.

4.2.3 Land Reallocation Modelling Approach

Based on the nine-step algorithm noted above for the land reallocation plan, the process can be split into two main sub-processes(although in practice it is treated as a unified procedure) for modelling purposes, namely, *land redistribution* and *land partitioning* that both involve evaluation aspects, i.e. alternative land redistribution and land partitioning plans. In particular, land redistribution involves decision making regarding the redistribution of ownerships that is usually concerned with the following five issues (in the case of Cyprus). Which landowners will take property in the new plan and which will not? What is the total area and value of the property that each landowner will receive in the new plan? How many parcels will each landowner receive in the new plan? What is the area and value of each new parcel? What is the approximate location of the new parcel(s) that each landowner will take? Land redistribution is based on legislation and other related documents which define a series of principles (discussed in the next section) and other criteria noted in Table 4.1, the existing land tenure structure, rules of thumb and experience of the planners. The output of this process is a global plan that consists of land blocks which are enclosed by roads and each land block contains a set of marks representing the approximate location of new parcels. Each mark is associated with an approximate size, a land value, a landowner and other information regarding the new parcel. In terms of modelling, this can be considered *as a multiple criteria decision making problem that may result in a discrete number of alternative solutions that need to be assessed to identify the most beneficial.*

Afterwards, land partitioning (or reparcelling), which accepts as input the land redistribution output, involves the subdivision of land into smaller 'sub-spaces' (i.e. land parcels) according to some criteria and design constraints and involves the final land consolidation plan. The process is carried out block by block. Conventionally, this is a trial and error process based on legislation, empirical design criteria, geometrical constraints, rules of thumb and criteria noted in Table 4.1. The aim of the process is to obtain a land partitioning plan with regularly shaped parcels that all have access to roads, and each new parcel is given an approximate area, land value and location by the land redistribution process including other constraints such as a minimum parcel size defined by legislation as fundamental principles (see Sect. 4.3.1). Furthermore, existing boundaries, especially if they are physical objects such as a stream, a river, a high stone wall, a series of trees or a wild plantation, should be taken into account if possible. Other technical constraints are the existence of buildings (e.g. a farmstead) or other kinds of construction (e.g. fencing) and should also be considered as potential constraints. In modelling terms, this process can be defined as a *multiple objective optimisation problem subject to a set of constraints that searches to find optimum solution(s) through an infinite number of potential solutions.*

4.2.4 Data Requirements

Land reallocation requires a huge number of datasets of various forms, originating from various sources as shown in Table 4.4. Normally, these data are stored in a GIS in the form of database layers.

Table 4.4 Datasets required for land reallocation

	Dataset	Original form	Digital form	Contents	Source
1	Cadastral plans	Paper or digital maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Parcel boundaries, roads, pathways, streams, rivers, etc	Land Surveys Department
2	Land ownership	Tabulated land ownership records	Databases	Land ownership (landowners and parcel attributes)	Land Surveys Department
3	Digital Terrain Model	Paper contour maps at a scale of 1:5,000 or in digital form	Vector	Contour lines	Land Surveys Department
4	Topographical surveys	Raw data collected by Total Stations and/or GPS	Vector	Existing features in the study area	Land Consolidation Department
5	Geodetic network	Listed coordinates	Vector	Third and fourth order geodetic points	Land Surveys Department
6	Zoning	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Development zones	Urban Planning and Housing Department
7	Geological	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Raster	Soil classification	Geological Survey Department
8	Irrigation network	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Irrigation pipe network, water supply points, etc.	Water Development Department
9	Electricity network	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Electricity poles and line network	Electricity Authority
10	Telephone network	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Telephone poles and line network	Telecommunications Authority
11	Drainage network	Paper maps at scales of 1:2,500, 1:5,000	Vector	Culverts and box culverts	Land Consolidation Department
12	Road network	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Existing and proposed roads	Urban Planning and Housing Department, Public Works Department

(continued)

Table 4.4 (continued)

	Dataset	Original form	Digital form	Contents	Source
13	Land use	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Land use	Land Consolidation Department
14	Aerial photos	Orthophotos at a scale of 1:7,500	Raster		Land Surveys Department
15	Hydrographic maps	Paper maps at scales of 1:2,000, 1:2,500, 1:5,000	Vector	Rivers, streams, catchments areas etc.	Water Development Department
16	Satellite image	Electronic form	Raster		Specialised private companies
17	Feasibility study survey	Questionnaire	Document	Answers by landowners	Land Consolidation Department

Further to these datasets, essential data inputs are those recorded in Sect. 4.2.2, i.e. landowners' preferences and decisions taken by the Head of the Department and the LCC.

4.3 Land Reallocation Principles

In Cyprus, land reallocation based on regulations derived from legislation, circulars, directives and legal expert advices which involve the principles for carrying out the process. Principles can be grouped in fundamental, namely those included in the Cyprus Land Consolidation Law [11] and in particular in Article 21 and complementary principles set out by the other sources noted above. Among a plethora of such principles the most important utilised in practice are listed below.

4.3.1 Fundamental Principles

1. Compulsory increase or decrease of a holding: The land reallocation plan may provide for the compulsory increase or decrease of the value of the property to be allocated to landowners, to such an extent as may be approved by the Head of the LCD.
2. The non-granting of a holding: The non-granting of property is possible, through compensation for the landowners whose aggregate area of holdings is smaller than that provided by the Immovable Property (Tenure, Registration and Valuation) Law. In particular, the minimum area of a new parcel should be 2 donums (0.27 ha) for permanently or seasonally irrigated land, plants and

vines; 4 donums (0.54 ha) for land which is able to be seasonally irrigated and 10 donums (1.34 ha) for dry and unplanted land. These figures can be reduced by half with the approval of the Head of the Department.

3. The rule of 'small-medium-large holding': This rule states that not more than one parcel shall be granted to a landowner of a 'small holding'; not more than two parcels to a landowner of a 'medium holding'; and not more than three parcels to a landowner of a 'large holding'. Exceptions are possible in justifiable cases, that is, due to the nature of the land or its utilization or due to its distance from the landowner's residence. As mentioned, the Head of the Department defines the size 'small', 'medium' and 'large' for holdings in the affected area and shall specify when a certain case shall be considered as a justifiable exception.
4. Access of new parcels to roads: All the new parcels must be readily accessible through a rural road.
5. Exempted properties from consolidation: In exceptional cases, those parcels which have less area than the minimum acceptable limits may be exempted from consolidation in the following cases:
   - property, the value of which is high on account of installations or plantations existing thereon, or on account of the development which took place in a neighbouring area or which, in the opinion of the Head of the Department, is of special character, irrespective of its value;
   - property which contains buildings of great value; and
   - property which belongs to a public institution or foundation, the purpose of which is the protection of the environment or places of historical interest or of antiquities, provided that their landowners wish them to be so exempted. Re-adjustments to the boundaries of the properties to be exempted are possible, where this is necessary. Exempted properties may refer to isolated parcels or to a group of parcels located in a land block or a broader area.
6. Holdings in un-divided shares: In the case of holdings which are held in undivided shares, each co-landowner may receive an individual parcel or parcels after consolidation, to be held in single ownership. Such ownership should be approximately equal in value to the land value of the share before consolidation, provided that the parcel or parcels shall be in conformity with the minimum area limits mentioned earlier. However, at the request of all co-landowners or with a decision of the Committee taken of its own volition, a consolidated holding may be granted in undivided shares, when such a holding will be cultivated by its landowners in common, as an integrated unit.
7. Equivalence property value before and after land consolidation: After consolidation, each landowner shall be granted a property of an aggregate value that is the same (after deducting the land value corresponding to the contribution coefficient) as the value of the property owned prior to consolidation. It is accepted that this principle is sometimes difficult to apply in practice for many reasons [12].

4.3.2 Complementary Principles

1. Exemptions of ownerships from the rule of 'small-medium-large ownership' can be justified for the following reasons:
   - if a parcel has high land value compared to others. Such parcels could be those irrigated and planted, with housing development prospects, coastal, with a frontage on an asphalt road, etc;
   - parcels located in areas which are desired by many landowners and where there is limited space and potential for concentration, without the displacement of other properties;
   - the ownership of many large parcels by a landowner, for which their concentration in a specific location might create problems and conflicts with other landowners;
   - shared parcels or dual land use parcels (i.e. those partly irrigated), parcels which are enclosed by roads and the external land consolidation area boundaries on all sides;
   - parcels which include buildings, boreholes and wells could be considered as well;
   - parcels in compact areas; and
   - parcels which are divided by streams or registered pathways.
2. The allocation of adjacent parcels to a landowner in a separate form, in terms of two or more title deeds, should be avoided. In such cases, unification of these parcels under one new title deed is desirable.
3. No landowner may receive a greater number of parcels than the number he/she had before land consolidation.
4. The location of the new parcels should be as similar as possible to that of the original parcels. No landowner will be allocated land close to the village if he/she did not have such land before land consolidation. In the extreme case, where it is necessary to displace a landowner from his/her parcel close to the village, then this should be done with the landowner's consent.
5. The land use of the new parcels received by a landowner should be similar to that of the original parcels.
6. The displacement of a landowner, who owns a parcel with access to a main road, should be avoided.
7. If a landowner has only one parcel, then he/she should take one in the same location. Any displacement should be avoided or otherwise fully justified.
8. The reallocation of parcels with buildings, wells, bores and trees, etc. to another landowner should be avoided.
9. Any drastic variation of the value of land ownership, before and after land consolidation, as well as the mean value per area, should be avoided.
10. The creation of new parcels with irregular shapes should be avoided.
11. A compulsory increase or decrease in the total value of an ownership in the new plan cannot exceed the percentage of the contribution coefficient, except if significant reasons are fully justified. If the compulsory increase of an

ownership can be avoided, then new non-allocated parcels can be created, to be used for solving problems raised with objections against the plan.

12. Decrease of ownership should be distributed in proportion to the parcels of a greater area, e.g. in a land block. The maximum decrease of ownership should be approved by the Head of the Department. This does not imply that the simultaneous approval of the other ownerships decreases. The amount of each ownership reduction should be separately defined based on the prevailing data of each case. A slight decrease of the ownership of landowners, who are unknown and who have not been present in the whole process, is considered as acceptable.
13. The decrease of the area of an ownership should be analogous to the land value decrease.
14. Completion of ownership: Land ownership, where the area is under the minimum limits, can be completed to reach these limits only after the submission of a relevant application from the landowner concerned. Every landowner who receives a 'completed property' should be satisfied with respect to the defined criteria by the Committee, when compared to any other landowner in the new plan. These criteria are: area and value of the ownership before land consolidation; residence; occupation; family and economic status of the landowner; and the occupation of other ownership by the landowner, etc. Ownership that does not fall within the above criteria will be expropriated. Additionally, applications for ownership completions should always be evaluated strictly on the principles of equity and equality, without negatively affecting other landowners.
15. Holdings in undivided shares: The allocation of a new parcel in undivided shares should be avoided. However, in the case where there is no potential for allocating separate parcels, the following prerequisites should be satisfied: all the landowners should have owned the same parcel in undivided shares before the land consolation; the written declaration should state that all the co-landowners will commonly cultivate and exploit the parcels as a unique agricultural unit; and such parcels should be permanent plants, vines, irrigated, with greenhouses and/or wells, and with a high land value.
16. Exempted properties from consolidation: An increase or decrease in the area of exempted parcels should not be significant. Additionally, the landowner(s) and the location of such parcels cannot be changed.
17. Increase/decrease of the area and value of a property: Additional to the equivalency principle, an attempt should be made to ensure that every landowner will be allocated approximately the same area of land originally held.
18. Importance of land: All the local factors (land use, other development prospects, distance from the village, main roads, housing zones, etc.) that affect the importance of land in a region should be taken into account so that each landowner will receive a holding of the same importance after land consolidation, especially when it is known that land valuation is out-dated at the time the plan is carried out.

Although the fundamental and complementary land reallocation principles strictly define a set of rules for the process, the role of land consolidation experts is extremely important. The success of the plan strongly depends on their knowledge, experience and judgement. On the one hand, the planner must carry out the process without violating the rules aiming to produce an efficient and fair land reallocation plan. On the other hand, the expert must satisfy the preferences and interests of hundreds of landowners. In addition, both dimensions of the problem may be in conflict with environmental protection issues. Thus, the planner must establish a compromise between these conflicting aspects so that the final plan respects legislation and simultaneously provides economic, social and environmental sustainability as much as possible. As a result, all these aspects should ideally be incorporated into land reallocation models.

4.4 Land Reallocation Research

Although land reallocation research began at the end of the 1960s and early 1970s, works published in the academic literature appeared much later. These studies can be classified in terms of scope into four categories: comprehensive studies which deal with land reallocation as a whole; studies which deal only with the automation of land redistribution; and studies which focus on automating land partitioning. In addition, this review involves land consolidation information systems as a fourth category.

4.4.1 Comprehensive Studies

Research about automating the land reallocation process began in the Netherlands at the end of the 1960s, a decade that was characterised by the establishment of large-scale computers, i.e. mainframes. In the early 1970s, a computer support system called LIN was introduced, which focussed on supporting the administrative problem of land reallocation. In particular, LIN was a registration system able to store original cadastral details before land consolidation, the intermediate design steps and the final design. Therefore, LIN was not designed to support the decision-making process of land reallocation directly [13]. About a decade later, Delft University of Technology and the Netherlands Cadastre cooperated to build a computer model for the process of land reallocation (Van der Schans 1972; cited in [13]. The model consisted of three consecutive steps: the design of a value allocation plan; the design of the general layout of the new parcels; and the fixation of the boundaries of each newly formed parcel. This system, called INOK, had two allocation algorithms: one based on a heuristic and the other based on a linear programming model [14] for accomplishing the tasks required.

Despite these efforts, a survey commissioned by the Netherlands Cadastre in 1994 revealed that INOK was insufficient to support land consolidation planners. It was underused because it was mainly an information management system rather than a decision support system (DSS). Rosman and Sonnenberg [13] note that the development of an integrated design support system for land reallocation was problematic which indicates, even 30 years after the first attempts at the end of the 1960s, how difficult a task it was to build a system for land consolidation planning that would be used by practitioners. During that period, two studies were carried out at Delft University of Technology to modify and improve the existing models of INOK. The first was that of Rosman and Sonnenberg [13] on land redistribution and the second by Buis and Vingerhoeds [15] on land partitioning, both of which are discussed later in the relevant sections. Ironically, Rosman [16] and Lemmen et al. [17] noted in the FIG (International Federation of Surveyors) conference which took place between 6 and 10 May in Rome (attended by the author) how difficult this task is and the fact that there is a lack of a generic land consolidation support system.

Semlali [18] used GIS and conventional programming to solve the problem of land reallocation by splitting it into two parts: the computed reallocation and the graphical reallocation. Constraints adopted in the model include the landowners' preferences, habitat, soil class and the cadastral situation before land consolidation and reallocation are carried out, based either on the area or the soil class and/or other constraints. The limitation of this method is that each constraint represents an 'extreme' reallocation strategy that cannot be combined together. Therefore, the results tend to be biased by the selected constraint. The system was evaluated using a test area and the author reports that the methodology is rapid and more consistent compared to classical methods. However, the author does not provide adequate information about how the model works, how landowners' preferences are taken into account, how reallocation conflicts are solved, how the location of the new parcels is defined and how the parcels are automatically generated. In addition, analytical system evaluation statistics were not provided.

Similarly, Essadiki [19] and Essadiki et al. [4] attempted to develop a new approach and a new conceptual methodology using GIS to support land consolidation in general and land reallocation in particular. They used both GIS and conventional programming tools to solve the problem of land reallocation, which is split into three stages: preliminary calculations, temporary land reallocation and definitive land reallocation. Five basic criteria are taken into account for land redistribution: the existing location of a parcel and the existing buildings, wells, etc.; the landowners' preferences; the existence of a dominant soil class in a land block (part of a land consolidation area which is enclosed by roads, other physical boundaries, e.g. rivers and the external boundaries of that area); and the existence of a parcel whose value is higher than the mean of all the parcels in a specific area. Every criterion is assigned a weight based on its importance. The model determines the list of landowners who will be allocated land in each block with an approximate position of the new parcels. However, this study does not provide adequate information about its methodological framework and system evaluation. One particular limitation is that the model provides a semi-automatic process since it involves intervention by the planner. According to the researchers, the evaluation of the system, which was tested using an actual project, showed promising results although the system was not the end product in itself.

4.4.2 Land Redistribution Studies

A number of studies focusing on the land redistribution process have been undertaken over the last two decades. Kik [20] treats the process as an optimization problem in which the objective function involves minimizing two factors: the mean parcel distance between the farmhouse and the land parcels and the number of parcels allocated. The method is fully automated and many alternative reallocations can be produced. A limitation of the method is that it does not comprise a spatial component and that other significant land reallocation criteria are ignored (e.g. legislation, expert knowledge, landowners' preferences and environmental issues) and hence results can be optimal in terms of the two criteria mentioned but they may be unrealistic and therefore inapplicable.

A mathematical optimisation model was also developed by Avci [21] to solve the problem of land redistribution. In particular, he adapted a model used in operations research to allocate resources. The objective function involves the maximisation of the land not exchanged (i.e. most of the landowners will be allocated land in the same location as their original parcels), subject to constraints such as the size of a farm and of the land block in which it is located, and the proportion of a farm size in that block. Reallocation was based only on the size of the original ownership and not on the land value. The model was tested on a case study area and, paradoxically, whereas the aim was to minimise exchange of land, the model gave an average number of parcels per farm close to 1. In other words, all the parcels of each farm are unified in one parcel, which is unrealistic in most cases. Similar to the previous study, the weakness of implementing such a mathematical optimisation method is that, while it may produce an optimised solution based on a limited number of criteria, the results may not be applicable at all, because they are unrealistic due to the fact that prominent land reallocation criteria are ignored.

More recently, Ayranci [9] also employed a model used in operations research for a mathematical optimisation of the land redistribution problem. The optimisation function aims to minimise a cost factor which takes into account four parameters: the road time index which represents the time taken by a farmer to visit his/her parcels each day; what the author calls the 'rate of the area', which is a parameter representing the share of a holding in a land block; the preference factors which allow farmers to give three alternative land blocks for reallocation; and fixed installations, which include facilities like farm buildings or wells, etc., that may prevent a parcel from being reallocated. Results are compared with those obtained from a previous version of a similar model [21] and the author concludes that the model is useful for designing land reallocation plans. Although the study takes into account some important land reallocation criteria, a disadvantage is that the system was tested only on a small hypothetical area which cannot represent the complex situation involved in a real project.

Rosman and Sonnenberg [13] tried to improve the existing INOK model mentioned previously and used by the Dutch Cadastre for designing a value allocation plan. They developed a system called TRANSFER which focused on the way landowners expressed their allocation wishes at the preference hearing and on the way the design decisions should be made. The preferences of landowners for certain land blocks will conflict, and as a result, a block may not be adequate in terms of area and land value to satisfy all landowners. Thus, some blocks may show a positive (i.e. a surplus) or negative (i.e. a deficit) residual in terms of area and value. The problem then focuses on balancing the supply of land (the blocks) with the demand for land (the alternatives). An algorithm balances supply and demand in a block and is able to search space for alternatives and placements by using the residuals in each block and by attaching weights to the placements. User interaction is also possible to solve local allocation problems and finalise decisions. Although the system capabilities seem interesting and advanced, an evaluation of the system results is not provided. Most recently, Jansen et al. [22] consider the use of TRANSFER in the land consolidation process in Turkey. The authors note that the model would be most supportive when combined with a standard GIS. This suggests that the current model is limited in this respect. It is worthy of note that Rosman [16] has made new efforts towards building a system capable of combining both land redistribution and land partitioning in a semi-automated manner. A comparison of TRANSFER with LandSpaCES is provided in Chap. 8.

Given that the land reallocation process involves a range of criteria, Yaldir and Rehman [3] attempted to develop a SDSS based on multi-criteria methods in which farmers evaluate their parcels based on a number of agreed criteria. Their system calculates an account (called the farmer's multi-criteria budget) of how much of each criterion corresponds to each farmer before the project, so as to ideally balance this account after reallocation. Afterwards, the system tries to allocate land based on the farmers' preferences and the calculated budget, with enforced threshold limits. It uses a heuristic search procedure, based on five components referred to as: reassign; unwanted; uncontested; adjacency; and deficit. Land reallocation focuses on farmers' preferences; hence the process is very narrow and, similar to previous studies, many other criteria are ignored. As a result, system evaluation showed that, in most of the cases, the results produced are not realistic. The authors note that such problems are not so easily resolved by conventional optimization and they require logical search procedures leading to compromise solutions that are acceptable to stakeholders. Such procedures could be provided by an ES.

Cay and Iscan [7] have treated the process of land redistribution as a linear optimisation problem. Similar to Avci [21], this method takes into account the maximisation of the amount of land that is not exchanged and is basically a value reallocation algorithm without spatial reference. This principle cannot be fundamental to reallocation because it violates one of the primary land consolidation aims, i.e. the reduction of the original number of parcels via the concentration of parcels into larger parcels. Another disadvantage of the method is that it reallocates parcels rather than properties which is a matter of the legislation in force. An effective way is to sum all of the area of the parcels owned by a landowner in the consolidated area, thereby producing a certain land value or agronomic value, and then reallocate this total ownership (based on the value or the area) as a number of new parcels in certain locations. This study also ignores significant criteria mentioned earlier. In addition, system results have not been evaluated in real conditions.

Most recently, Cay and Iscan [23, 24] have attempted to introduce fuzzy logic into the land reallocation process. Whilst in the previous research they argued that land reallocation can be modelled mathematically as an optimisation problem, in this research, they have revised this view, using fuzzy logic to represent the problem. In this fuzzy model, attention is paid to four reallocation criteria: the location of the biggest parcel of land owned by the farmer; the location where the farmer owns the majority of his/her parcels; the location of the immovable facilities owned by the farmer; and the location of the second biggest parcel of land owned by the farmer. These criteria are the input variables to the fuzzy logic system and the results of this fuzzy model have been compared with an interview-based model that takes into account the landowners' preferences [25]. The former was more successful in terms of land reallocation efficiency indicators while the latter was better at satisfying the landowners' preferences. However, it seems that the extremely high percentage of holdings combined in one parcel via each model after land consolidation (i.e. 94.94 % and 75.10 % respectively) is not realistic in most cases. It could be applicable only in homogenous areas in terms of land value with low prices. Moreover, this model, like several of the others, does not provide a spatial component, i.e. calculations are made without a GIS environment being available for storing and processing the data.

4.4.3 Land Partitioning Studies

Buis and Vingerhoeds [15] have used knowledge-based systems (KBS) and GIS for the design of new parcel layout in land consolidation projects. Their systems do not support land redistribution. The concept is based on the fact that land partitioning*is largely a hand crafted process, involving a balanced approach of optimization, handling constraints and experience* [15, p. 308]. The search for an optimal solution is obtained using a control strategy of steering the search process in a promising direction using heuristics and rules of thumb. It is a hierarchical generate-and-test process, in which solutions are incrementally constructed and tested to ensure each constraint holds. It is basically a kind of hill-climbing approach. An advantage of this research is that, further to agricultural efficiency issues (i.e. the shape and size of parcels), ecological considerations are strongly taken into account. The basic limitations of this method are that it is semi-automated and also does not face the problem as an optimization search process; hence, an optimum (or near optimum) solution cannot be obtained. In particular, the shaping of parcels and the evaluation of its quality are made for each parcel one by one; thus a global optimum solution is not possible. Furthermore, another system limitation is that the GIS and KBS are separate systems joined by loose coupling.

Although Tourino et al. [26, 27] built a sophisticated comprehensive GIS-based tool to support several tasks of land consolidation, it is remarkable that their system does not provide an automated or even semi-automated algorithm for land redistribution. However, its most valuable module is that which undertakes land partitioning. In particular, land partitioning has been automated by combining a region-growing algorithm and simulated annealing optimization. An iterative seeded growing method is used to generate an initial redistribution of the tessellated area among the domains (parcels). The area is divided into 'stands' (i.e. land blocks) and each stand is divided into square cells (pixels). Region-growing uses a heuristic flooding process based on a linear objective function. It is a heuristic function comprised of six terms where each term is a constraint to guide the growth of the parcels. The planner may guide the process by weighting the importance of each term via a coefficient. The algorithm works separately for each stand, trying to obtain the most feasible set of parcels possible (in terms of shape). Region-growing may generate many alternative parcel partitions by changing the weights. Thereafter, simulated annealing is used to generate the new parcels (in terms of shape without changing their location) by minimising a non-linear objective function that is comprised of two terms, the first representing the objective to obtain parcels with regular shapes and the second being a constraint to maintain the score for each landowner. The reason for trying to obtain as far as possible the initial parcel shapes using the region-growing algorithm is that simulated annealing depends strongly on the starting solution. This is a disadvantage of this method as well as of classical optimization methods because the search for an optimum solution relies on one initial solution which iteratively may converge to an optimum or near optimum solution. As a result, even though simulated annealing is robust, fast and capable for solving large combinatorial problems, it does not guarantee the optimum solution [28].

Another limitation of the system is that it cannot take into account all the factors of the process, such as barriers (e.g. buildings, irrigation channels, wells) and pictorial elements (e.g. contour map, slope map). System evaluation showed that the results were strongly influenced by the shape of the stand and the size of the original parcels. In addition, the final output was far from that which experts would have produced, i.e. those who can also intervene in the process and adjust the partitioning accordingly. Nevertheless, the results were judged by researchers as moderate but encouraging. The authors suggest that another important conclusion of the research is that new optimization techniques can be considered and the objective functions need to be improved. This suggestion provided us with a challenge to use other optimization methods such as genetic algorithms and seek a better objective function in the context of this research. Genetic algorithms do not have the disadvantage of simulated annealing mentioned above because they use a population of solutions while searching for the optimum, instead of one initial solution. Despite the limitations mentioned, the system seems to be a powerful tool for decision making regarding land reallocation, which dramatically reduces the time and cost of land consolidation planning. The process is more transparent and has the advantage of involving landowners through direct participation.

4.4.4 Land Consolidation Information Systems

Further to focused algorithms for automating and supporting the two sub-processes of land reallocation, some attempts were undertaken for building generic modules for supporting land consolidation/land administration tasks. In particular, the JAKO Cadastre is a multi-purpose cadastral system used by the National Land Survey of Finland [29, 30]. The new tools of JAKO, introduced in 1998, and which deal with land administration, provide functions for land consolidation. In particular, a module of the JAKO Land Administration System is the Valuation and Land Consolidation module. However, the available functions of this module focus on specific customised functions regarding database management, statistical analysis, and financial matters and aid the design of a land consolidation project. No advanced analytical models to support the planner or automate the land reallocation process are provided. Similarly, ArcCadastre is a relatively new cadastral and map management program to support multi-purpose cadastral and geographical related activities. It has been developed in cooperation with the Swedish Mapping, Cadastral and Land Registration Authority and ESRI [31]. Although no information is provided as to whether it includes any specific tools for land consolidation, it could be used as a generic modern LIS (Land Information System).

In the same vein, Aslan and Arici [32] constructed a model called ARTOP in a GIS environment which has been developed to support the planning and design of large-scale land consolidation projects. In particular, it is an information system capable of dealing with information organisation, processing, querying, analysis, display and archiving. Furthermore, it facilitates the comparison and consideration of different types and combinations of data for assisting decision making. It consists of three basic modules: Basic Information System; Planning Information; and Assessment (Analysis). The Basic Information System provides generic and specific database management functions related to the various GIS layers, such as the whole project, the ownership and topographic data, etc. In addition, information about the existing roads, irrigation, drainage, land use and soil data is provided to assist the planner. The Planning Information System supports the design of infrastructural systems, such as roads, irrigation and drainage. The most interesting is the Assessment-Analysis module which provides statistical analysis regarding land fragmentation, the infrastructure (i.e. road, irrigation and drainage systems) and surface analysis functions (DTM, slope analysis, etc.). Overall, this is a customised land consolidation information system, with generic and specific query, display and analysis functions, which indirectly supports decision making. Although such a system is a necessity for any land consolidation organisation, land consolidation planners need a system with advanced modelling capabilities regarding the various complex land consolidation decision making tasks.

4.5 Land Reallocation and the Ex-ante EU Evaluation Framework

4.5.1 The Ex-ante EU Evaluation Framework

Evaluation is an important component of any planning process. Thus it is a requirement in the EU for subsiding rural programmes and hence a set of relevant guidelines are provided by the EU [33–36]. It involves the definition, description and quantification of a project's needs, results, effects and impacts so that a judgement can be made about a project's effectiveness to satisfy the objectives, the efficiency of employed resources and the relevance of the intervention. Depending on the stage, evaluation requires the collection or prediction of primary and secondary quantitative and qualitative information. It can be distinguished by three main features depending on the time carried out in relation to a project's stage: ex-ante evaluation; intermediate (or on going) evaluation; and ex-post evaluation. Ex-ante evaluation is conducted in the planning stage of a programme. It investigates the needs, the expected results and the effects of a project. Intermediate evaluation monitors the evolution of an on going programme, usually in the early period or mid-term. It assists the planners and decision makers to reconsider any matter related to the project. Ex-post evaluation is undertaken after the completion of a project, aimed at recording its real effects and impacts. To carry out an evaluation of any of the three basic stages effectively, an appropriate methodology is required where a plethora of evaluation methods and techniques are proposed in the respective literature [37, 38].

Ex-ante evaluation [39] is the most important phase of evaluation because it represents the starting point for ongoing evaluation within the Common Monitoring and Evaluation Framework and is the basis for effective monitoring, mid-term and ex-post evaluations. It is crucial because its reliability and accuracy ensures the success of the programme in terms of achieving its strategic and operational objectives. Thus, Article 85 of the EU Council Regulation 1698/2005 states that ex-ante evaluation shall be carried out under the responsibility of the Member States.

A key tool of the EU evaluation framework called 'intervention logic', which should be created for each specific programme, is a flowchart that guides the assessment of a programme's contribution in achieving its objectives. A proposed intervention logic chart for land consolidation introduced in this research is illustrated in Fig. 4.1. *Needs*, which is the starting point for planning interventions,

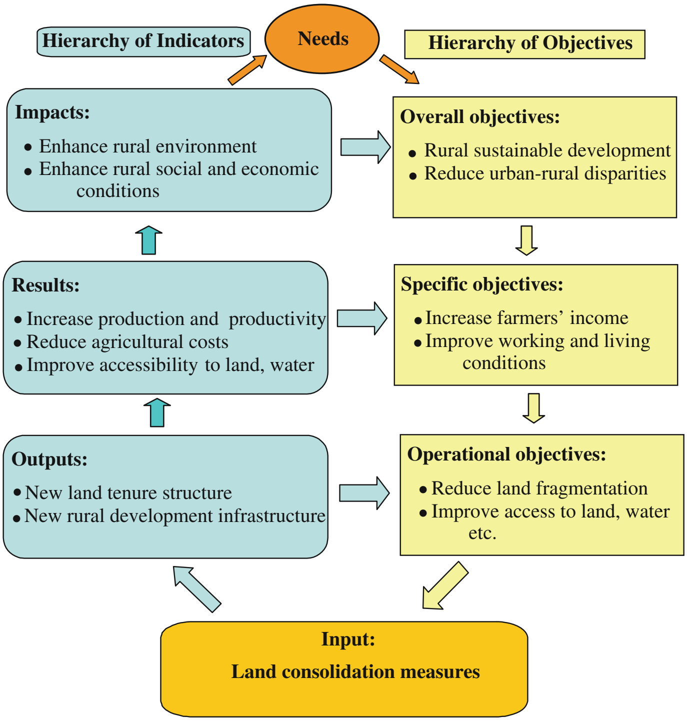


Fig. 4.1 The land consolidation intervention logic flowchart (after [52])

relate to economic, social and environmental requirements to which land consolidation should respond. *Inputs*, which include the set of land consolidation measures (concentration of parcels, improve parcel shape, increase the mean area of parcels, provision of access through road network to all parcels, etc.) generate the *outputs* which will achieve the intended operational objectives.

The main land consolidation outputs are the rearrangement of the existing land tenure structure and the construction of infrastructure for agricultural and rural development (i.e. roads, irrigation and drainage networks, etc.). The subsequent *results* are the most immediate impacts of the programme, in other words, the contribution of the operational objectives to the specific objectives. The most dominant results of land consolidation are the increase in production and productivity, the reduction of agricultural costs and the improvement of accessibility to land and water. *Overall impacts* are linked to the overall objectives of the programme which, in the case of land consolidation, is economic, social, and environmental sustainability. In a well-designed programme, overall impacts should meet the identified needs that led to the implementation of the programme.

As shown in Fig. 4.1, the prediction of land consolidation outputs are utilised as input data for estimating/predicting the results and impacts noted earlier for a land consolidation project in the context of an ex-ante evaluation. Therefore, the need for reliable land reallocation models, that may represent as close as possible the outputs of a land consolidation project before implementation, is a necessity. This latter need is also addressed by objectives 4, 5 and 6 of this research.

4.5.2 Land Consolidation Evaluation Studies

Land consolidation evaluation studies can be classified into three categories based on the scope of each study: suitability evaluation; comprehensive project evaluation; and land reallocation plan evaluation, which is the focus of this section. In particular, suitability evaluation studies [39–41] are carried out before project implementation and aim to investigate the potential for applying land consolidation in a broader region or in a certain area. Comprehensive evaluation studies [42–48] have a broad view, attempting to capture all the potential impacts of the whole project. As the name implies, comprehensive evaluation attempts to cover all of the issues of evaluation and has three main components: economic efficiency evaluation, which is related to the improvement of land fragmentation indices and the consequent agricultural benefits (e.g. production, productivity, farmers' income); evaluation of environmental impacts, which may be caused by a project; and social impact evaluation, covering the potential project impacts on landowners or on a group of people or society as a whole. Comprehensive evaluation can be applied ex-ante or ex-post with the latter being the most usual case. Review has shown a lack of automated models, i.e. land reallocation models, for feeding the ex-ante evaluation with the appropriate data, which is an EU requirement for rural programmes as noted in the previous section.

Land reallocation plan evaluation studies [26, 49–51] have a narrow scope, focussing on the quality of the land reallocation plan before and during the design stage, which is a kind of ex-ante evaluation. In particular, the system developed by Tourino [26] contains an Evaluation module for land reallocation plans which uses three groups of existing indicators: classical; morphological; and dispersion. Classical indicators which represent land fragmentation indices are the number of parcels, the consolidation (or concentration) coefficient and the reduction coefficient. The weaknesses of this type of indicator have been already noted in Sect. 2.2.5. Morphological indicators refer to the shape and size of the new parcels: the perimeter of a parcel; the ratio area divided by perimeter; and the ratio area divided by the squared perimeter. The drawbacks of this kind of indicator are discussed extensively in Sect. 7.4.2. Dispersion indicators measure the scattering of parcels of each landowner in the consolidated area. Such indicators are the centroid dispersion and the Hamiltonian circuit. Centroid dispersion is the sum of distances between the centre of gravity of all parcels of a landowner and the centroid of each parcel. If these distances are weighted by the score of each parcel, then the weighted centroid dispersion indicator can be calculated. The Hamiltonian circuit measures the distance of a Hamiltonian circuit that traverses all the parcels of a landowner. The disadvantages of these indicators are set out in Sect. 9.2.3. In addition to these indicators, the satisfaction of the landowners' preferences regarding the land reallocation is measured by the petition adjustment indicator, which measures the dispersion of parcels of each landowner in relation to his/her original preference.

Gonzalez et al. [49, 50] developed a GIS-based approach for the evaluation of land redistribution, which takes into account three dominant land fragmentation indices: parcel size; shape; and dispersion. Shape and size have a significant influence on the efficiency of agricultural operations which take place in a parcel. However, Gonzalez et al. [49] did not consider the distance between the parcels or the distance between the parcels and a farmer's residence as significant factors in their study of Galicia, although these factors were included in Gonzalez et al. [50]. Based on these indices, the yield and the working costs for certain land redistribution were predicted. The yield of a parcel depends on its useful area which in turn depends on the parcel size and shape. Working costs comprise the tillage time, which also depends on parcel shape and size, and transport costs, which depend on the traveling distance to each parcel. The model combines the three factors, i.e. useful area, tillage time and traveling time. Useful area was calculated from the coordinated data derived from a GIS and the parcel type. Parcels were classified into 36 types. It is emphasized and easy to prove that for rectangular parcels, the 'dead area', i.e. the area that cannot be ploughed using tractors, was minimized for parcels with a length/breadth ratio of 4:1. In addition, this study showed that this ratio also provides the maximum useful area for a wider shape of parcels.

The approach was tested with a hypothetical example. Results showed that parcel shape and size and the dispersion of parcels are significant factors for assessing the benefits of a landowner, despite he/she receiving a property that is equivalent in terms of value after the project. A weakness of this method is that parcel shapes, which were classified into 36 types, may not represent the actual shapes found in reality because the latter are more complex, often with many corners, sharp angles and different side lengths, etc. Instead of classifying parcel shapes, a formula that would take into account any shape and that would lead to the estimation of more realistic evaluation factors is a demand that is addressed in this research (Sect. 7.4) by developing a new index (*PSI*). Another disadvantage is that the approach has not been tested in a case study which has many more complicated parcel shapes.

Aslan et al. [51] used some basic land fragmentation indices for the assessment of land reallocation plans. These indices can be grouped into two categories: those regarding size and scattering of parcels and those regarding parcel shape. The former group includes simple measures such as the number of parcels, the average number of parcels per owner, the average size of parcels, the reduction index, which is the ratio of the number of parcels before and after the project, and the consolidation (or concentration) coefficient, which combines the reduction index with a ratio of the number of parcels before the project and the number of landowners. As noted earlier, these land fragmentation indices present weaknesses that have been already noted in Sect. 2.2.5.

The second group of indices include: the Total Edge, which is the total perimeter of all parcels of a project; the Edge Density, which represents the total perimeter of parcels per unit area; and the Shape Index, which uses the perimeter and the area of a parcel and is independent of parcel size. Other indices are: the Fractal Dimension, which represents the degree of shape complexity; the Mean Shape Index, which divides the shape index with the number of parcels; and the Area-Weight Mean Shape Index, which combines the shape index with the area of the parcels. There is also the Double Log Fractal Dimension, which equals 2 divided by the slope of the regression line obtained by regressing the logarithm of parcel area against the logarithm of the parcel perimeter. The Shape Index and Fractal Dimension, which have been utilized for evaluating parcel shapes, have serious disadvantages; these are discussed extensively in Sect. 7.4.2.

As mentioned, the land fragmentation indices including indicators for evaluating parcel shape and metrics for estimating the dispersion of parcels utilized by the above studies present weaknesses which are discussed in the noted sections. Thus, this research responds to this gap by developing a new land fragmentation index, including a new parcel shape index (Chap. 7) and a new formula for measuring the dispersion of parcels,in addition to a new metric for measuring the landowner satisfaction rate (Chap. 9).

4.6 Conclusions

Land reallocation has proved to be a very complex spatial allocation problem with many conflicting criteria and constraints. The conventional approach employed to solve this problem involves some basic calculations, decision-making and design in the context of an iterative, trial and error process. The large number of reallocation principles imposed by a country's legislation and land consolidation authority's regulations and other criteria involved in combination with hundreds of stakeholders involved, makes the planners' role extremely important and complicated. The planner utilises his/her knowledge, experience and judgment to satisfy a wide spectrum of each project's objectives. The review of the literature in this chapter points to the need for powerful support tools to aid the planner in speeding up or even automating the entire process. This research splits the modelling of land reallocation into two main sub-problems: land redistribution and land partitioning that both involve evaluation aspects.

Although research and development of such tools has been occurring since the end of the sixties including the development of more advanced geoplanning tools during the last two decades, the support provided to the planner is clearly not sufficient. Existing systems have limitations and weaknesses. The entire process has not been automated and the weight is still on the planner's shoulders in terms of design and decision making. In particular, all the studies that have attempted to support/automate the problem of land redistribution treat it as a mathematical optimisation problem. Thus, although results are sometimes optimal in terms of efficiency, they are not realistic and applicable, since they ignore significant parameters of the problem. This problem is addressed by objective 4 of this research via the development of a new land redistribution design model (Chap. 8).

A couple of the studies reviewed in the chapter that dealt with the land partitioning problem produced operationally encouraging results but these were far from experts' expectations and thinking. This problem is addressed by objective 6 of this research via the development of a new land partitioning model (Chap. 10). In addition, EU regulations define a compulsory evaluation framework for rural development programmes undertaken by Member States. This involves ex-ante evaluation which is a crucial part of the process, since it supports the preparation of proposals at the initial stage. Existing land consolidation/reallocation evaluation studies suffer from the lack of models that are capable of providing the necessary data (before the implementation) of a programme for predicting the consequent results and impacts, which is a gap addressed by the development of both land reallocation models noted earlier. Furthermore, although these studies utilise a large number of land reallocation efficiency indicators, they also present limitations and weaknesses. Thus, the introduction of new, better indicators, in the context of a systematic evaluation methodology, is addressed by objectives 3 and 5 via the development of a new land fragmentation model (Chap. 7) and a new land redistribution evaluation model (Chap. 9).

Based on these conclusions, the next chapter investigates how state-of-the-art technologies, methods and techniques can be employed to develop the four models noted above under a common framework and computerised platform.

References

1. Sonnenberg, J. (2002). Fundamentals of land consolidation as an instrument to abolish fragmentation of agricultural holdings. *In: Proceedings of the 22nd International FIG Congress*, Washington, DC, 19–26 Apr 2002. Available from: http://www.fig.net/pub/fig_2002/Ts7-4/TS7_4_sonnenberg.pdf.
2. Yomralioglu, T. (1993). *A nominal asset value-based approach for land readjustment and its implementation using GIS*. PhD thesis, Department of Surveying, University of Newcastle upon Tyne.
3. Yaldir, A., Rehman, T. (2002). A methodology for constructing multi-criteria decision support systems for agricultural land consolidation using GIS and API: an illustration from Turkey. *Computers and Electronics in Agriculture*, *36*, 55–78 (Retracted).
4. Essadiki, M., Ettarid, M., & Robert, P. (2003). Optimisation of technical steps of a rural land consolidation using a geographic information system: Land reallocation step. *In*: *Proceedings of FIG Working Week, Still on the Frontline*, 13–17 April, Paris, France. Available from: http://www.fig.net/pub/fig_2003/TS_13/PP13_2_Essadiki_et_al.pdf.
5. Van Dijk, T. (2003). *Dealing with central European land fragmentation*. Delft: Eburon.
6. Van den Brink, A. (2004). Land consolidation and the emergence of the metropolitan landscape. *In*: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 Sept, Volvic (Clermont-Ferrand), France. Available from: http://www.fig.net/commission7/france_2004/papers_symp/ts_03_vandenbrink.pdf.

7. Cay, T., & Iscan, F. (2006). Optimisation in land consolidation. *In: Proceedings of the 23rd FIG Congress, Shaping the Change,* 8–13 Oct, Munich, Germany. Available from: http://www.fig.net/pub/fig_2006/papers/ps07/ps07_14_nam_kim_0406.pdf.
8. Thomas, J. (2006). What's on regarding land consolidation in Europe? *In: Proceedings of the 23rd FIG Congress, Shaping the Change,* 18–13 Oct, Munich, Germany. Available from: http://www.fig.net/pub/fig_2006/papers/ts80/ts80_03_thomas_0311.pdf.
9. Ayranci, Y. (2007). Re-allocation aspects in land consolidation: A new model and its application. Asian network for scientific information. *Journal of Agronomy, 6*(2), 270–277.
10. Cay, T. & Iscan, F. (2004). Algorithm developing for land consolidation software. Accessed on 1st 2007 September at URL:http://www.isprs.org/istanbul2004/comm3/papers/352.pdf.
11. Republic of Cyprus. (1998). *Land consolidation Law (1969).* Nicosia.
12. FAO. (2003). *The Design of land consolidation pilot projects in Central and Eastern Europe*. Rome: FAO.
13. Rosman, F., & Sonnenberg, J. (1998). New method for the design of the reallocation plan in land consolidation projects. FIG conference. *In: Proceedings of the 21st FIG Congress Brighton, Developing the Profession in a Developing Word,* 19-25 July, Brighton, UK.
14. De Vos, W. & Rosman, F. (1991). The development of instruments for land consolidation projects. *In*: *Proceedings of the 2nd Dutch-Polish Symposium on Geodesy*, University of Delft, The Netherlands.
15. Buis, A., & Vingerhoeds, R. (1996). Knowledge-based systems in the design of a new parcelling. *Knowledge-Based Systems, 9*, 307–317.
16. Rosman, F. (2012). Automated parcel boundary design systems in land consolidation. *In: Proceedings of the FIG Working Week, Knowing to manage the territory, protect the environment, evaluate the cultural heritage,* 6–10 May, Rome, Italy. Available from: http://www.fig.net/pub/fig_2012/papers/ts02e/TS02E_rosman_5924.pdf.
17. Lemmen, C., Jansen, L., & Rosman, F. (2012). Informational and computational approaches to land consolidation. *In: Proceedings of the FIG Working Week, Knowing to manage the territory, protect the environment, evaluate the cultural heritage,* 6–10 May, Rome, Italy. Available from: http://www.fig.net/pub/fig2012/papers/ts02e/TS02E_lemmen_jansen_et_al_6049.pdf.
18. Semlali, H. (2001). A GIS solution to land consolidation technical problems in Morocco. *In: Proceedings of FIG Working Week, New Technology for a New Century,* 6–11 May, Seoul, Republic of Korea. Available from: http://www.fig.net/pub/proceedings/korea/full-papers/pdf/session24/semlali.pdf.
19. Essadiki, M. (2002). New method for land reallocation by using a geographic information system. *In*: *Proceedings of the 22nd International FIG Congress*, 19–26 April, Washington, DC, USA. Available from: http://www.fig.net/pub/fig_2002/Js9/JS9_essadiki.pdf.
20. Kik, R. (1990). A method for reallotment research in land development projects in The Netherlands. *Agricultural Systems, 33*, 127–138.
21. Avci, M. (1998). A new approach oriented to new reallotment model based on block priority method in land consolidation. *Turkish Journal of Agriculture and Forestry, 23*, 451–457.
22. Jansen, L.J.M., Karatas, M., Kusek, G., Lemmen, C.H.J., & Wouters, R. (2010). The computerised land re-allotment process in Turkey and the Netherlands in multi-purpose land consolidation projects. *In*: *Proceedings of the 24th International FIG Congress*, 11–16 April, Sydney, Australia. Available from: http://www.fig.net/pub/fig_2010/papers/ts09h%5Cts09h_jansen_karatas_et_al_4574.pdf.
23. Cay, T., & Iscan, F. (2008). Determination of land piece given to farmers in land reform by using the fuzzy logic method. *In: Proceedings of the 23rd FIG Congress, Shaping the Change,* 8–13 Oct, Munich, Germany. Available from: http://www.fig.net/pub/fig_2008/papers/ts02e/ts02e_04_cay_iscan_2754.pdf.
24. Cay, T., & Iscan, F. (2010).Application of fuzzy logic in land consolidation activities. *In*: *Proceedings of the XXIV International FIG Congress*, April 11-16, Sydney, Australia. Available from URL: http://www.fig.net/pub/fig_2010/papers/ts10h%5Cts10h_cay_iscan_4351.pdf.

25. Cay, T., Ayten, T., & Iscan, F. (2006). An investigation of reallocation model based on interview in land consolidation. *In: Proceedings of the 23rd FIG Congress, Shaping the Change,* 8–13 Oct, Munich, Germany. Available from: http://www.fig.net/pub/fig_2006/papers/ts89/ts89_02_cay_etal_0429.pdf.
26. Tourino, J., Boullon, M., & Gonzalez, X. (2003). A GIS-embedded system to support land consolidation plans in Galicia. *International Journal of Geographical Information Science, 17*(4), 377–396.
27. Tourino, J., Rivera, F., & Alvarez, C. (2001). COPA: a GIS-based tool for land consolidation projects. *In: Proceedings of the 9th ACM International Symposium on Advances in Geographic Information Systems,* 9–10 Nov, Atlanta, GA, USA (pp 53–58).
28. Datta, D., Deb, K., Fonseca, C., Lobo, F., & Condado, P. (2006). *Multi-objective evolutionary algorithm for land use management problem*. Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Report Number 2006005. Available from: http://repository.ias.ac.in/82720/1/1-a.pdf.
29. Uimonen, M. (2002). New tools and processes for land consolidation. *In*: *Proceedings of the 22nd International FIG Congress*, 19–26 Apr, Washington, DC, USA. Available from: http://www.fig.net/pub/fig_2002/Ts7-4/TS7_4_uimonen.pdf.
30. Vitikainen, A. (2002). Land consolidation and the guidelines on land administration. Accessed on 12 September 2009 at URL:http://www.survey.ntua.gr/main/labs/photo/research/wg_33/wpla/papers/TPS6.4.Arvo%20Vitikainen(abstract).doc.
31. Ollen, J. (2002). ArcCadastre and EULIS—New tools for higher value and increased efficiency in the property market efficiency in the property market. *In: Proceedings of the 22nd International FIG Congress,* 19–26 April, Washington, DC, USA. Available from: http://www.fig.net/pub/fig_2002/Js8/JS8_ollen.pdf.
32. Aslan, T., & Arici, I. (2005). GIS-supported land consolidation planning information system: ARTOP. *Die Bodenkultur, 56*(2), 103–110.
33. European Commission. (2000). *Part A: Introduction: Purpose and use of common questions with criteria and indicators.* European Commission Directorate General for Agriculture.
34. European Commission. (2000). *Part B: The set of common evaluation questions with criteria and indicators.* European Commission Directorate General for Agriculture.
35. European Commission. (2004). *Guidance note B: Evaluation guidelines*. Luxemburg: Office for Officials Publications of the European Communities.
36. European Commission. (2004). *Guidance note C: Ex-ante evaluation guidelines including SEA*. Luxemburg: Office for Officials Publications of the European Communities.
37. Patton, M. Q. (1986). *Utilisation-focused evaluation*. London: Sage.
38. Aravossis, K., & Koutsiana, E. (2003). *Program evaluation methodologies: A comparative assessment* (vol. 9 (17) pp. 387–404). Department of Planning and Regional Development, School of Engineering, University of Thessaly. Discussion Paper Series.
39. Miranda, D., & Crecente, R. (2004). Suitability model for land consolidation projects: a case study in Galicia, Spain. *In*: *Proceedings of Symposium on Modern Land Consolidation*, 10–11 Sept, Volvic (Clermont-Ferrand), France. Available from: http://www.fig.net/commission7/france_2004/papers_symp/ts_04_miranda.pdf.
40. Zou, X., Luo, M., Su, W., Li, D., Jiang, Y., Ju, Z., et al. (2008). Spatial decision support system for the potential evaluation of land consolidation projects. *WSEAS Transactions on Computers, 7*(7), 887–898.
41. Thapa, G., & Niroula, G. (2008). Alternative options of land consolidation in the mountains of Nepal: An analysis based on stakeholders' opinions. *Land Use Policy, 25*(3), 338–350.
42. Janssen, R., & Rietveld, P. (1985). Multi-criteria evaluation of land reallotment plans: a case study. *Environment and Planning A, 17*, 1653–1668.
43. Van Huylenbroeck, G., Coelho, C., & Pinto, P. A. (1996). Evaluation of land consolidation projects (LCPs): A multidisciplinary approach. *Journal of Rural Studies, 12*(3), 297–310.
44. Coelho, C., Pinto, P. A., & Silva, M. (2001). A systems approach for the estimation of the effects of land consolidation projects (LCPs): A module and its application. *Agricultural Systems, 68*, 179–195.

45. Tristany, M., & Coelho, J. (2005). GIS as a tool for the evaluation of land consolidation projects and land-use alternatives: The case study of Aldeia da Luz. *In: Proceedings of the 5th Conference of the European Federation for Information Technology in Agriculture, Food and Environment and the 3rd World Congress on Computers in Agriculture and Natural Resources, Joint Congress on IT in Agriculture*, 25–28 July, Vila Real, Portugal.
46. Crecente, R., Alvarez, C., & Fra, U. (2002). Economic, social and environmental impact of land consolidation in Galicia. *Land Use Policy, 19*(2), 135–147.
47. Miranda, D., Crecente, R., & Alvarez, M.F. (2006). Land consolidation in inland rural Galicia, N.W. Spain, since 1950: An example of the formulation and the use of questions, criteria and indicators for the evaluation of rural development policies. *Land Use Policy*, *23*(11), 511–520.
48. Sklenicka, P. (2006). Applying evaluation criteria for the land consolidation effect to three contrasting study areas in the Czech Republic. *Land Use Policy, 23*(4), 502–510.
49. Gonzalez, X. P., Alvarez, C. J., & Crecente, R. (2004). Evaluation of land distributions with joint regard to plot size and shape. *Agricultural Systems, 82*, 31–43.
50. Gonzalez, X. P., Marey, M. F., & Alvarez, C. J. (2007). Evaluation of productive rural land patterns with joint regard to the size, shape and dispersion of plots. *Agricultural Systems, 92*, 52–62.
51. Aslan, T., Gundogdu, K., & Arici, I. (2007). Some metric indices for the assessment of land consolidation projects. *Pakistan Journal of Biological Sciences, 10*(9), 1390–1397.
52. European Commission. (2004). *Guidance note A: Choice and use of indicators*. Luxemburg: Office for Officials Publications of the European Communities.

Chapter 5
System Development Framework

5.1 Introduction

After providing the background regarding the problem domains of this research in the preceding three chapters, this chapter sets out the foundations for defining the development framework of the system under study. In particular, this chapter is divided into five main sections. Section 5.2 explores the theoretical foundations for the spatial decision-making process and critically reviews the existing tools provided to support this process, i.e. DSS, GIS, SDSS and PSS. Inherently, decision making is strongly associated with multi-criteria decision methods (MCDM) which are examined in Sect. 5.3. In this section, the general framework of multi-criteria evaluation (MCE) and separately multi-attribute decision-making methods (MADM) and multi-objective decision-making methods (MODM) are discussed. Decision making is also related to expert systems, which are perhaps the earliest information technology tool exclusively used to support these kinds of tasks. The necessary background of these systems, their role in supporting spatial decision making and in particular their appropriateness for solving the land redistribution problem are considered in Sect. 5.4. Thereafter, Sect. 5.5 briefly introduces classical optimisation methods compared with a powerful artificial intelligence technique, i.e. genetic algorithms (GAs). The contribution of GAs in solving spatial problems, and in particular, their potential for solving the land partitioning problem is also investigated. Finally, Sect. 5.6 presents the system's development framework, both the conceptual and operational involving the rationale and methodologies utilised including the aims of the system.

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_5, © Springer International Publishing Switzerland 2014

5.2 Spatial Decision-Making Support

5.2.1 Decision-Making Framework

Everyday human life activities involve decisions. A decision is a choice between two or more alternative courses of action. Decision making is a process which involves a series of stages beginning with the identification of a decision problem and ending with a potential solution to that problem. It is usually an iterative process in which the sequence of activities can be organised in various ways so as to transform data to information and information into instructions. Instructions are intended actions that affect the current status of a system in such a way as to improve its performance. These instructions are evaluated in the context of the decision-making process.

There are two major decision theories: normative and descriptive [70]. The first refers to the way that decisions should be made and the second to the way that decisions are actually taken. For both theories there is an agreement that the aim is rational decision making. Simon [136], a Nobel Prize winner, distinguishes two rational decision-making paradigms: o*bjective rationality* and *bounded* (*or procedural*) *rationality*. In the first paradigm, the goal of decision making, the desired outcome and all the relevant information are available so as to reach the best possible solution. This process can be supported by normative models and optimisation techniques [134, 146, 147]. The land partitioning problem falls within this category of decision making. In the second paradigm, the goal of decision-making is to find a 'good enough' or 'satisfactory' solution rather than the 'best solution'. Thus, aspiration levels are set for what defines an acceptable solution. This decision-making principle can be supported by descriptive models and simulation techniques [134,146, 147]. Simon [137] also emphasises that the use of heuristic methods fits within the framework of bounded rationality. The land redistribution problem falls into this latter category of decision making.

Both decision theories should rely on an appropriate framework. Thus, a number of models have been proposed representing the phases of decision making. Simon's model is currently considered as the most widely accepted generalisation of the decision-making process among others [22, 112, 161]. He suggested that any decision-making process can be structured into three major phases: *intelligence, design* and *choice*, as shown in Fig. 5.1. He later added a fourth phase of implementation. The contents of each phase are addressed via a corresponding question shown in the relevant figure. The intelligence phase involves scanning of the current system usually via exploratory analysis methods to identify potential problems or opportunities for system change. The design phase involves inventing, analysing and developing potential courses of action, i.e. alternative problem solutions. The choice phase is for the evaluation of these alternatives and the selection of the best one (or one that satisfies a given set of criteria).

In practice, Simon's model can be utilised for solving a decision problem. Ackoff [1] recognises, as a decision problem, a situation when a decision-making

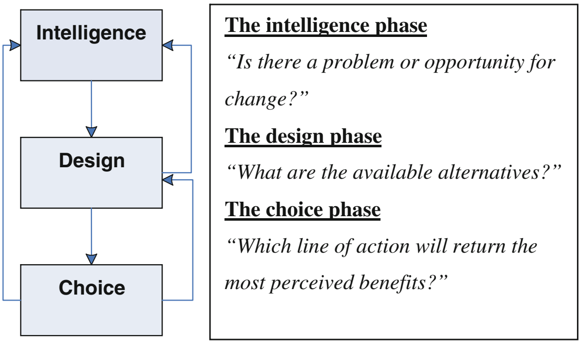


Fig. 5.1 Simon's decision making model

individual or group perceives a difference between a present state and a desired state under three conditions: there are alternative courses of action available; the choice may have a significant effect; and the selection of a best possible alternative is not always straightforward. Accordingly, a decision problem which has a geographical reference component can be called a *spatial decision problem* [106].

Several decision problem classifications have been used. The most widely used is that of Simon's [136] which is based on the degree to which the problem is structured. According to this, any decision-making problem falls along a continuum that ranges from highly *structured* (or programmed or well-defined) to highly *unstructured* (or non-programmed or ill-defined) decisions. A problem is characterised as structured when all phases of the decision-making process can be formalised in a sequence of procedures or in a flowchart, or as a formula etc., and then a decision maker obtains a solution (the best one or at least one that is good enough) by applying the data from the problem. These problems are usually repetitive and routine and they can be easily programmed in a computer readable form. The participation of the decision makers is not necessary since the problem can be fully modelled with a computer.

On the other hand, unstructured problems are those in which none of the phases of decision-making can be formalised. Such problems are those that do have not defined procedures, they are not repeated frequently and a general solution cannot be developed for a computer. These kinds of problems are solved by decision makers based on their knowledge and experience. When the situation falls between these two extremes, i.e. some phases of decision-making can be formalised and some not, then the problem is referred to as *semi-structured* (or semi-programmable). Most real-life spatial decision problems, and hence spatial planning problems, are inherently semi-structured [106]. Based on the evidence provided in Chap. 4, land consolidation planning, and in particular the land reallocation process, is clearly a semi-structured problem because although it consists of a series of well-defined procedures, the outcome is partly based on non-explicit data; thus, it may vary from planner to planner and hence a large number of alternative solutions can be generated. The application of DSS has a potentially great contribution to make towards the solution to these problems [83, 106].

Based on the previous considerations, planning, which involves semi-structured or un-structured problems, is interrelated with decision making, and in particular, it follows, in practice, Simons' model. Thus, the two terms, i.e. planning and decision making, are used as part of each other or separately. In a broad sense, planning is the activity of formulating plans and strategies, evaluating their performance against particular goals, which are aimed at solving existing or future problems of society, and eventually implementing the best possible actions. As such, "planning is clearly an activity that requires information about existing as well as future situations and many types of planning have either implicit or explicit spatial dimensions whether they are distinguished by scale or by sector" [140]. Planning under this scope consists of the following stages: problem definition, problem exploration, development and evaluation of alternative plans/scenarios, decisions and implementation [14, 157, 162]. It is a special kind of decision-making process since it involves a series of decisions: What should be done? When? Why? How? By whom? [147].

Despite this common view about planning, some commentators separate planning from decision making. For instance, Harris and Batty [71, p. 26] define planning as "the premeditation of action" and decision-making as "the conclusions of planning" which are then translated into norms and instructions. Similarly, Sharifi et al. [134] prefer to see planning as the preparation of plans and decision making as the process of evaluating and deciding about these plans. They argue that this differentiation facilitates distinguishing planning support from decision support. In our view, plans and decisions, and hence planning and decision-making, are interchangeable and interrelated terms within a common framework. Boulding [19, p. 11] successfully interpreted this interrelation and its importance stating that "The world moves into the future as a result of decisions, not as a result of plans. Plans are significant only insofar as they affect decisions…if planning is not part of a decision-making process, it is a bag of wind, a piece of paper and worthless diagrams".

Therefore, Sharifi et al. [134] synthesised both views under a common integrated "planning and decision-making framework" based on Simons' (1960) model. This framework is illustrated in Fig. 5.2 and each stage has been split into specific tasks. It can be used as a systematic approach for supporting spatial decision making. This research, and in particular the conceptual framework of the system under development, is based on this approach as described later in Sect. 5.6.

5.2.2 Decision Support Systems

The systematic study of computerised models to aid decision making and planning began in the 1960s. The concept of DSS was first introduced by Scott Morton in February 1964. In contrast, Malczewski et al. [108] claims that the concept was actually based on Simon's seminal work from the 1950s and 1960s. Later, Gorry and Morton [67, p. 27] define the term DSS as "an interactive computer-based

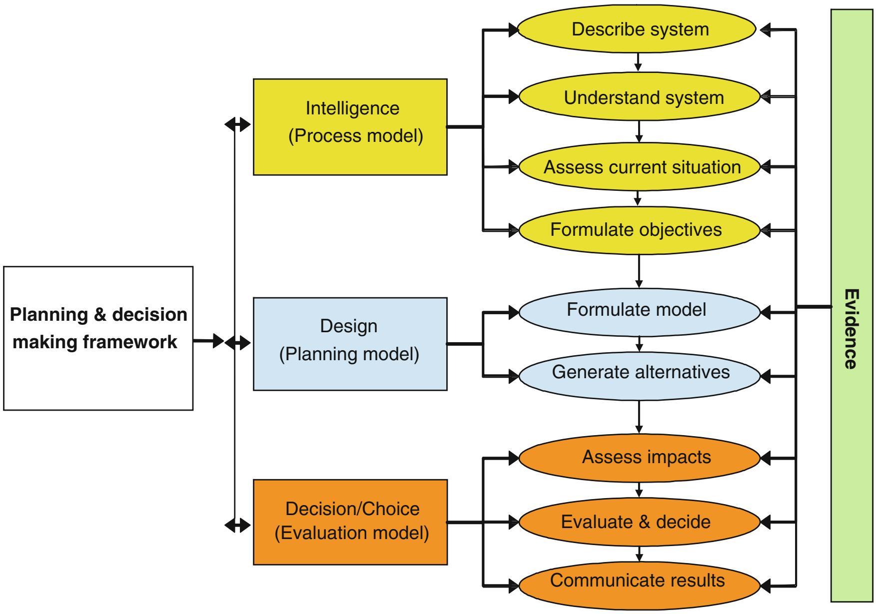


Fig. 5.2 Planning and decision-making framework (Adapted from [134])

system that helps decision makers to utilize data and models to solve unstructured problems". By the 1980s, the field of DSS had begun to expand beyond the initial business and management application domains (e.g. agriculture, marketing, sustainable development, etc.). Thus, the term is actually a content free expression since different people perceive the field from various perspectives depending upon their scientific background and domain. However, it is generally accepted that a DSS is an umbrella term covering information systems built for helping a narrow domain, individual or group decision-making to solve semi-structured or unstructured problems. It is emphasised in the literature that the aim of DSS is to extend the decision makers' capabilities to handle a certain problem but not to replace their judgement.

A typical DSS comprises four main components: a database management subsystem (DBMS), which contains the relevant data; a model base management subsystem (MBMS), which includes models that provide analytical capabilities to the system; a user interface for the communication between the user and the system; and a knowledge based management subsystem (KBMS), which is optional, aimed at supporting the other three components using artificial intelligence techniques. The synergy of these components may provide a variety of capabilities facilitating decision making.

However, despite the great popularity of such systems, it is interesting that some authors argue that many DSS have failed since they have never or have hardly ever been used in practice. Uran and Janssen [148] identify reasons for this such as the systems are too detailed, complex, time consuming and costly to use, outputs are not reliable and generally system functionality is inappropriate for the decision problem, etc. They note that these reasons are a consequence of the limited involvement of users in the development and inadequate training. These findings clearly suggest the need for utilising a user-centred approach in the system development.

A special kind of DSS are those used for spatial decision-making support called geotechnology tools by Geertman and Stillwell [59]. The most well-known are GIS, SDSS and PSS, which are examined next.

5.2.3 GIS: A Fundamental Spatial Support System

It is accepted that GIS is a spatially oriented information system able to manage, present data from various sources and carry out relevant advanced analysis. GIS is a prominent class of geotechnology tool employed to support a wide range of spatial domains using geoinformation [59, 61]. It has gained importance and widespread acceptance as a tool for decision support [152] in various geographical domains such as resources, environment, land infrastructure, urban and regional planning, transportation, etc. [133]. GIS provide the spatial planning decision maker with an effective set of functionalities and operations for the management and analysis of spatial information [27]. An extensive overview regarding GIS can be found in many core textbooks (e.g. [17, 72, 103, 38]).

Spatial support is achieved via two major components of GIS: information management and spatial analysis. Information management involves a number of fundamental functions, which are those commonly available in most GIS and considered to be useful for a wide range of tasks. These functions are capturing, storing, retrieval, manipulation, basic analysis, presentation of data and outputs, etc. On the other hand, spatial analysis includes advanced functions such as data modelling, topological modelling, cartographic modelling, network analysis, geostatistics, geocoding, etc. Advanced functions are not provided by all proprietary systems. Furthermore, only a few proprietary GIS such as IDRISI and ILWIS (developed at ITC, Netherlands) include planning and decision-making capabilities. While the first operational GIS was developed in 1962 in Canada, the main developments occurred from the middle of the 1980s onwards. GIS is currently a popular tool in private and public organisations, industry, universities etc., and is used for a wide range of applications that involve individual decision making and group decision making [76]. A collection of advanced spatial analysis applications are provided by Longley and Batty [100, 101] and Stillwell and Clarke [139].

Despite the great capabilities and the popularity of GIS, it has been criticised by many authors, especially from within the planning domain. Carver [27] emphasises that GIS is operationally restricted to certain deterministic spatial analysis tools such as overlay and buffer. It lacks the ability of treating multiple and conflicting criteria and objectives. Thus, GIS require further analytical skills than the current systems provide since real world spatial problems are complicated [18]. Similarly, Laaribi et al. [92] point out the inability of GIS to incorporate decision makers' preferences or to evaluate alternative solutions with conflicting criteria and objectives. Stillwell et al. [140] conclude that GIS is not a problem oriented technology and needs to enhance its functionality beyond simple spatial analysis. Batty [13] notes that GIS software is too generic for any kind of spatial analysis and representation, restricting the tool to be descriptive rather than predictive.

Moreover, Geertman and Stillwell [59] state that GIS are lacking analytical and modelling functionalities. As a result, GIS cannot always support a systematic decision-making process [94, 133]. In fact, proprietary GIS do not provide decision-making modules, so the user has to formalise the decision rules a *priori* and then reach decisions based on manual techniques and his/her judgement [2]. In a similar vein, Li et al. [96] point out that GIS have a low level of automated intelligence, especially regarding decision-making processes.

As a result of these deficiencies, GIS do not adequately fulfil the requirements for supporting planning [62] and decision making. Thus, in order to overcome this mismatch between the demands of planners and the supply of existing geoinformation systems, a new generation of tools has appeared in the spatial decision-making arena, such as SDSS [31, 46] and PSS [61].

5.2.3.1 Spatial Decision Support Systems

Conceptually, the distinction between DSS and Spatial Decision Support Systems (SDSS) is that the latter has an explicit spatial component, i.e. they deal with geo-referenced data which makes the problems more complex. SDSS have been evolved in parallel with DSS since the 1970s [47]. Similar to DSS, SDSS are dedicated to the support of semi-structured spatial decision problems. Geertman and Stillwell [61] consider SDSS as specific purpose systems aimed at supporting the executive decision-making process for a certain complex spatial problem. In other words, they focus on short-term policy making processes, rather than on professional planning tasks. Such systems, which are a class of DSS, may support an individual decision maker or a group of decision makers for effective spatial decision making [106].

Incorporation of knowledge from a problem domain into such systems is a vital component to provide the user with appropriate functionalities to systematically formulate a problem and design and assess alternative scenarios [6, 47]. Birkin et al. [18] use the term 'Intelligent GIS' when referring to intelligent hybrid systems [66] which actually represent a generation of enhanced GIS with statistical, mathematical and modelling capabilities that are close to the concept of SDSS. The architecture of such an intelligent GIS is presented by Paliulionis [122]. In addition, a broader term that heralded the launch of a new research agenda in geographical analysis, modelling and GIS in general, is 'Geocomputation', which was introduced by Stan Openshaw in 1996. Indeed, since then, several authors have focused their research in Geocomputation [57, 102, 119], which usually involves the integration of GIS with artificial intelligence techniques [120] such as LACONISS.

Ayeni [7] emphasises that the difference between a SDSS and conventional GIS is the higher level of analytical and statistical modelling capabilities provided by the former. Thus, it is accepted that a typical SDSS should comprise three main components: a database management system (DBMS) containing data and data processing procedures; a model base management system (MBMS) containing the functions to manage the model base; and a dialog generation and management system (DGMS) which is the user interface and the reports/display generator [5, 7, 108].

There is a plethora of SDSS developed for a wide spectrum of spatially related applications such as for land-use planning [3, 24, 109], agriculture (MicroLEIS DSS, [33, 130]), environmental management ([154, 171]; GRAS, [124, 165]), transportation [141], sustainable development [10], water resource management (WinBOS, [149]; Mulino DSS, [64]), aquaculture [116], forest protection [150], solid water planning [105], location planning [9], real estate management [125], etc. Collections of other applications are included in Birkin et al. [18], Timmermans [143], Kersten et al. [85] and Thomas and Humenik-Sappington [142].

Despite the great popularity of SDSS, a considerable number of systems are rarely or are never used in practice due to the absence of a close link between the end-users and the developers [94, 148]. This suggests again the need for the adoption of a user-centred approach in the development so that users are an integral part of the process. Heywood et al. [72] emphasise this need and analyse the methodology to employ a user-centred approach in the development of such GIS which can be adopted for SDSS as well. Reeve and Petch [126] use the term peopleware, in addition to the classical information science terms hardware and software, which expresses the need to adopt a socio-technical approach for developing GIS in organisations.

5.2.4 Planning Support Systems

Although it is recognised that the term Planning Support Systems (PSS) was introduced by Britton Harris in 1989 [13, 60, 89], the concept is older going back to the 1950s. A representative definition given by Geertman and Stillwell [61, p. 291] for PSS states that “PSS is a subset of computer-based geo-information instruments, each of which incorporates a unique suite of components that planners can utilise to explore and manage their particular activities. The components may include data sets, computer algorithms and display facilities, as well as more abstract theoretical constructs, knowledge and modelling capabilities”.

Definitions of PSS in a similar vein have been given in many other documents [12, 21, 60, 62, 87, 88, 157]. Similarly to DSS and SDSS, ideally a PSS will consist of four main sub-systems: a database management system (DBMS); a model base management system (MBMS); a knowledge base; and a user friendly interface. Geertman and Stillwell [60] express the basic three components of a PSS in a different way: transformation models from data to information, the specific planning tasks at hand and the system models which represent the planning process, i.e. analysis, prediction and prescription.

Despite PSS having much in common with SDSS and distinguishing between them is not straightforward, some authors have attempted to clarify this distinction. In contrast to SDSS, PSS focus on long-range problems and strategic issues which are sometimes constructed specifically for group interaction and discussion [61]. Some forms of the latter are public participation GIS (PP-GIS) and web-GIS. Also, while SDSS are concentrated on executive decision making, PSS are dedicated to planning activities in the whole or in part of a professional planning task. Similarly, Sharifi et al. [134] note that PSS are focused on the second phase of the planning and decision-making framework, i.e. in the design phase, whereas SDSS are more involved in the third phase, i.e. in the choice phase (evaluation). Also, the role of PSS goes beyond supporting semi-structured decision-making compared to SDSS. These systems are extended to provide interaction, communication and dialogue between the stakeholders involved [87]. Sharifi et al. [134], in an attempt to synthesise the two terms, introduced the term integrated planning and decision support systems (IPDSS) to rationalise both the planning and the decision-making process by supporting all the three phases of decision-making. The latter term is used for the system developed in this research since its broader scope fits to the entire planning and decision-making framework noted earlier.

A plethora of PSS have been developed to support a wide range of planning activities. Collections of PSS applications are those of Timmermans [143], Stillwell et al. [140], Brail and Klosterman [21], Geertman and Stillwell [60], Brail [20] and Geertman and Stillwell [62]. It is a common conclusion that despite the substantial number of PSS that have been developed since the 1980s, their usage in planning practice is very limited [21, 60, 62, 140, 157, 90]. Klosterman [90] states that this is a result of a new planning conception adopted by PSS regarding community planning, i.e. the transfer from the traditional concept 'planning for the public' to the modern 'planning with the public', which is good in theory but hard to implement in practice.

Furthermore, current planning practices are limited to routine administrative tasks and do very little regarding traditional planning which involves analysing and assessing alternative scenarios for the present and future. In addition, Klosterman [90] emphasises the fact that these systems require much more than purchasing and installation of a computer for success. Organisational issues and a continuous high level education of the staff involved in the whole process is another necessity. Vonk [157] reveals two bottlenecks blocking the widespread usage of these systems: the main one was the instrumental quality of these systems with regard to the needs of practitioners and the little awareness, experience and intention of using these systems.

Brail [20] also sees a gap between what PSS offer and what planning needs. On the other hand, Timmermans [144] has had positive experiences with the use of

PSS in many planning domains, such as retail planning, transportation and land use. He also defended planning practitioners and planning authorities and criticised academics who either fail to transfer the technology into practice or produce systems of little operational value to practitioners and authorities. Thus Klosterman [90] suggests that efforts for developing PSS should be focused on the professional environment concerned. Also Vonk [157] emphasises the important role of marketing in promoting geo-technologies. In addition, Waddell et al. [158] and Geertman [58] note that PSS have gained significant attention and interest from a variety of potential users. The development of these systems has really been focused on the supply side (systems), which does not satisfy the rather high requirements of the demand side (planners) [114].

Despite the under-use of PSS, it is also a common belief that they have great potential to support planners in various problem domains in the whole planning and decision-making process, so as to become more effective, efficient and transparent. Batty [13] foresees significant development in PSS in the next decade with fully integrated modelling in 2D and 3D GIS virtual environments. This research has carefully considered these lessons learnt, which has subsequently guided the development framework of the system in terms of both the demand for land consolidation planning clearly defined in the preceding chapters and the involvement of five land consolidation experts (including end-users) during the development process.

5.3 Multi-Criteria Decision Methods

5.3.1 Definitions and Classification

Multi-criteria decision methods (MCDM) is a branch of decision theory [70] that deals with decision problems characterised by a number of evaluation criteria [115]. Although these methods are well known for the evaluation of alternative problem solutions on the basis of multiple and conflicting criteria [27, 92, 123], they have evolved over the years by providing a set of techniques and procedures for structuring decision problems, and designing and evaluating alternative solutions [106, 107, 134]. The primary goal of MCDM is to facilitate decision making in an effective way. Conventional MCDM assume spatial homogeneity across the study area. As a result, impacts of an alternative for one criterion are measured without needing some sort of spatial relation, hence the performance for that criterion is represented by a unique value. However, this assumption in many cases can be unrealistic since evaluation criteria vary across space (e.g. in a road alignment problem or in a site suitability problem), hence a performance value for each criterion corresponds to each alternative location, e.g. each pixel. Thus, there is a distinction between conventional non-spatial MCDM and spatial MCDM.

MCDM use specific definitions. In particular, a criterion is a general term which includes both the concepts of attributes and objectives. The term attributes, which is usually used interchangeably with the term criteria, represent the features of entities in a real world geographical system. An attribute is defined as a standard of judgement to test the performance of an alternative course of action (option) to satisfy an objective. An option (or alternative) represents a certain course of action available to the decision maker which is evaluated against multiple and potentially conflicting objectives. An objective is a statement about the desired state of the system under consideration. For a given objective, several different attributes may be utilised to assess the degree to which an objective has been satisfied. For example, different land reallocation plans constitute alternative courses of action, i.e. options. Two conflicting objectives of land reallocation are: 'to reduce land fragmentation' and 'to satisfy landowners' preferences'. The indicators 'concentration of parcels' and 'percentage of agreement of landowners' can be the attributes to test the performance of these different land reallocation plans for each objective, respectively. Based on these concepts, Malczewski [106, 107] distinguishes two broad classes of MCDM: *multi-attribute decision making* (*MADM*) and *multi-objective decision making* (*MODM*).

5.3.2 Multi-Attribute Decision Making

MADM is a selection process between a discrete and limited number of alternatives which are described by several attributes (criteria). A general model of MADM is illustrated in Fig. 5.3. Initially, a set of alternative options are defined for the problem concerned and the aim is to rank these solutions based on their performance for a set of criteria. Thus, the next step involves the specification of the criteria to evaluate the decision problem concerned. The result is an effect table of alternatives in columns and criteria in rows. All criteria are measured as indicators/attributes. Quantitative criteria are measured with units and qualitative criteria are measured with descriptors (e.g. plus or minus signs). The structure is normally based on a hierarchical tree with three branches, representing objectives, criteria and indicators. Each score in the table represents the performance of each alternative for each criterion. When criteria are measured in different scales, then the relevant scores need to be standardised.

Standardisation can be carried out by utilising appropriate methods among which very popular are value functions that provide the involvement of decision makers. Value functions, which are basic elements of the so called value focused thinking [84], are mathematical representations of human judgement. These functions translate the performances of the alternatives into a value score, i.e. the degree to which a decision objective is achieved. The value is a dimensionless score between 0 and 1. Usually a value of 1 indicates the best available performance while 0 indicates the worst performance. Beinat [15] suggest several methods for defining values functions. There are linear and non-linear value functions that can be distinguished as cost and benefit functions. For a cost, the higher the value of the criterion, the worse it is, whereas for a benefit, the higher

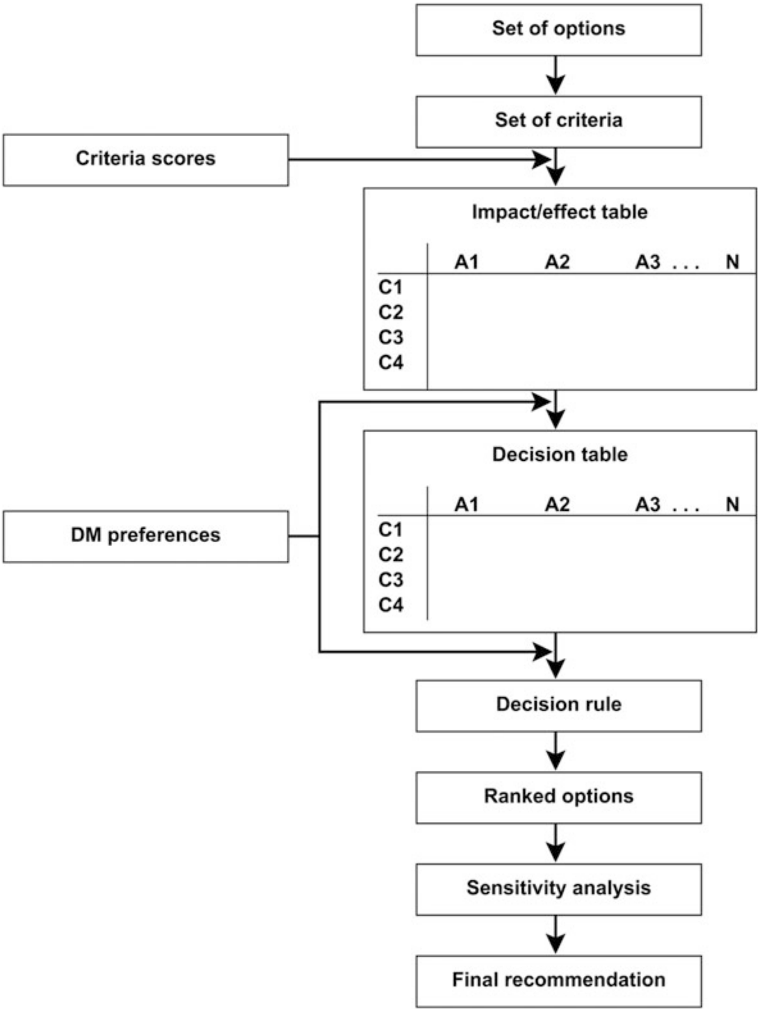


Fig. 5.3 General model of MADM (Adapted from [134])

the value the better. The result of standardisation is the so-called decision table. In addition to standardisation, this phase involves establishing a prioritisation scheme for the objectives and criteria depending on the importance that the decision maker assigns to each of them. Importance is expressed in terms of weights (or weight vectors) associated with a criterion set. Weights are very important because they can differ greatly between decision makers and even more between stakeholders involved. Priority information is established through weighting methods. The most common methods are divided into three categories: direct assessment, rankings methods and pairwise comparison. A detailed description of these methods is also given in Malczewski [106] and Sharifi et al. [134]. No perfect method exists to be used under all conditions. In addition, a critical factor for assigning weights in some problems is the range of attribute values that should be taken into account [15, 56, 156].

Afterwards, the overall performance of each alternative for all criteria is calculated by applying a decision rule. Decision rules comprise the evaluation method followed in order to rank alternatives, i.e. the utilisation of an aggregation method so that a unique preference structure can be derived for the whole set. Three such methods are dominant: compensatory methods, outranking methods and non-compensatory approaches. Compensatory methods are the most popular. They include the multi-attribute value theory (MAVT), the weighted summation, the ideal point method and the analytical hierarchy process (AHP). These kinds of methods are appropriate when all criteria are quantitative, although AHP may be applied with qualitative criteria as well. The simplest and most popular method is called weighted summation that involves multiplying weights with the standardised scores and then summing them up for each alternative. Overall performance results in a ranking of alternatives from best to worst. However, before reaching a final recommendation, a sensitivity analysis needs to be carried out to ensure the robustness of ranking under various sources of uncertainty.

Both the land fragmentation model and the land redistribution evaluation model are developed based on the MADM.

5.3.3 Multi-Objective Decision Making

In contrast to MADM which has a discrete search space, MODM is a design process with a continuous search space looking for the best solution among an infinite number or a very large set of feasible alternatives, which can be found anywhere within the feasible region. In a MADM problem the feasible alternatives are explicitly known, but in a MODM problem they are only implicitly defined. The difference between MADM and MODM is not only the way the decision alternatives and the attribute-objective relations are specified, but also that they use different decision rules. MADM are based on the assumption that the attributes serve as both decision variables and objectives. There is a one-to-one relationship between an objective and its underlying attribute; that is, each objective is measured by means of a single attribute. MODM make a distinction between the concept decision variables and decision criteria.

The MODM approach provides a framework for designing a set of alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions. The alternatives within MODM are found within the set of feasible solutions. This set is defined by a set of decision variables and is limited by a set of constraints imposed on the decision variables. In mathematical terms, a multi-objective decision problem can be formulated as follows:

$$Min.\,f(x)(\text{minimise or maximise function}) \tag{5.1}$$

subject to constraints:

$$g_j(x) \geq 0 \quad j = 1, 2, \ldots, n \text{ (inequality constraint)} \tag{5.2}$$

$$h_k(x) = 0 \quad k = 1, 2, \ldots, n \text{ (equality constraint)} \tag{5.3}$$

$$x_i^L \leq x_i \leq x_i^U \quad i = 1, 2, \ldots, n \text{ (variables upper } (U) \text{ and lower } (L) \text{ bounds)} \tag{5.4}$$

$$\text{where, } x = (x_1, x_2, \ldots x_n) \text{ is a vector of decision variables} \tag{5.5}$$

The *land partitioning process* is a design/optimisation problem which falls into this category since it has a large search space and an infinitive number of alternatives.

5.3.4 MCDM Cases Studies

There is a vast body of literature regarding the integration of MCDM with GIS to form either a SDSS or PSS. Carver [27] is one of the earliest relevant works and one of the most widely cited in the literature. Malczewski [107] carried out a survey in order to classify 319 GIS-MCDM articles published between 1990 and 2004. It is remarkable that 70 % of these were published during the last five years of the study period, which reveals the increasing interest in decision analysis methods regarding spatial problems. This is most likely due to the incorporation of MCDM functions in proprietary GIS packages (e.g. IDRISI and ILWIS) or other related multi-criteria evaluation (MCE) software. In addition, another finding of that survey showed the great diversity of problem domains to which GIS and MCDM are applied. In particular, the most popular application domains are environment/ecology, transportation, urban and regional planning, waste management, hydrology/water resources, agriculture, forestry, natural hazards, etc. Further classification of the case studies surveyed indicated that 69 % of them concerned the integration of GIS and MADM and 31 % involved the integration of GIS with MODM.

5.4 Expert Systems

5.4.1 Background

An *expert system* (also known as a knowledge based system or knowledge based expert system) is a computer system that is able to represent and reason with knowledge, aimed at solving a specific well defined problem domain that would ordinarily require human expertise [49, 75, 146]. In other words, such a system attempts to emulate the decision-making ability of a human expert in a specific task of knowledge [63, 111, 117]. Expert systems (ES) are one of the earliest, traditional, most important and successful applications of artificial intelligence [63, 121]. Although the foundation of expert systems was identified around the late 1950s and early 1960s in academia, increased commercial interest began in the 1970s with an impressive boom in the 1980s to early 1990s spreading to a wide range of domains. Some of the problem areas addressed have been: interpretation, prediction, diagnosis, design, planning, monitoring, etc.

The benefits provided by ES technology are tremendous. Turban [146], Giarratano and Riley [63], Padhy [121] and Negnevitsky [117] list many of them including: increased productivity since ES can work faster than humans and as a consequence reduce downtime by giving speedy responses at all times under even hazardous environments for a human; increased quality, reliability and transparency by providing consistent, permanent, steady, unemotional advice and reducing error rates; capture of scarce and expensive expertise to provide access to non-expert personnel to solve problems that would otherwise require expertise; flexibility in terms of diversity of potential applications since it may support any narrow problem domain that involves knowledge; ability to work with incomplete or uncertain information in contrast to conventional systems; capability to be utilised as a training tool and an intelligent tutor for less experienced personnel by proving an explanation facility for justifying reasoning of decisions made to be understandable; integration with other computerised systems such as MIS, GIS etc.; ability to solve complex unstructured or semi-structured problems that involve single or multiple human decision making.

Despite the above benefits, ES have some limitations that have led to their decline since the 1990s. In particular, Giarratano and Riley [63] note that a practical limitation of current ES is the lack of causal knowledge and their natural cognitive limits [146]. Namely, an ES does not really have an understanding of the causes and effects in the system, so as to be self-adaptive in current circumstances or self-learning through the process of reasoning. This is an inherent weakness of ES since they are based on 'shallow knowledge', i.e. empirical and heuristic knowledge rather than 'deep knowledge', which is based on the structure, function and behaviour of objects. In addition, the process of knowledge acquisition (the gathering and transferring of human knowledge into the system) is considered by most researchers as the major obstacle preventing the building of ES. Furthermore, the fact that such systems are focused on narrow problem domains limits their general capabilities and increases the construction cost, but it increases the quality of the performance.

Based on the above weaknesses, ES have received criticism by authors of various disciplines [86, 120, 129]. In contrast, Giarratano and Riley [63] and Noran [118] argue that, despite the presence of limitations, ES have been very successful in modelling real world decision-making problems, which conventional programming techniques are unable to handle. In the same vein, Liao [97] found that, in the period 1995–2004, 166 articles from 78 academic journals related to ES applications indicating the current power of ES methodologies, which is based on their ability to continually change to meet new requirements.

As illustrated in Fig. 5.4, a typical ES consists of three main components: the *user interface*, which is responsible for the communication between the system and the user; the *knowledge base*, which contains the knowledge about a problem domain and the *inference engine*, which carries out the reasoning for reaching a solution. The user provides the system with facts. Facts include information regarding the problem in the form of a database, user preferences in the form of answers given to the system's questions and any other relevant information. Then the inference engine (or control mechanism), which is the brain of the system, links the knowledge base with the supplied facts to draw conclusions, which are then sent back as expert advice or expertise to the user via the user interface.

In addition to these basic components, an ES may also provide an *explanation facility*, which is able to justify the reasoning for reaching a decision; and a *knowledge acquisition facility,* which offers an automatic way for the user to enter knowledge in the system rather than having the knowledge engineer explicitly code the knowledge. Knowledge (in the knowledge base) may be represented in several ways [151], some of which are: *rules* (or otherwise production rules) and hence they are called rule-based systems, semantic nets, frames, script logic, conceptual graphs and others [63, 146].

The choice of an appropriate method depends on the nature of the problem concerned [113]. In particular, it depends on the pre-existing format of the knowledge, the type of classification desired and the context dependence of the

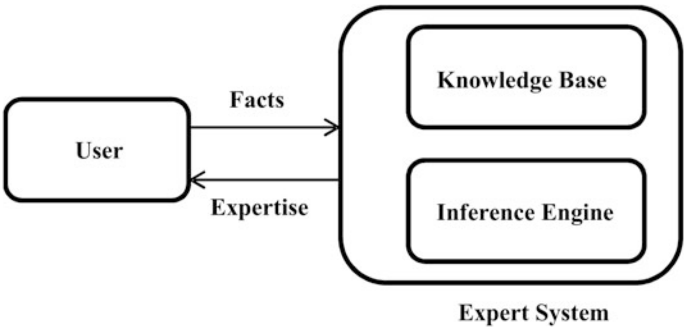


Fig. 5.4 The basic components of an ES (adapted from [63])

inference process [111]. It is accepted that rules are the most popular representation technique used for ES [63, 111]. The main reasons are two: First, rules are a very simple form of representation, which is very close to the cognitive behaviour of people when they make decisions for many cases, both simple and complex. Second, rules provide a flexible way of building knowledge. In particular, knowledge can be built incrementally, i.e. rules in a knowledge base can be gradually added once a new piece of knowledge emerges. In this manner, the performance and the validity of the system can be continually verified [63]. Moreover, rules facilitate inference and explanations, modifications and maintenance and the incorporation of uncertainty. For the two main reasons noted earlier, it was decided that the land redistribution Design module would be a rule-based system, i.e. knowledge is represented in the form of condition-action pairs:

> **IF** this condition (or premise or antecedent) occurs **THEN** some action (or results or conclusion, or consequence) will or should occur. For example,
>
> **IF** the total area of the property of a landowner is less than a minimum area limit defined by the LCC **THEN** the landowner will not receive property in the new plan and he will receive pecuniary compensation and his/her property will be allocated to other landowners.

Inferencing with rules is carried out based on two search mechanisms: *forward chaining* and *backward chaining*. Forward chaining is a data or event-driven approach, which is used when data or basic ideas or events are a starting point. In other words, it is bottom-up reasoning, since it reasons from low-level evidence, i.e. facts, to the top-level conclusions, which are based on these facts. This approach is usually used for data analysis, design and concept formulation [111]. Moore [113] notes that this method is appropriate for representing 'What if?' scenarios, i.e. a standard operation of spatial planning processes. Clearly, the land redistribution process, as it has been described in Sect. 4.2.2, it is a forward chaining problem. On the other hand, backward chaining is a goal-driven approach, which starts with a goal (a hypothetical solution) and searches for rules that will provide the evidence to support it. This approach is appropriate when the solution to the problem concerned involves reaching a unique fact/goal through inferencing.

In a forward chaining system, the process runs as follows: Initially, the inference engine searches the conditional parts of rules, i.e. the left hand side (LFS) of a rule, to determine if the input facts are satisfied using a rule control strategy such as the algorithms of Markov and Rete [63]. A rule whose conditional part is satisfied is said to be *activated* or *instantiated* and is put in a list called an *agenda*. If there is more than one activated rule, then they form a *conflicting set of rules*. However, in this case the system must select only one rule for execution (or firing). The process that the inference engine uses to give priority to a rule, when there are multiple rules that are activated at once, is called a *conflict resolution strategy*. Available conflict resolution approaches have been reviewed by Padhy [121] and Jackson [75]. The result of firing a rule is the execution of the THEN part of the rule (i.e. the rights hand side—RHS), which involves some actions or conclusions and which may create new facts. This cycle is repeated until all of the possible information has been extracted from facts and rules and the system reaches the final result. A similar procedure with converse logic is followed for backward chaining.

The available software for developing ES can be divided into three main categories [50, 63, 75, 121, 146]. First, are expert system shells, that is, a specific purpose tool with a user friendly environment which provides the basic components of an ES (inference engine, explanation facility, user interface etc.) except the knowledge base which should be built by the developer. Shells are the most popular tools for developing ES. There are many commercial ES shells such as EXSYS, XpertRule, EMYCIN, Nexpert, etc. Secondly, high level programming languages such as LISP, OPS5, PROLOG, etc. and thirdly, knowledge engineering tools (or environments) that involve a language plus associated utility programs to facilitate the development, debugging and delivery of knowledge based application programs. Examples of popular tools are CLIPS, KEE, ART, etc.

The above tools comprise the classical software for ES development, but they are mainly appropriate for stand-alone ES, rather than for hybrid systems, which may require the use of conventional programming languages as well. The latter can also be used to build ES from scratch, which involves a difficult and inefficient task. The selection of the most appropriate and efficient tool for developing an ES is a crucial matter which is discussed later in Chap. 8.

5.4.2 Spatial Expert Systems

It has already been noted that spatial decision making is a complex process. GIS have been the traditional tool for supporting this process. Thus, it is reasonable that the use of ES in solving spatially related problems is focused on its integration with GIS. Moore [113] notes that the synergy between the two technologies has lagged behind for many reasons compared to the use of ES in other disciplines such as business, manufacturing and medicine. However, this is logical because ES, as well as DSS, were initially developed to support management decisions and then other disciplines followed. Thus, attempts for integrating ES and GIS had begun in the early 1980s, a period marked by a boom of interest in ES applications for a wide range of disciplines.

The majority of views regarding the contribution of ES from a geographical perspective are positive. In particular, the advantages of integrating ES with GIS have been recognised by several authors [6, 26, 53, 55, 80, 82, 98, 104, 113, 128, 160, 170]. For example, Fisher [55] notes that GIS without intelligence have a limited chance to effectively solve spatial decision support problems in a complex or imprecise environment. Thus, there is no doubt that ES would be an integral part of any intelligent GIS [78]. In addition, Zhu and Healey [170] support the idea that the synergy of ES and GIS provides a great potential for solving ill-structured spatial decision-making problems. The need for integration is also pointed out by Leung [94], who notes that any intelligent spatially based system should possess knowledge and an inference mechanism for reaching decisions, and that ES remain a powerful technology. On the other hand, Openshaw and Openshaw [120] and Durkin [49] argue that despite great efforts in constructing ES with a geographical scope and in particular in integration with GIS, it appears that only 1 % of such systems are currently in operational use.

Since the 1980s, when the interest began for the integration of GIS and ES for solving spatial problems, a plethora of applications were developed. This was followed by a decline in interest in the 1990s [129] because of the ambiguousness of their power, especially for solving these kind of problems. Several of these studies were carried out after 2000. Specifically, Jun [80] developed an intelligent GIS for multi-criteria site analysis. Chuenpichai et al. [30] developed an integrated system for land development. Choi [29] developed a knowledge-based GIS for aerial photograph interpretation. Kalogirou [81] integrated GIS and ES for land suitability analysis. Sekkouri and Ouazar [132] developed an intelligent spatial data preparation system for groundwater modelling. Vlado [155] developed a knowledge-based GIS for site suitability assessment. Filis et al. [54] built an integrated geographical expert database system. Eldrandaly et al. [51] developed a COM-based SDSS for industrial site selection. Yeh and Qia [164] proposed a component based approach in the development of a knowledge based PSS. Eldrandaly [52] developed a COM-based expert system for selecting the suitable map projection in ArcGIS. Jin et al. [79] outline the development of GIS-based ES for site storm water management. Wilcke et al. [159] built a GIS-based ES for land-use planning. McCarthy et al. [110] constructed a GIS-ES for hazard monitoring.

All the above studies reveal that despite the disappointments of ES, they are still 'alive' and their integration capabilities with GIS offer great potential, at least in the appropriate problem domains. The great evolution of geospatial technologies in the 2000s has contributed to a reinvigoration of interest in the creation of fully integrated Expert GIS to solve spatial problems. Furthermore, ES' ability to change (e.g. fuzzy expert systems, object oriented expert systems etc.) and obtain new understanding, gives them extra power and prospects [97].

An important issue raised in several studies is how to integrate GIS with ES [55, 74, 80, 98, 99, 135, 164, 170]. Based on the relevant literature, there are three main possible integration models: *loose coupling, tight coupling and full integration*. In particular, in loose coupling, the GIS and the ES are two separate applications. Communication is possible via data exchange from one system to another. Advantages include improved synergy, ease of system development and simplicity of design. The main disadvantages are: the reduction in speed of operations; the limitation that data exchange files should be in a specific format; and poor overall system maintenance. In tight coupling (or close coupling) the ES can work as a shell of the GIS or vice versa. Systems are separate independent modules. The main system calls the other and then control is returned back to the main application. There is only virtual seamless integration. Communication is accomplished by direct parameter or data passing. This integration model is practical when a small subset of the functions of the called module is needed. Advantages include improved run-time operation, retention of modularity, flexibility in design and improved robustness. Disadvantages are increased development and maintenance complexity, redundant parameters and data processing and issues of system validation and verification.

In full integration, both systems share data and knowledge representation, offer communication via their dual structure and allow cooperative reasoning. With this integration model, interactive exchange between system elements is done in real time and in a seamless way without user interaction. Advantages include robustness and improved problem solving potential. System development and operation are contained in one common environment, which results in better design and implementation of the overall application. Also, a more uniform user interface and reduced system maintenance can be achieved. A main disadvantage is the increased development time and complexity, validation and verification issues, and maintenance compatibility.

It is clear from a review of the literature that the selection of the appropriate systems integration model depends on the specific application requirements and the available resources (time, budget and skills). The land redistribution Design module uses the full integration approach via a common GIS environment.

5.4.3 Is the Land Redistribution Problem Appropriate for Expert Systems?

This is probably the most important question to be asked for an ES project. The literature suggests that ES are effective for solving only certain problem domains. However, Openshaw and Openshaw [120] note that, in general, any geographical problem which involves the application of well-defined skills that require expert knowledge may be solved by ES. Giarratano and Riley [63] define five critical questions that are addressed and answered below:

*Q*1. *Can the problem be solved effectively by conventional programming?*

If the answer is yes, then an expert system is not the best choice. As noted ES are best suited for situations in which there is no efficient algorithmic solution. Such cases are ill-structured problems and semi-structured problems for which reasoning may offer the only hope of a good solution.

A1. As discussed in Sect. 4.4, almost all related works that have attempted to solve the problem of land redistribution have the common characteristic of handling the problem as a mathematical optimisation problem, using strong algorithmic approaches which are appropriate for structured problems; hence the results are not realistic. In contrast, it has been acknowledged that land redistribution is a semi-structured decision-making problem, which is based on legislation, rules of thumb and expert knowledge that fits an ES approach.

Q2. Is the problem domain well defined?

It is very important to have a well bounded problem domain so it is clear what the system is expected to know and what its capabilities will be.

A2. Land redistribution is a narrow problem domain with well-defined and explicit outcomes because it is bounded by a great number of principles noted in Sect. 4.3.

Q3. Is the problem solving knowledge heuristic and uncertain?

The expert knowledge may be a trial-and-error approach rather than based on logic and algorithms. If the problem can be solved simply by logic and algorithms, it is better to use conventional programming.

A3. As already explained, land redistribution is a process based on heuristics (legislation, rules of thumb, experience) with clearly defined data but with many alternative solutions, which may depend on the experts' strategy to solve the problem.

Q4. Is there a need and a desire for an expert system?

A4. The demand for such system has been discussed and proved in Chap. 4.

Q5. Is there at least one human expert who is willing to cooperate and is he able to transfer the necessary knowledge?

A5. Yes, as the author is an expert with 15 years of expertise about land consolidation. However, since experts may use different practices to solve the problem (hence, decisions taken may be different), knowledge should be gathered by more than one expert to ensure that it reflects as much as possible the decision-making practices used by the organisation.

These answers indicate that the land redistribution problem fulfils the criteria to be solved using ES.

5.4.4 Development Methodology

Several researchers have proposed various ES development approaches, which are mainly based on the classical waterfall model of the software life cycle [63, 111, 121, 146]. According to Giarratano and Riley [63], a life cycle model that has been successfully used in a number of ES projects is the Linear Model. However, this model is usually used for large commercial ES. For small research type prototype ES, which are not intended for general use, not all the tasks or stages are necessary [63, 146]. Thus, once a problem domain has been defined and analysed, the Linear Model can be condensed into the following three main stages: First, s*ystem design* that is comprised of five tasks: system definition, knowledge acquisition, knowledge representation, knowledge base building and the definition of the following: facts (system inputs), control process, system outputs. Secondly, s*ystem development*, which involves selection of the appropriate development tools, definition of the implementation strategy and the coding/debugging, and thirdly, s*ystem evaluation*, which involves system verification and validation using a case study. The development of the land redistribution model (Chap. 8) follows the latter methodology.

5.5 Genetic Algorithms

5.5.1 Classical Optimisation Methods

Optimisation is a search procedure for finding and comparing feasible solutions of a problem, until no better solution can be found [35]. The optimisation task can be split into seven main steps: identify problem parameters, choose design variables from parameters, formulate constraints, formulate objective function, set up variable bounds, choose an optimisation algorithm and obtain results [36]. Goldberg [65] emphasises that optimisation means improvement of the performance of a system towards some optimal point and does not necessarily mean truly optimal. In mathematical terms, it involves the searching and of finding a set of decision variables that minimise or maximise one or more objective functions subject to satisfying a set of constraints.

Optimisation problems can be divided into *single objective* and *multi-objective* problems. As the terms suggest, the former involves an optimisation problem which has only one objective function and the latter an optimisation problem which has more than one objective function. An *objective function* is associated with a problem and determines how good a solution is. The task in single objective optimisation problems is to find one solution which optimises the sole objective. In contrast, in multi-objective problems having conflicting objectives, there is no unique solution which simultaneously optimises all objectives. Thus the resulting outcome is a set of optimal solutions with a varying degree of objective values that are based on the trade-off between the various objectives. These solutions are called *Pareto optimal solutions*. Many real world problems from various disciplines fall in this category. Some of them are the optimal engineering design and manufacturing, scheduling and planning, forecasting and prediction, machine learning data mining, etc. Land partitioning falls within this category of problems as well.

There exist many algorithms and applications involving multiple objectives. However, the majority of these applications avoid the complexities involved in a true multi-objective optimisation problem and transform them into a single objective function by using some user defined parameters (weights). In fact, in these studies, multi-objective optimisation is considered as an application of a single objective optimisation for handling multiple objectives [34]. A plethora of search and optimisation methods have been developed to tackle single and multi-objective optimisation problems. The oldest methods have been around for more than 40 years and are referred to as classical (or conventional) methods to distinguish these from newer methods such as evolutionary algorithms.

The common features of most classical methods are that they use a single solution updated during each iteration and a deterministic transition rule for approaching the optimum solution. Thus, the search uses local information to find the best possible solution until it reaches an optimal one. Goldberg [65] and Deb [34] note that classical methods are not robust and efficient for many practical problems: the convergence of an optimal solution depends upon the initial solution; they have a local scope in terms of optimal; they are not efficient for problems with discrete search spaces; every classical algorithm is designed to solve a specific problem and it may not be applicable to a different problem; they are not efficient in solving non-linear, complex problems with large search spaces and many conflicting objectives; they cannot be used in a parallel machine since they use a point by point search to arrive at the optimal solution. These disadvantages suggest the need to find more efficient optimisation methods which may alleviate most of the weaknesses of classical methods. Such methods are evolutionary algorithms, and in particular genetic algorithms.

5.5.2 Classical Genetic Algorithms

GAs were invented by John Holland and developed by him and his students and colleagues in 1975. GAs are a class of stochastic optimisation technique called *evolutionary algorithms* (or evolutionary computation methods), which also combine evolutionary strategies and evolutionary programming. They are all inspired by the Darwinian theory of evolution. It is accepted that GAs are computerised randomised search and optimisation algorithms that are capable of evolving optimal or near optimal solutions [35, 65, 120, 121, 153].

These algorithms attempt to simulate natural evolution. Specifically, the standard process of a GA involves: creating a population of individuals (candidate solutions of the problem); evaluating their fitness using an objective function; generating a new population by selecting and mating individuals and repeating this process a number of times (or generations) until finding the optimum solution [117]. They are very popular with a widespread applicability, because they often outperform classical methods, especially in real world problems due to their global perspective and inherent parallelism [121]. GAs use highly specialised terms, most of which have been borrowed from natural genetics.

In particular, classical GAs manipulate *individuals* (data structures), which are like living organisms, that undergo a set of changes and transformations as they evolve through time. Each individual contains information about its properties, like genetic material, in one or more *chromosomes*. Chromosomes are strings of information that represent DNA and serve as a model for the whole organism. A chromosome consists of genes which are represented as bits of strings usually coded in the binary system, representing blocks of DNA. A *gene* is a part of a chromosome responsible for one feature of the individual. Each gene encodes a particular trait, which defines a characteristic of the organism. The values of a trait are called *alleles*. Also, each gene has its own position in the chromosome called a *locus*. A set of individuals comprise a *population*.

Furthermore, *fitness* is a measure of the individual in terms of satisfying the objectives of the algorithm and is represented via an *objective function*. The *generation* is one evolutionary cycle. The parent population is a set of individuals of the current generation and the offspring (or child) population is a set of individuals of the next generation. *Evolutionary operators* are transformation processes which take place during evolution and they are applied to genes, and hence to chromosomes and eventually to individuals. The most significant evolutionary operators are *selection*, *crossover* and *mutation*. *Selection* is the process of choosing couples of individuals from a population for crossover. *Crossover* is the process of mating two individuals (i.e. parents) by exchanging genetic material (i.e. genes) to create a new individual (i.e. an offspring). *Mutation*, which is rare in nature, involves a random change to the genetic material (i.e. to the gene) of an individual. *Initialization* is the process of randomly generating an initial population of individuals. Crossover and mutation operators are applied according to specified probabilities (Pc and Pm). Probabilities represent the rate that an operation is carried out. A *terminating function* is a function that defines the condition which terminates the evolutionary process.

Solving a problem with GAs begins with designing a proper problem representation. Although traditionally GAs are encoded using the binary string system (i.e. 0 and 1), many other representations are utilized to satisfy the requirements of a variety of problems. Further to binary coding, real and integer number coding are used. In addition, genes may represent arrays, trees, lists etc. [121]. It is highly important to use the most appropriate representation scheme for a given problem. Another important element of the problem is defining a cost function (to be minimized or maximized), which contains the problem variables and the potential constraints. Similarly, the proper definition of the objective function is of great importance for finding optimal solutions.

Furthermore, before running the algorithm, an initialization method for generating the initial population must be established followed by a method for selecting individuals from the population. For GAs to perform well, the initial population needs to be diverse [73]. Commonly, the initial population is generated using an appropriate random method for the problem concerned, which may require some design. Then, a selection method needs to be defined for selecting members from the population for mating. Some of the most popular methods are: *tournament selection*, *roulette wheel selection*, *ranking selection* and *elite selection*. Each of these methods has advantages and disadvantages, which need to be carefully considered before deciding upon which one to use for a particular problem domain.

There is no mathematical proof for guaranteeing the convergence of a GA; hence it is very difficult and often impossible to predict the behaviour of a GA, especially on a specific problem in a complex, highly nonlinear domain. However, the theoretical foundation (in the case of binary coding) of the success of GAs is based on the *Schema Theorem* which shows that the performance of a GA depends strongly on the combination of similarity templates (i.e. schemata) among a population of strings. In particular, GAs iteratively search for schemata with better fitness by biasing the sampling in every new generation [65].

GAs have been used widely and successfully for a variety of optimisation problems [127] and their superiority in solving complex and ill-structured problems has been widely recognised [169]. However, they have many limitations, most of which are discussed by Openshaw and Openshaw [120] and Turban et al. [147]. Nevertheless, GAs are recognised as a powerful tool that should be applied in a careful and intelligent manner [120].

5.5.3 Spatial Genetic Algorithms

GAs have already been used in spatial problem domains since the 1980s, e.g. in location modelling, spatial interaction modelling, suitability modelling, aggregation, data mining, generalization of spatial data, display of continuous data, etc. It seems that a positive trend has developed during the last decade towards the development of spatial evolutionary models, some of which have been integrated in a GIS environment. In particular, Brooks [23] employed a raster based GA for site allocation and optimal patch configurations, respectively. In addition, Matthews et al. [109] used GAs for land use planning. Similarly, Jha et al. [77] used GAs for highway developments. Delahaye [37] used GAs for air space sectoring. Hamda and Schoenauer [69] used GAs for topological optimum shape structure design. Van Dijk et al. [153] presented a framework for solving hard problems in GIS using GAs. Renner and Ekart [127] used GAs for computer aided design. Bennett et al. [16] developed a technique based on a GA to obtain optimal solutions to a large class of land management problems. Zhang and Armstrong [168] used GAs to generate alternatives for multi-objective corridor location problems. Stewart et al. [138] used a GA approach for multi-objective land use planning. Similarly, Bacao et al. [8] applied a GA for zone design. Li and Yeh [95] integrated GAs and GIS for optimal location search in urban applications for sitting facilities. Datta et al. [32] applied a multi-objective GA to a land use management problem. Wyatt and Hossain [163] developed a GIS based software package that incorporates a GA to optimize crop distributions across a region.

Krzanowski and Raper [91] and Van Dijk et al. [153] note that spatial problems are particularly suited to these approaches and they should be an integral part of a GIS toolbox. Specifically, Krzanowski and Raper [91] introduced the term ‘spatial evolutionary models’ as a separate, distinct class of computer evolutionary models and developed a general framework for developing spatial evolutionary models, which is used here in developing the land partitioning module. These evolutionary models possess unique rules governing their behaviour, a unique genome design to represent a model specific data structure, a set of unique operators that cannot be readily applied in non-spatial problems and a problem specific language.

5.5.4 Are GAs Appropriate for Solving the Land Partitioning Problem?

This question does not have a definitive answer but the following evidence suggests that GAs may be able to solve this problem. In particular, Banzhaf et al. [11] summarised the following types of problems for which EAs are potentially suitable: the interrelationships among the relevant variables are poorly understood; finding the size and shape of the ultimate solution to the problem is a major part of the problem, which is exactly the land partitioning problem; conventional mathematical analysis does not or cannot provide analytical solutions; an approximate solution is acceptable or is the only result that is ever likely to be obtained; small improvements in performance are routinely measured and highly prized; there is a large amount of data, in computer readable form, which requires examination, classification, and integration. All these characteristics (except the fifth) are true of the land partitioning problem. This enhances the view that this problem has great potential for being solved using GAs.

A second piece of evidence is that, unlike classical (and strong) optimisation methods, evolutionary methods which are considered as weak optimization methods, are not problem specific. As a result, they have been proven to be very efficient in solving complex, non-linear, multi-objective optimisation problems in a large search space which are the characteristics of the land partitioning problem whilst classical methods have not been able to solve this problem due to the following four fundamental differences between them [65]: GAs work on a coding of parameters instead of parameters, and thus they exploit the coding similarities to achieve a parallel search; GAs work on a population of points instead of a single point and hence they are likely to find global solutions; GAs do not require any derivative or auxiliary information and hence the application of GAs to a wide variety of problem domains is possible; GAs use probabilistic transition rules instead of deterministic transition rules and thus the bias in the search is reduced. Moreover, a third piece of evidence is provided by Openshaw and Openshaw [120] who note that GAs work well enough for many geographical problems, and they are especially robust and reliable for non-linear optimization problems that previously could not be solved at all.

5.6 The Development Framework of LACONISS

5.6.1 The Conceptual Framework

The name of the system under development is LAnd CONsolidation Integrated Support System (LACONISS), which is based conceptually on the planning and decision-making framework illustrated in Fig. 5.2, which has been modified to fit the process of land reallocation as shown in Fig. 5.5. The *Intelligence phase*

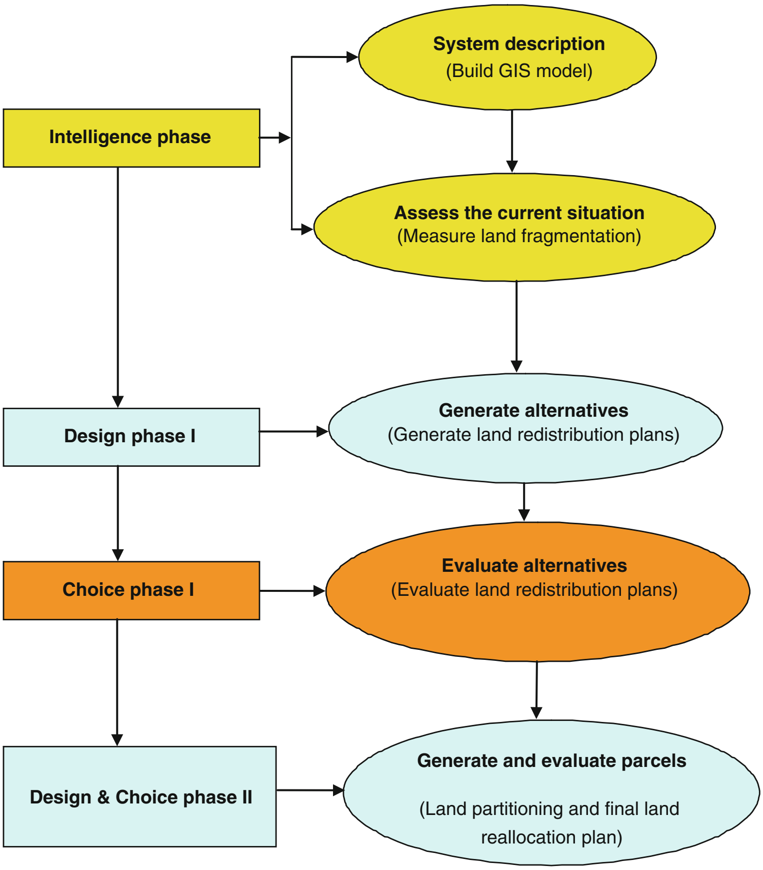


Fig. 5.5 The conceptual framework of LACONISS

includes system representation by building a GIS model and assessing the current system situation to identify if land fragmentation is a problem requiring a solution, i.e. land consolidation. When the planners' decision is to continue with land consolidation, the reallocation process begins. In particular, *Design phase I* involves the generation of alternative land redistributions. These alternatives can then be evaluated in the *Choice phase I* to identify the best land redistribution plan. Afterwards, this plan is passed to the dual *Design and Choice II* phase, which generates the new parcels and hence the final land reallocation plan.

5.6.2 The Operational Framework

Based on the conceptual framework noted earlier, the operational framework of LACONISS is illustrated in Fig. 5.6. LACONISS consists of three sub-systems:

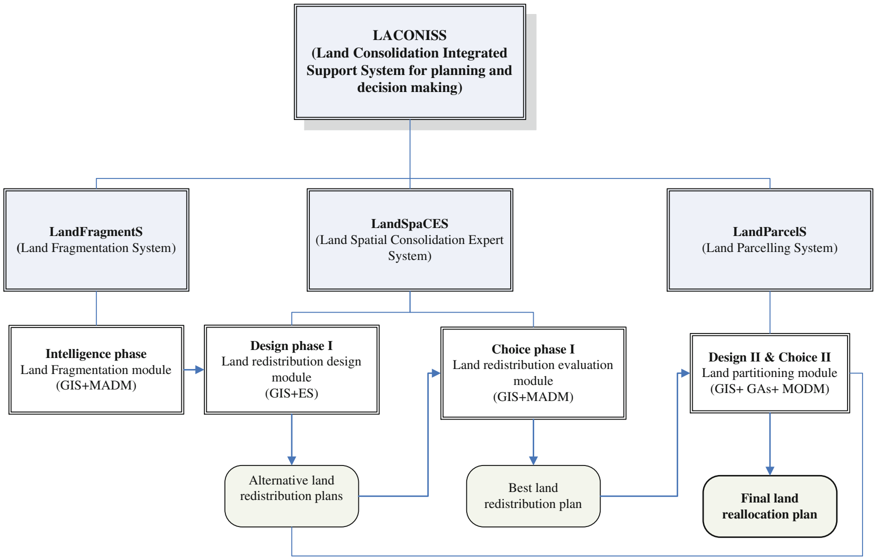


Fig. 5.6 The operational framework of LACONISS

LandFragmentS (Land Fragmentation System); LandSpaCES (Land Spatial Consolidation Expert System); and LandParcelS (Land Parcelling System). LandFragmentS [42, 45] represents the 'Intelligence phase' of the process and involves a new land fragmentation module that is capable of measuring the extent of land fragmentation on a scale from 0 (worst) to 1 (least) by analysing the current status of the land tenure system. LandSpaCES contains (1) a new land redistribution Design module [39, 40] that employs an expert system (ES) to automatically generate alternative land redistribution plans ('Design phase I') and (2) a new land redistribution Evaluation module [41, 44] that uses multi-attribute decision-making (MADM) methods to evaluate these alternative plans and identify the one which is the most beneficial ('Choice phase I'). The final output from LandSpaCES is then transferred to LandParcelS [43], which is capable of automatically designing the new parcels in terms of shape, size and land value by integrating a genetic algorithm (GA) with multi-objective decision-making (MODM) methods ('Design and Choice phase II').

5.6.3 Development Methodology

Many methodologies have been proposed and used for the development of information systems and several authors have focused on GIS development [4, 68, 93, 145]. The most well-known are the waterfall model, ETHICS, Multiview etc., which are classified as socio-technical methodologies; and the organic life cycle, evolutionary delivery etc., which are classified as rapid development methodologies [126]. The aim of this research is to develop a prototype system with emphasis on exploring, designing and developing innovative methods and techniques for the problem domain and not on constructing a commercial software system or a system that will be formally implemented in an organisation. It is not appropriate to use a formal system development methodology but it is adequate to follow the basic stages (or sub-stages) met in most of methodologies, i.e. *problem analysis, needs assessment, system design, system development and system evaluation*. The first two stages have already been extensively discussed in Chaps. 2–4. Therefore, the other three stages will be separately followed for the development of each sub-system illustrated in Fig. 5.6.

The development platform is ArcGIS and the development tools are Visual Basic for Applications (VBA) and ArcObjects [25, 28, 48, 166, 167]. Visual Basic for Applications (VBA) is an object-oriented programming language which is embedded within ArcMap and ArcCatalog of ArcGIS [25]. It is a simplified version of Visual Basic 6 [131]. ArcObjects is the development platform for ArcGIS, which consists of a series of programmable objects. These objects are built using Microsoft's Component Object Model (COM) technology. Developing applications for ArcGIS requires knowledge of both VBA and ArcObjects. Figure 5.7 shows the LACONISS interface, which consists of four toolbars within ArcGIS corresponding to the four modules noted above and illustrated in Fig. 5.6.

5.6.4 System Aims

The general aim of LACONISS is to convert land consolidation planning into a systematic, automated, transparent and efficient process fully integrated in a GIS environment as illustrated in Fig. 5.6. As a result, the expected benefits are aimed

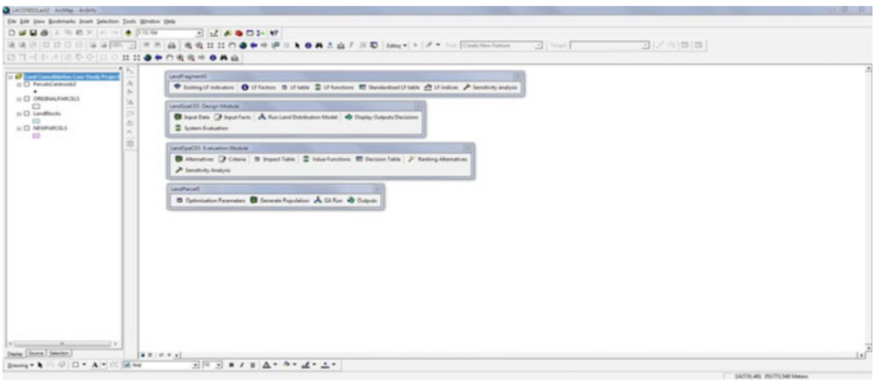


Fig. 5.7 The LACONISS interface

at alleviating the three main problems that confront land consolidation, which were discussed in Sect. 3.5.5, namely, the long duration of projects; the high operational costs; and the conflicts of interests between the stakeholders involved, which are all related to the land reallocation process. In particular, the system is designed to reduce the overall duration of the land reallocation process, which currently takes at least 6 months and may exceed one year, and therefore the overall operational cost. A reduction in the time needed to undertake the reallocation process will be achieved through automatically generating alternative land redistribution plans (LandSpaCES Design module), which can be easily evaluated via the LandSpaCES Evaluation module to find the most beneficial based on a set of criteria, which are then passed to LandParcelS. This latter module automatically generates the land partitioning plan that constitutes the final land consolidation plan. In this manner, the new system has the potential to drastically reduce the duration of the land reallocation process to days or even hours, depending upon the complexity of the project. It is clear that this translates to a considerable potential time and therefore cost savings.

As well as significant benefits in terms of reduced time and improved performance that follow from using an automated system, the quality of the decisions made will be enhanced since the system will be able to provide a large number of alternative solutions by simply changing the input variables and experimenting with ‘what if’ scenarios. This is in contrast to the current situation where the planner is only able to generate a small number of solutions. In addition, the capability to incorporate expert knowledge within the system will create a potential for preserving the valuable and expensive expertise of planners in computerized form, which can then be held in the system for transfer to younger, more inexperienced planners.

Furthermore, the new system will also be able to confront the problem of conflicts between the stakeholders involved since the transparency of the land reallocation process will be improved and the equity and trust among landowners will be enhanced by structuring the land reallocation plan in a systematic and standardised way. Although the system does not directly use the landowners’ preferences as inputs, they will be predicted (regarding the location of the new parcels) using the *PPI* (see Sect. 8.3.4), and the land redistribution process will therefore be carried out in a standard and fairer manner than is currently the case.

Moreover, further to the above, which refers to the system benefits that can be provided after a decision for applying land consolidation has been taken, the system may run (the modules noted above) before the decision has been taken and the outputs can then be used as an input to the ex-ante evaluation to predict land consolidation results and impacts, as discussed in Sect. 4.5.1. In addition, measuring existing land fragmentation quickly and reliably (LandFragmentS) can be a dominant element for deciding whether or not to apply land consolidation, which saves significant time compared to the semi-automated and manual methods currently utilised for analysing the existing land tenure structure.

5.7 Conclusions

This chapter has set out the operational framework of LACONISS after reviewing the methods, tools and techniques involved in the development process. The new system consists of three sub-systems that comprise four modules: the land fragmentation model (LandFragmentS); the land redistribution Design model (LandSpaCES Design); the land redistribution Evaluation model (LandSpaCES Evaluation); and the land partitioning model (LandParcelS), which correspond to objectives 3, 4, 5 and 6, respectively and which are addressed in Chaps. 7, 8, 9 and 10, respectively. The synergy of these models aims to alleviate the current problems faced by the land consolidation process. The literature review showed that GIS and MADM are appropriate for both developing the land fragmentation and the land redistribution evaluation models. Similarly, the review showed that GIS and ES are well suited for solving the land redistribution problem, and that GIS, GAs and MODM can adequately handle the land partitioning problem. Lessons learnt from existing spatial planning tools suggest both a deep investigation of the needs of the problem concerned and the involvement of domain experts including end-users in the development procedure as factors for success, both of which are taken into account in this research. Chapter 4 presents the case study area utilised for the development and evaluation of the aforementioned modules of the system.

References

1. Ackoff, R. (1981). The art and science of mess management. *Interfaces, 11*(1), 20–26.
2. Al-Shalabi, M., Mansor, S., Ahmed, N., & Shiriff, R. (2006). GIS based multi-criteria approaches to housing site suitability assessment. In: *Proceedings of the XXIII FIG Congress, Shaping the Change,* October 8–13, Munich, Germany. Available from URL: http://www.fig.net/pub/fig2006/papers/ts72/ts72_05_alshalabi_etal%20_0702.pdf.
3. Alshuwaikhat, H., & Nassef, K. (1996). A GIS-based SDSS for suitability assessment and land use allocation. *The Arabian Journal for Science and Engineering*, *21*(4A), 321–339.
4. Anderson, S., & Harmon, J. (2003). *The Design and Implementation of Geographic Information Systems*. New Jersey: Wiley.
5. Armstrong, P., & Densham, J. (1990). Database organisation alternatives for spatial decision support systems. *International Journal of Geographical Information Systems, 4*, 3–20.
6. Armstrong, D., Densham, P., Lolonis, G., Rushton, G., & Tewari, K. (1990). A knowledge-based approach for supporting locational decision making. *Environment and Planning B: Planning and Design, 17*, 341–364.
7. Ayeni, B. (1997). The design of spatial decision support systems in urban and regional planning. In H. Timmermans (Ed.), *Decision Support Systems in Urban Planning*. E & FN SPON, 3–22.
8. Bacao, F., Lobo, V., & Painho, M. (2005). Applying genetic algorithms to zone design. *Soft Computing, 9*, 341–348.
9. Baloye, D. O., Adesina, F. A., & Kufoniyi, O. (2010). A spatial decision support system approach to sustainable physical development planning. *Journal of Geography and Regional Planning, 3*(9), 219–233.

10. Banai, R. (2005). Land resource sustainability for urban development: spatial decision support system prototype. *Environmental Management, 36*(2), 282–296.
11. Banzhaf, W., Nordin, P., Keller, R. E., & Francone, F. D. (1998). *Genetic programming: An introduction*. San Francisco, USA: Morgan Kaufmann, Inc.
12. Batty, M. (1995). Planning support systems and the new logic of computation. *Regional Development Dialogue, 16*, 1–17.
13. Batty, M. (2008). Planning support systems: Progress, predictions, and speculations on the shape of things to come. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 3–30). Cambridge, MA: Lincoln Institute of Land Policy.
14. Batty, M., & Densham, P. (1996). *Decision support, GIS and urban planning*. University College of London, Centre for Advanced Spatial Analysis (CASA). Available from URL: http://www.acturban.org/biennial/doc_planners/decission_gis_planning.htm.
15. Beinat, E. (1997). *Value functions for environmental management*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
16. Bennett, D., Xiao, N., & Armstrong, M. (2004). Exploring the geographic consequences of public policies using evolutionary algorithms. *Annals of the Association of American Geographers, 94*(4), 827–847.
17. Bernhardsen, T. (2002). *GIS: An introduction* (3rd ed.). New York: Wiley.
18. Birkin, M., Clarke, G., Clarke, M., & Wilson, A. (1996). *Intelligent GIS: Location decisions and strategic planning*. Glasgow: Geoinformation International.
19. Boulding, K. (1975) Reflections on planning: The value of uncertainty. *Strategy and Leadership*, *3*(l), 11–12.
20. Brail, R. (2008). *Planning support systems for cities and regions*. Cambridge, Massachusetts: Lincoln Institute of Land Policy.
21. Brail, R., & Klosterman, R. (2001). *Planning support systems*. Redlands: ESRI Press.
22. Brim, O. G., Glass, D. C., Lavin, L. E., & Goodman, N. (1962). *Personality and decision processes: Studies in the social psychology of thinking*. Stanford, CA: Stanford University Press.
23. Brooks, C. (1997). A parameterized region-growing programme for site allocation on raster suitability maps. *International Journal of Geographical Information Science, 11*(4), 375–396.
24. Bui, T. (1999). Decision support systems for sustainable development. In G. Kersten, Z. Mikolajuk, & A. Yeh (Eds.), *Decision support systems for sustainable development: A research book of methods and applications* (pp. 1–10). Ottawa: International Development Research Centre.
25. Burke, R. (2003). *Getting to know ArcObjects*. California: ESRI Press.
26. Burrough, P. A. (1986). *Principles of geographical information systems for land resources assessment*. Oxford: Oxford University Press.
27. Carver, S. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems, 5*, 321–339.
28. Chang, K. (2005). *Programming ArcObjects with VBA*. Florida: CRC Press.
29. Choi, J. (2002). *A rule-based expert system using an interactive questions-and-answer sequence*. Department of Geography, University of Georgia, USA. Available from URL:http://www.ucgis.org/summer2002/choi/choi.htm.
30. Chuenpichai, K., Chuenpichai, S., & Somrang, A. (2002). GIS and expert system integration for land development village, Thailand. ESRI professional papers (Paper No.755). Available from URL: http://proceedings.esri.com/library/userconf/proc02/pap0755/p0755.htm.
31. Crossland, M., Wynne, B., & Perkins, W. (1995). Spatial decision support systems: An overview of technology and a test of efficacy. *Decision Support Systems, 14*, 219–235.
32. Datta, D., Deb, K., Fonseca, C., Lobo, F., & Condado, P. (2006). *Multi-objective evolutionary algorithm for land use management problem*. Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Report Number 2006005. Available from URL: http://repository.ias.ac.in/82720/1/1-a.pdf.

33. De la Rosa, D., Mayol, F., Diaz-Pereira, E., Fernandez, M., & De la Rosa, D. (2004). A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection: With special reference to the Mediterranean region. *Environmental Modelling & Software, 19*, 929–942.
34. Deb, K. (2001). *Multi-objective optimization using evolutionary algorithms*. West Sussex: Wiley.
35. Deb, K. (2008). *Optimisation. Lecture notes*. Finland: Helsinki School of Economics.
36. Deb, K. (2009). *Evolutionary computing methodologies for single and multi-objective optimization. Lecture notes*. Finland: University of Jyvaskyla.
37. Delahaye, D. (2001). Airspace sectoring by evolutionary computation. In R. Krzanowski & J. Raper (Eds.), *Spatial evolutionary modelling* (pp. 203–233). New York: Oxford University Press.
38. Demers, N. M. (2008). *Fundamentals of geographical information systems*. New Jersey, USA: Wiley.
39. Demetriou, D., Stillwell, J., & See, L. (2010). *LandSpaCES: A design module for land consolidation: Methods and application*. Working Paper 10/07. School of Geography, University of Leeds, p. 77. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/10-07.pdf.
40. Demetriou, D., Stillwell, J., & See, L. (2011). LandSpaCES: A spatial expert system for land consolidation. In S. Geertman, W. Reinhardt, & F. Toppen (Eds.), *Advancing Geoinformation science for a changing world* (pp. 249–274). Berlin: Springer.
41. Demetriou, D., Stillwell, J., & See, L. (2011). *A multi-attribute decision-making module for the evaluation of alternative land consolidation plans.* Working Paper 11/02. School of Geography, University of Leeds, p. 56. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/11-02.pdf.
42. Demetriou, D., Stillwell, J., & See, L. (2011). *The development and evaluation of a new model for measuring land fragmentation.* Working Paper 11/05. School of Geography, University of Leeds, p. 57. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/11-05.pdf.
43. Demetriou, D., Stillwell, J., & See, L. (2012). *LandParcelS: A module for automated land partitioning.* Working Paper 12/02. School of Geography, University of Leeds, p. 59. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/12-02.pdf.
44. Demetriou, D., See, L., & Stillwell, J. (2012). A spatial multi-criteria model for the evaluation of land redistribution plans. *ISPRS International Journal of Geo-Information*, *1*(3), 272–293.
45. Demetriou, D., Stillwell, J.,& See, L. (2013). A new methodology for measuring land fragmentation. *Computers, Environment and Urban Systems 39*, 71–80.
46. Densham, J. (1991). Spatial decision support systems. In J. Maguire, M. Goodchild, & D. Rhind (Eds.), *Geographical information systems: Principles and applications* (Vol. 1, pp. 403–412). London: Langman.
47. Densham, P. J., & Goodchild, M. F. (1989). Spatial decision support systems: A research agenda. In *Proceedings SIG/LIS'89* (vol. 2, pp. 707–716) Orlando, Florida.
48. Detwiler, J. (2007). *GIS programming and customization. Lecture notes*. USA: Penn State University.
49. Durkin, J. (1996). Expert systems: A view of the field. *Intelligent Systems and Their Applications, 11*(2), 56–63.
50. Durkin, J. (1998). Expert system development tools. In J. Liebowitz (Ed.), *The handbook of applied expert systems* (pp. 4-1–4-26). MA, USA: CRC Press.
51. Eldrandaly, K. (2003). A COM-based spatial decision support system for industrial site selection. *Journal of Geographic Information and Decision Analysis, 7*(2), 79–92.
52. Eldrandaly, K. (2006). A COM-based expert system for selecting the suitable map projection in ArcGIS. *Expert Systems with Applications, 31*, 94–100.

53. Eldrandaly, K. (2007). Expert systems, GIS, and spatial decision making: Current practices and new trends. In A. Tyler (Ed.), *Expert systems: Research trends* (pp. 207–228). New York: Nova.
54. Filis, I., Sabrakos, M., Yialouris, C., Sideris, A., & Mahaman, B. (2003). GEDAS: An integrated geographical expert database system. *Expert Systems with Applications, 24*, 25–34.
55. Fischer, M. (1994). From conventional to knowledge-based geographic information systems. *Computers, Environment and Urban Systems, 18*(4), 233–242.
56. Fischer, G. (1995). Range sensitivity of attribute weights in multi-attribute value models. *Organisational Behaviour and Human Decision Processes, 62*(3), 252–266.
57. Fischer, M., & Leung, Y. (2001). *GeoComputational modelling*. Berlin: Springer.
58. Geertman, S. (2008). Planning support systems: A planner's perspective. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 213–230). Cambridge, Massachusetts: Lincoln Institute of Land Policy.
59. Geertman S., & Stillwell J. (2000). *Geoinfomration, geotecnology and geoplanning in the 1990s*. Working Paper 00/01. School of Geography, University of Leeds, Leeds. Available from URL: http://eprints.whiterose.ac.uk/5027/1/00-1.pdf.
60. Geertman, S., & Stillwell, J. (2003). *Planning support systems in practice*. Berlin: Springer.
61. Geertman, S., & Stillwell, J. (2004). Planning support systems: An inventory of current practice. *Computers, Environment and Urban Systems, 28*(4), 291–310.
62. Geertman, S., & Stillwell, J. (2009). *Planning support systems: Best practice and new methods*. Dordrecht: Springer.
63. Giarratano, J., & Riley, G. (2005). *Expert systems: Principles and programming*. Canada: Course Technology.
64. Giupponi, C., Mysiak, J., & Fassio, A. (2004). Mulino DSS. User's Guide. Venice, Italy.
65. Goldberg, D. (1989). *Genetic algorithms: In search, optimisation and machine learning*. Crawfordsville: Addison Wesley.
66. Goonatilake, S., & Khebbal, S. (1995). *Intelligent hybrid systems*. Chichester: Wiley.
67. Gorry, A., & Morton, S. (1971). A framework for management information systems. *Sloan Management Review, 13*, 56–70.
68. Grimshaw, D. (2000). *Bringing geographical information systems into business* (2nd ed.). New York: Wiley.
69. Hamda, H., & Schoenauer, M. (2002). Topological optimum design with evolutionary algorithms. *Journal of Convex Analysis, 9*(2), 503–517.
70. Hansson, S. (1994). *Decision theory: A brief introduction*. Sweden: Department of Philosophy, Uppsala University.
71. Harris, B., & Batty, M. (2001). Locational models, geographic information, and planning support systems. In R. Brail & R. Klosterman (Eds.), *Planning support systems* (pp. 25–57). Redlands: ESRI Press.
72. Heywood, I., Cornelius, S., & Carver, S. (2002). *An introduction to geographical information systems* (2nd ed.). Harlow: Pearson Education Limited.
73. Hluck, G. (1998). Genetic algorithms. In J. Liebowitz (Ed.), *The handbook of applied expert systems* (pp. 12-1–12-11). MA, USA: CRC Press.
74. Huang, B., & Jiang, B. (2002). AVTOP: A full integration of TOPMODEL into GIS. *Environmental modelling and software, 17*, 261–268.
75. Jackson, P. (1999). *Introduction to expert systems* (3rd ed.). Essex: Addison-Wesley.
76. Jankowski, P., & Nyerges, T. (2001). GIS for group decision making. Taylor & Francis.
77. Jha, M., McCall, P., & Schonfeld, P. (2001). Using GIS, genetic algorithms and visualization in highway development. *Computer-aided Civil and Infrastructure Engineering, 16*(6), 399–414.
78. Jia, J. (2000). IntelliGIS: Tool for representing and reasoning spatial knowledge. *Journal of Computing in Civil Engineering, 14*(1), 55–59.
79. Jin, Z., Sieker, F., Bandermann, S., & Sieker, H. (2006). Development of a GIS-based Expert System for on-site storm water management. *Water Practice & Technology, 1*, 1.

80. Jun, C. (2000). Design of an intelligent geographical information system for multi-criteria site analysis. *URISA Journal, 12*(3), 5–17.
81. Kalogirou, S. (2002). Expert systems and GIS: An application of land suitability evaluation. *Computers, Environment and Urban Systems, 26*, 89–112.
82. Kao, J., Chen, W., Lin, H., & Guo, S. (1996). Network expert GIS for landfill sitting. *Journal of Computing and Civil Engineering, 10*(4), 307–317.
83. Keen, P. G. W., & Scott-Morton, M. S. (1978). *Decision support systems: An organizational perspective*. Reading, MA: Addison-Wesley.
84. Keeney, R. L. (1992). *Value-focused thinking*. Cambridge: Harvard University Press.
85. Kersten, G., Mikolajuk, Z., & Yeh, A. (2000). *Decision support systems for sustainable development: A resource books of methods and applications*. Ottawa: International Development Research Centre.
86. Keyes, J. (1989). Why expert systems fail. *AI Expert, 4*(11), 50–53.
87. Klosterman, R. (1997). Planning support system: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17*, 45–54.
88. Klosterman, R. (1999). The what if? Collaborative planning support system. *Environment and Planning, B: Planning and Design, 26*, 393–408.
89. Klosterman, R. (2001). The what if? Planning support system. In R. Brail & R. Klosterman (Eds.), *Planning support systems* (pp. 263–284). Redlands: ESRI Press.
90. Klosterman, R. (2008). A new tool for a new planning: The what if?™ Planning support system. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 85–99). Cambridge, Massachusetts: Lincoln Institute of Land Policy.
91. Krzanowski, R., & Raper, J. (2001). *Spatial evolutionary modelling*. New York: Oxford University Press.
92. Laaribi, A., Chevallier, J. J., & Martel, J. M. (1996). A spatial decision aid: A multi-criterion evaluation approach. *Computers and Urban Systems*, *20*(6), 351–366.
93. Laurini, R. (2001). *Information systems for urban planning*. London: Taylor and Francis.
94. Leung, Y. (1997). *Intelligent spatial decision support systems*. Berlin: Springer.
95. Li, X., & Yeh, G. (2005). Integration of genetic algorithms and GIS for optimal location search. *International Journal of Geographical Information Science, 19*(5), 581–601.
96. Li, L., Wang, J., & Wang, C. (2005). Typhoon insurance pricing with spatial decision support tools. *International Journal of Geographical Information Science, 19*(3), 363–384.
97. Liao, S. (2005). Expert system methodologies and applications-a decade review from 1995–2004. *Expert Systems with Applications, 28*, 93–103.
98. Lilburne, L., Benwell, G., & Buick, R. (1997). GIS, expert systems and interoperability. *Transactions in GIS, 2*(3), 233–243.
99. Loh, D., & Rykiel, E. (1992). Integrated resource management systems: Coupling expert systems with databases management and GIS. *Environmental Management, 16*(2), 167–177.
100. Longley, P., & Batty, M. (1996). *Spatial analysis: Modelling in a GIS environment*. New York: Wiley.
101. Longley, P., & Batty, M. (2003). *Advanced spatial analysis*. Redlands: ESRI Press.
102. Longley, P., Brooks, S., McDonnel, R., & Macmillan, B. (1998). *Geocomputation: A primer*. Chichester: Wiley.
103. Longley, P., Goodchild, M., Maguire, D., & Rhind, D. (2005). *Geographic information systems and science* (2nd ed.). Chichester: Wiley.
104. Lukasheh, A., Droste, R., & Warith, M. (2001). Review of ES, GIS, DSS and their applications in landfill design management. *Waste Management and Research, 19*, 177–185.
105. MacDonald, M. (1997). A multi-attribute spatial decision support system for solid waste planning. *Computers, Environment and Urban Systems, 20*(1), 1–17.
106. Malczewski, J. (1999). *GIS and multi-criteria decision analysis*. New York: Wiley, Inc.
107. Malczewski, J. (2006). GIS-based multi-criteria decision analysis: A survey of the literature. *International Journal of Geographical information Science, 20*(7), 703–726.

108. Malczewski, J., Moreno-Sanchez, R., & Bojorquez-Tapia, L. A. (1997). Environmental conflict analysis in the Cape Region, Mexico. *Journal of Environmental Planning and Management, 40*, 349–374.
109. Matthews, K., Sibbald, A., & Craw, S. (1999). Implementation of a spatial decision support system for rural land use planning: Integrating geographic information system and environmental models with search and optimisation algorithms. *Computers and Electronics in Agriculture, 23*, 9–26.
110. McCarthy, J., Graniero, P., & Rozic, S. (2008). An integrated GIS-expert system framework for live hazard monitoring and detection. *Sensors, 8*(2), 830–846.
111. Medsker, L., & Liebowitz, J. (1994). *Design and development of expert systems and neural networks*. New York: Macmillan College Publishing.
112. Mintzberg, H. (1976). The structure of "unstructured" decision processes. *Administrative Science Quarterly, 21*(2), 246–275.
113. Moore, T. (2000). Geospatial expert systems. In S. Openshaw & R. Abrahart (Eds.), *GeoComputation* (pp. 127–159). London: Taylor & Francis.
114. Moore, T. (2008). Planning support systems: What are practicing planners looking for? In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 231–256). Cambridge, MA: Lincoln Institute of Land Policy.
115. Mysiak, J. (2004). *Mulino DSS: Decision methods*. Venice, Italy.
116. Nath, S., Bolte, J., Ross, L., & Aguilar-Manjarrez, J. (2000). Applications of geographical information system for spatial decision support in aquaculture. *Aquacultural Engineering, 23*, 233–278.
117. Negnevitsky, M. (2002). *Artificial intelligence: A guide to intelligent systems* (2nd ed.). Essex: Addison Wesley.
118. Noran, O. (1998). *The evolution of expert systems*. School of Computing and Information Technology. Griffith University.
119. Openshaw, S., & Abrahart, R. (2000). *GeoComputation*. London: Taylor and Francis.
120. Openshaw, S., & Openshaw, C. (1997). *Artificial intelligence in geography*. West Sussex: Wiley.
121. Padhy, N. (2005). *Artificial intelligence and intelligent systems*. New Delhi: Oxford University Press.
122. Paliulionis, V. (2000). Architecture of an intelligent GIS. *Informatica, 11*(3), 269–280.
123. Peckham, R. (1997). Geographical information systems and decision support for environmental management. In H. Timmermans (Ed.), *Decision support systems in urban planning*. E & FN SPON, 75–86.
124. Pelizaro, C., Arentze, T., & Timmermans, H. (2009). GRAS: A spatial decision support system for green space planning. In S. Geertman & J. Stillwell (Eds.), *Planning support systems: New methods and best practice* (pp. 191–208). New York: Springer.
125. Peterson, K. (1998). Development of spatial decision support systems for residential real estate. *Journal of Housing Research, 9*(1), 135–156.
126. Reeve, D., & Petch, D. (1999). *GIS organizations and people: A socio-technical approach*. Padstow: Taylor and Francis.
127. Renner, G., & Ekart, A. (2003). Genetic algorithms in computer-aided design. *Computer Aided Design, 35*(8), 709–726.
128. Robinson, B., Frank, U., & Karimi, H. (1987). Expert systems for GIS in resource management. *AI Applications*, *1*(1).
129. Rodriguez-Bachiller, A., & Glasson, J. (2004). *Expert systems and GIS for impact assessment*. London: Taylor and Francis.
130. Sante, I., Crecente, R., Miranda, D., Tourino, J., Canzobre, F., & Doallo, R. (2004). A GIS web-based tool for the management of the PGI potato of Galicia. *Computers and electronics in agriculture, 44*, 161–171.
131. Schneider, D. (2004). *An introduction to programming using Visual Basic 6.0* (4^{th} edn.). New Jersey: Pearson Education Inc.

132. Sekkouri, H., & Ouazar, D. (2002). An expert system for data preparation for groundwater modelling. In *Proceedings of the 17th Salt Water Intrusion Meeting*, Delft, The Netherlands.
133. Sharifi, A., & Rodriguez, E. (2002). Design and development of a planning support system for policy formulation in water resource rehabilitation. *Journal of Hydroinformatics, 4*(3), 157–176.
134. Sharifi, A., Herwijnen, M., & Toorn, W. (2004). *Spatial decision support systems*. Lecture Notes. The Netherlands: ITC, International Institute for Geo-Information Science and Earth Observation.
135. Sikder, I. U. (2009). Knowledge-based spatial decision support systems: An assessment of environmental adaptability of crops. *Expert Systems with Applications, 36*, 5341–5347.
136. Simon, A. (1960). *The new science of management decision*. New York: Harper & Row.
137. Simon, H. (1979). Rational decision making in business organisations. *The American Economic Review, 69*(4), 493–513.
138. Stewart, T., Janssen, R., & Herwijnen, M. (2004). A genetic algorithm approach to multi-objective land use planning. *Computers & Operations Research, 31*, 2293–2313.
139. Stillwell, J., & Clarke, G. (2004). *Applied GIS and spatial analysis*. Chichester: Wiley.
140. Stillwell, J., Geertman, S., & Openshaw, S. (1999). *Geographical information and planning*. Berlin: Springer.
141. Tarantilis, C., & Kiranoudis, C. (2002). Using a spatial decision support system for solving the vehicle routing problem. *Information & Management, 39*(5), 359–375.
142. Thomas, C., & Humenik-Sappington, N. (2009). *GIS for decision support and public policy making*. Redlands: ESRI Press.
143. Timmermans, H. (1997). Decision support systems in urban planning. E & FN SPON.
144. Timmermans, H. (2008). Disseminating spatial decision support systems in urban planning. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 31–43). Cambridge, Massachusetts: Lincoln Institute of Land Policy.
145. Tomlinson, R. (2003). *Thinking about GIS*. California: ESRI PRESS.
146. Turban, E. (1995). *Decision support and expert systems*. New Jersey: Prentice Hall.
147. Turban, E., Aronson, J., Liang, T., & Sharda, R. (2007). *Decision support and business intelligence systems* (8th ed.). New Jersey: Pearson Prentice Hall.
148. Uran, O., & Janssen, R. (2003). Why are spatial decision support systems not used? Some experiences from the Netherlands. *Computers, Environment and Urban Systems, 27*, 511–526.
149. Uran, O., Rietveld, P., Janssen, R., & Scholten, H. (2003). Spatial decision support systems: A user's perspective. *Journal of Geographic Information and Decision Analysis, 7*(1), 47–63.
150. Vacik, H., & Lexer, M. (2001). Application of a spatial decision support system in managing the protection forests of Vienna for sustained yield of water resources. *Forest Ecology and Management, 143*, 65–76.
151. Vamos, T. (1997). Knowledge representation. In J. Liebowitz (Ed.), *The handbook of applied expert systems* (pp. 3-1–3-22). MA, USA: CRC Press.
152. Van der Meulen, G. (1992). Geographical information and decision support. *Computers, Environment and Urban Systems, 16*, 187–193.
153. Van Dijk, S., Thierens, D., & Berg, M. (2002). Using genetic algorithms for solving hard problems in GIS. *Geoinfomatica, 6*(4), 381–413.
154. Van Herwijnen, M. (1999). *Spatial decision support for environmental management*. PhD thesis, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
155. Vlado, V. (2002). *Knowledge based GIS for site suitability assessment*. ESRI library. Available from URL: http://proceedings.esri.com/library/userconf/proc02/pap1185/p1185.htm.
156. Von Nitzsch, R., & Weber, M. (1993). The effect of attribute ranges on weights in multi-attribute utility measurements. *Management Science, 39*(8), 937–943.

157. Vonk, G. (2006). *Improving planning support: The use of planning support systems for spatial planning*. Utrecht: Netherlands Geographical Studies, Faculty of Geosciences, Utrecht University.
158. Waddell, P., Liu, X., & Wang, L. (2008). UrbanSim: An evolving planning support systems for evolving communities. In R. Brail (Ed.), *Planning support systems for cities and regions* (231–256). Cambridge, Massachusetts: Lincoln Institute of Land Policy.
159. Wilcke, D., Zacharias, S., Jin, Z., & Sieker, F. (2006). *GIS-based expert system for land use planning as a contribution to flood mitigation*. Available from URL: http://www.kolleg.loel.hs-anhalt.de/studiengaenge/mla/mla_fl/conf/pdf/conf2006/22Wilcke_L.pdf.
160. Witlox, F. (2005). Expert systems in land use planning: An overview. *Expert Systems Applications, 29*, 437–445.
161. Witte, E. (1972). Field research on complex decision processes: The phase theorem. *International Studies of Management and Organisation, 59*, 555–561.
162. Wyatt, R. (1997). Reversing decision support systems to reveal differences in human strategising behaviour. In H. Timmermans (Ed.), *Decision support systems in urban planning*. E & FN SPON, 87–106.
163. Wyatt, R., & Hossain, H. (2006). Evolutionary computing for optimising a region's distribution of agricultural production. *Applied GIS*, *2*(3), 21.1–21.22.
164. Yeh, A., & Qiao, J. (2004). Component based approach in the development of a knowledge based planning support system (KBPSS). Part 1: The architecture of the KBPSS. *Environmental and Planning B: Planning and Design, 31*, 517–537.
165. Zarkesh, M. (2005). *Decision support system for floodwater spreading site selection in Iran*. PhD Thesis, ITC, Netherlands.
166. Zeiler, M. (2001). *Exploring ArcObjects. Vol. I-Applications and cartography*. California: ESRI Press.
167. Zeiler, M. (2001). *Exploring ArcObjects. Vol. II-Geographic data management*. California: ESRI Press.
168. Zhang, X., & Armstrong, M. P. (2008). Genetic algorithms and the corridor location problem: Multiple objectives and alternative solutions. *Environment and Planning B: Planning and Design, 35*(1), 148–168.
169. Zhang, X., Srinivasan, R., Zhao, K., & Van Liew, M. (2009). Evaluation of global optimization algorithms for parameter calibration of a computationally intensive hydrologic model. *Hydrological Processes, 23*(3), 430–441.
170. Zhu, X., & Healey, R. (1992). Towards intelligent spatial decision support: Integrating geographical information systems and expert systems. In *Proceedings of GIS/LIS'92*, November 10–12, San Jose, CA.
171. Zhu, X., Healey, R., & Aspinall, R. (1998). A knowledge-based systems approach to design of spatial decision support systems for environmental management. *Environmental Management, 22*(1), 35–48.

Chapter 6
Case Study

6.1 Introduction

The four modules that comprise LACONISS have been implemented and evaluated using a real world land consolidation case study, which is presented in this chapter. The study area and the rationale for the selection are presented in Sect. 6.2. Section 6.3 describes the types of data collected whilst Sect. 6.4 discusses the building of the GIS model. Finally, some data quality issues are outlined in Sect. 6.5.

6.2 The Land Consolidation Project

The selection of an appropriate case study to implement and evaluate the system is a crucial matter for many reasons, i.e. time constraints, reliable evaluation, etc. Thus, the following criteria were chosen for this purpose: (1) the volume of the data should reflect a manageable problem involving reasonable time for proof of concept and testing purposes; (2) the land consolidation project should be a typical project both in terms of the existing situation before land consolidation, which involves a variety of land fragmentation problems as noted in Sect. 2.2.2, and applying the various land reallocation principles and practices followed by the experts as noted in Sect. 4.3. The former is necessary for developing and testing the land fragmentation model whilst the latter is necessary for developing and evaluating the land redistribution design model; (3) although the LCD is not able to provide relevant data in a GIS form, they should be available (at least the databases) in a computerised form where possible so as to avoid excessive time for building the GIS model and; (4) the project should have been carried out by a team of land consolidation experts in which the author has not been involved. Thus, the relevant land reallocation solution, i.e. both land redistribution and land partitioning, should be absolutely independent from the person who has developed the system (i.e. the author). A search of completed land consolidation projects in Cyprus indicated that the Chlorakas village project fulfils the above requirements; hence it was selected as the case study.

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_6, © Springer International Publishing Switzerland 2014

Fig. 6.1 Location of the case study village on the map of Cyprus

The land consolidation area is a part of the broader region of Chlorakas, a village in the District of Pafos, which is located at an altitude of 70 m above mean sea level and at a distance of 3 km to the north of the town of Pafos. The location of the village in Cyprus is shown in Fig. 6.1 and its corresponding location in the District of Pafos is shown in Fig. 6.2.

Fig. 6.2 Location of the case study village in the District of Paphos

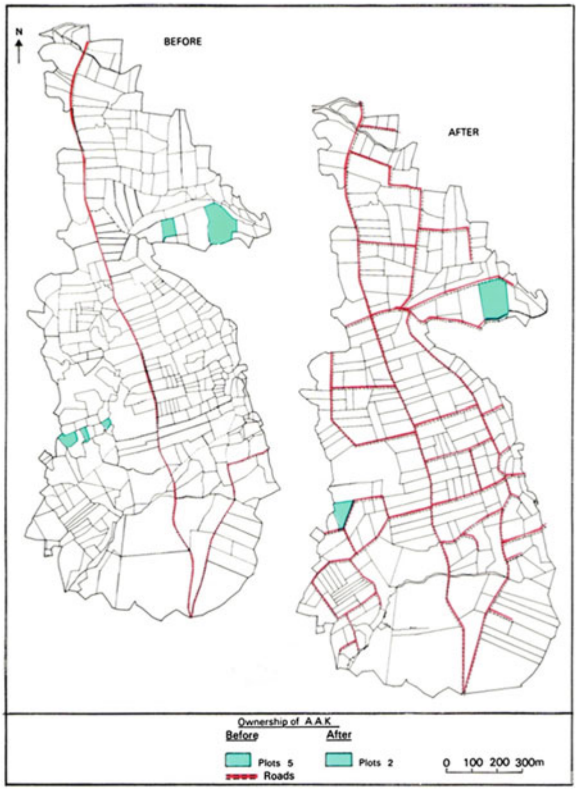


Fig. 6.3 The study area before and after land consolidation (LCD [1])

The village administrative boundaries cover a total area of 492 ha of lowland while the extent of the consolidated area is 195 ha. The main crops cultivated in the area are citrus fruits, grapes, vegetables and bananas. The project was one of the first to be applied in Cyprus. It began in March 1971 and was completed in June 1974. A cadastral map showing the layout of the parcels the roads etc., before and after land consolidation, is illustrated in Fig. 6.3. Comparative statistics before and after land consolidation implementation are shown in Table 6.1.

The basic statistics before land consolidation reveal a relatively significant land fragmentation problem. In particular, the average ownership size is 0.70 ha whilst the average parcel (or share) size is 0.4 ha, 13 % of the parcels are held in shares and 62 % of the parcels are not accessible by road. In addition, as illustrated in Fig. 6.3, several parcels have irregular shapes. In contrast, the basic statistics after land consolidation show a considerable elimination of land fragmentation. In particular, the average size of ownership increased by 31.4 %, the average size of parcels/shares increased by 70 %, the number of parcels fell by 22.8 %, the number of parcels held in shares declined by 88.5 %, the average number of parcels or shares per landowner was reduced by 18.8 and 100 % of the new parcels

Table 6.1 Comparative statistics before and after land consolidation (LCD [1])

Item	Before	After	Percentage of increase/decrease	
Aggregate number of owners	278	204	–	26.6
Local residents	198	159	–	19.7
Residents of neighbouring villages and of Pafos town	60	34	–	43.3
Residents of other towns	10	5	–	50.0
Residents of distant villages	5	3	–	40.0
Overseas residents	5	3	–	40.0
Unknown residence	0	0		–
Total area (ha)	195.0	187.8	–	3.7
Area held in whole ownership (ha)	161.0	187.5	+	16.4
Percentage of area held in whole ownership	82.6	99.8	+	20.8
Area held in undivided shares	34.0	0.3	–	99.1
Percentage of area held in undivided shares	17.4	0.16	–	99.1
Average size of ownership (ha)	0.70	0.92	+	31.4
Number of plots or shares	436	27.0	–	93.8
Number of plots	347	268	–	22.8
Number of plots held in whole ownership	302	266	–	11.9
Number of plots held in shares	45	2	–	95.5
Number of shares	134	4	–	97.0
Percentage of plots held in shares	13.0	1.5	–	88.5
Average number of plots or shares per owner	1.6	1.3	–	18.8
Average size of plot/share (ha)	0.4	0.7	+	75.0
Length of roads (km)	4.8	12.7	+	164.6
Area served by roads (ha)	110.0	187.5	+	70.4
Percentage of area served by roads	56.4	99.8	+	77.0
Plots served by roads	132	268	+	103.0
Percentage of plots served by roads	38.0	100.0	+	163.2

have access to a road. These results illustrate that the project was successful and hence legislation and practices were appropriately applied by the experts.

6.3 Data Collection

For the purpose of this research, three types of data were provided by the LCD regarding the study area: databases; cadastral maps (hard copy); and various documents. In particular, five database files were provided in dbf format, which contain the attribute information about landowners, original and new parcels, etc. The files were initially cleaned by removing unnecessary or unused fields, and files and fields were renamed for the purpose of this research. The final structure of the collected databases is shown in Table 6.2.

Table 6.2 The original databases provided

	Database file name		Database fields	Field type	Field description
1	LandOwnersEN	1	Owner_ID	Number	Primary key; it is a unique number for each landowner
		2	Owner_Code	Text	It is a code for each landowner used by the department
		3	Owner-Name	Text	Name and surname of an owner
		4	Total_Old_Area_Owned	Number	The original total area (in sqm) of the property owned by an owner in the study area
		5	Total _Old_Value_Owned	Number	The original total value (in Cyprus pounds) of the property owned by an owner in the study area
		6	Total_New_Area_Owned	Number	The total area (in sqm) of the property received by an owner in the new plan
		7	Total_New_Value_Owned	Number	The total value (in Cyprus pounds) of the property received by an owner in the new plan
2	OriginalParcels	1	Parcel _ID	Text	Primary key; it is a unique number for each original parcel
		2	Parcel_Sheet_Number	Text	The cadastral sheet number in which a parcel belongs
		3	Parcel_Area	Number	The official registered area of a parcel
		4	Parcel_Value	Number	The value (CyP) of a parcel as it has been defined by the Valuation Committee
3	OriginalParcelsOwnership	1	Owner-ID	Number	It is a unique number for each landowner
		2	Owner _Code	Text	It is a code for each landowner used by the Department
		3	Parcel_ID	Text	It is a unique number for each original parcel
		4	Share_Numerator	Number	The numerator of the fraction of a share for a parcel
		5	Share_Denominator	Number	The denominator of the fraction of a share for a parcel
		6	Only_Trees	Boolean	The property includes only trees
4	NewParcels	1	Parcel_ID	Text	Primary Key; it is a unique number for each new parcel
		2	Parcel_Area	Number	The area of a new parcel
		3	Parcel_Value	Number	The value of a new parcel
5	NewParcelOwnership	1	Owner-ID	Number	It is a unique number for each landowner
		2	Owner_Code	Text	It is a code for each landowner used by the Department
		3	Parcel_ID	Text	It is a unique number for each new parcel
		4	Share_Numerator	Number	The numerator of the fraction of a share for a parcel
		5	Share_Denominator	Number	The denominator of the fraction of a share for a parcel

In addition, the following three cadastral maps were provided: a cadastral map at a scale of 1:5,000 showing the original cadastral situation before land consolidation; a land consolidation plan at a scale of 1:5,000 drawn by hand, that presents (in reduced size) the cadastral situation after the implementation of land consolidation; and a cadastral map at a scale of 1:2,500 after the registration of the new cadastral status by the LSD. Furthermore, the following two kinds of documents were provided: catalogues, in which the cadastral situation before and after land consolidation is recorded using two indexes by landowner name and parcel ID and; photocopies of some documents (e.g. the proceedings of the meetings of the LCC), which contain useful information about the decisions of the Committee regarding the land consolidation project.

In conjunction with the above, many discussions were undertaken with human experts who carried out the project to clarify aspects related to the data and to get other useful information not included in the data provided.

6.4 Building the Geo-database

Based on the data collected, a geo-database was created consisting of two datasets: Dataset 1 and Dataset 2 contain the information before (original data) and after (the human expert's solution) land consolidation, respectively. The former dataset has been used as input for the land fragmentation and land redistribution Design models whilst the latter dataset was utilised for the evaluation of the land redistribution Design model. Both datasets are comprised of layers and database tables as shown in Table 6.3. In particular, Dataset 1 consists of three layers and two database tables. The first feature class named 'OriginalParcels', which has polygon geometry, was created to represent the original parcels. The shapes of the original parcels were drawn through 'screen digitising' of the scanned original cadastral map. A part of this layer is shown in Fig. 6.4. This process was carried out using the functions of the Editor Toolbar of ArcMap. Once the original parcels were created, their attributes, which were contained in the OriginalParcels database table as rows of information, were copied into the feature class. It is noted that a feature class in ArcMap is a kind of database table (i.e. with columns as fields and rows as records) and a feature is a type of row that may represent, in this case, a parcel or a road or a stream.

The second and third feature classes named 'Roads' and 'Streams' were created in the same way using the same scanned map and they both have polygon geometry. In particular, the former represents the surface of the road network that was constructed in the context of the primary network before the land reallocation study and that was proposed by the experts as a complementary road network constructed after the land reallocation study, while the latter represents streams that have been surveyed in their real location. A part of both layers (roads illustrated in red and streams in blue) is shown in Fig. 6.5. These three feature classes along with the 'Landowners' and the 'OriginalParcelOwnership' database tables

Table 6.3 The data input to the system

Type of data	Data before land consolidation (Dataset 1)	Data after land consolidation (Dataset 2)
Layers	OriginalParcels.shp Roads.shp Streams.shp	NewParcels.shp
Database tables	OriginalParcelOwnership.dbf	NewParcelOwnership.dbf LandOwners.dbf

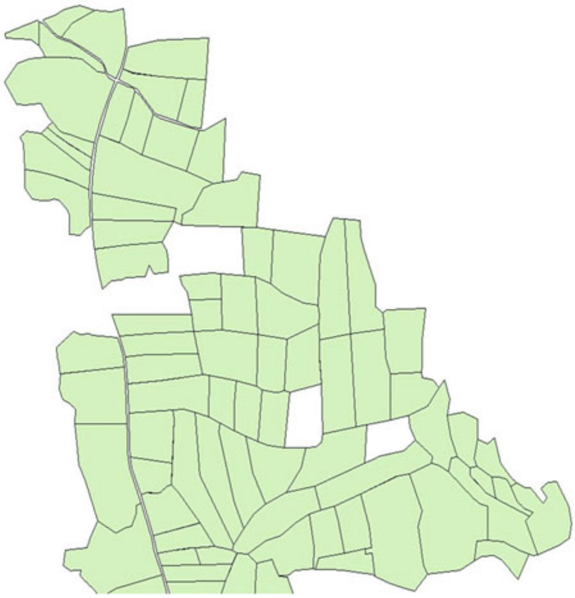


Fig. 6.4 The OriginalParcels layer (a part of the study area)

constitute the data inputs to the system. The system creates output tables and feature classes, which are described in the relevant chapters for each module that follow.

Dataset 2 consists of one layer and two database tables. Specifically, the 'NewParcels' feature class, with polygon geometry, represents the new parcels allocated by the experts, i.e. the new land consolidation plan. It was digitised in the same way using a scanned image of the actual land consolidation plan and by adding the attributes of the NewParcels table to this layer. This feature class and its related database tables, 'NewOwnership' and 'LandOwners', were used as inputs to evaluate the system outputs regarding the land redistribution design model. It should be noted that this dataset is the outcome of the work of two human land consolidation experts who worked on the preparation of the final land consolidation plan. The conventional process for preparing the land reallocation plan is described in Sect. 4.2.2.

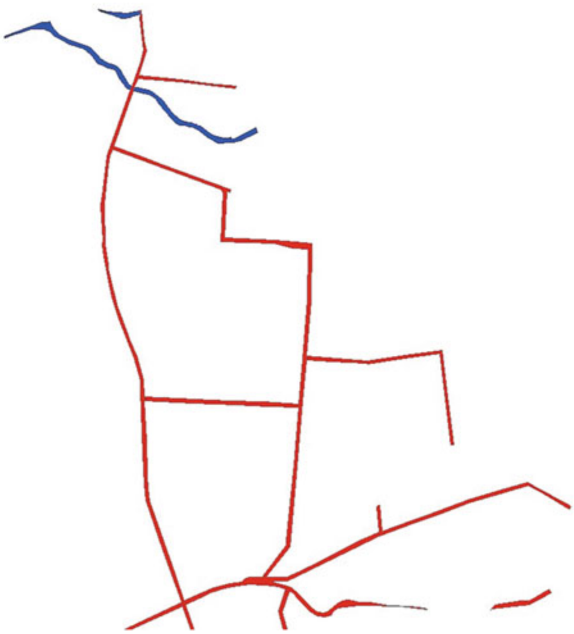


Fig. 6.5 The roads and streams layers (a part of the study area)

Both datasets involve a link between databases and feature classes. In particular, for each the two datasets, a relationship was established among layers and database tables, which are shown graphically in Fig. 6.6. In particular, the established relationships for Dataset 1 can be noted as follows: the OriginalParcelOwnership table is a junction table between LandOwners and the OriginalParcels tables. As an example, a landowner with a unique Owner_ID may have many Ownerships, i.e. parcels, shares in other parcels (shared ownership), and trees in other parcels (dual ownership). The attributes of these parcels are contained in the OriginalParcels layer. A similar relationship has been established for Dataset 2.

6.5 Data Quality

Data quality is used to give an indication of how good the data are. It describes the overall fitness or suitability of the data for a specific purpose or it is used to indicate if the data are free from errors and other problems [2]. The two datasets mentioned earlier, which were used to build and evaluate the system, need to be *complete*, *compatible*, *consistent* and *applicable* for the task to be performed. Also, other parameters of data quality such as *accuracy, precision, bias and resolution* should be taken into account. Definitions for these quality parameters can be found in any basic GIS textbook (e.g. [2, 3]) and other specific papers deal with data

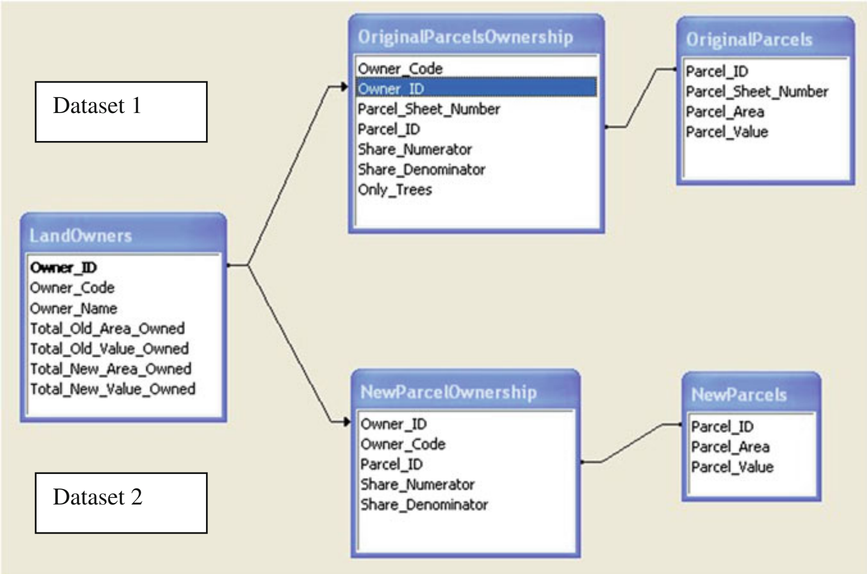


Fig. 6.6 The established relationships for each dataset

quality issues (e.g. [4]). In this case study, both attribute and spatial errors are possible hence their potential sources need to be identified. *Attribute errors* may be inherited in the database files and may be introduced during data processing. *Spatial errors* may be introduced during the conversion of maps to digital format via digitizing.

The data quality parameters noted above may provide a useful checklist of quality indicators. Data quality information is frequently used to construct a *data lineage*. Lineage is a record of data history that presents essential information about the development of data from their source to their present format. Instead of creating a complete lineage for this project, the data quality parameters noted earlier are briefly discussed. Completeness refers to a lack of errors of omission in a database [4]. Databases contain all the necessary cadastral and other information, which is relevant to the development of all the four modules of the system. In addition, cross-checking of all information regarding the data chain owners-ownerships-parcels-shares has been carried out and any errors found were appropriately corrected.

Compatibility refers to the ability of different datasets or different layers and databases to be combined to produce outputs. All data are compatible with each other and hence they can be combined. The only necessary correction was that the external boundary of the land consolidation area was slightly modified in an appropriate way so as to be consistent with the NewParcels layer and the OriginalParcels layer. Consistency refers to the absence of apparent contradictions in a database [4]. Some spatial and attribute inconsistencies were detected in the data, e.g. some polygons (i.e. parcels) were present on the map but not in the attribute table and vice versa. Also, landowners, which did not receive property in the new plan, were not included in the databases. The necessary corrections made after clarifying some issues with the experts who carried out the real project. Applicability is used to describe the appropriateness or suitability of data for a set of commands, operations or analyses [2]. The applicability of the created geo-database for the particular problem and the execution of special operations such as overlays, extractions, conversions etc. for further analysis was confirmed by manual tests.

Accuracy concerns spatial and attribute data. The accuracy of spatial data is that provided by the hard copy maps at a scale of 1:5,000 (2–3 m). This fact affects the accuracy of the coordinates of the original parcels and consequently its location, shape and area. As a result, the calculated parcel size may differ from the registered parcel size (as it is recorded on the title deeds). However, both accuracy errors do not constitute a problem for the purpose of this research because the calculations for land redistribution based on the ownership size were provided officially by the LSD whilst other relevant calculations were not affected by these accuracies because the final outcome was not so sensitive to them, e.g. for calculating the *PSI* or the centroid of a parcel. Bias in a GIS dataset is the systematic variation of data from reality [2]. Bias is a possible error (e.g. in digitizing) for this project that may affect the real shape, size and location of original parcels. Cross-checking of the digitised map with the original map has been undertaken and the necessary corrections were made. In addition, as noted earlier, these potential errors do not affect the outputs since they were either not involved in the decisions taken (e.g. for land redistribution) or they were so small that they had no actual influence in calculating the various indices, e.g. the *PSI*, *PCC*, etc. Precision is the recorded level of detail of a dataset [2]. Both datasets have the required level of detail to run and test all the four modules of the system. Some relevant issued have been noted above.

6.6 Conclusions

This chapter has presented the case study that has been used for the development and evaluation of the four modules of LACONISS. Selection of the appropriate case study, data collection, building the geo-database and data quality issues were addressed. The task of building and checking the geo-database was laborious and relatively long because the GIS model was built almost from scratch. The quality of the GIS model is adequate so as to ensure the reliability of the system development and evaluation that follows in the next four chapters that correspond in the four modules of the system.

References

1. Land Consolidation Department (LCD). (1993). *Land Consolidation in Cyprus*. Nicosia: Ministry of Agriculture and Natural Resources of Cyprus.
2. Heywood, I., Cornelius, S., Carver, S.: (2002). An introduction to geographical information systems. Pearson Education Limited, Harlow
3. Bernhardsen, T. (2002). *GIS: an introduction* (3rd ed.). New York: Wiley.
4. Howard, V.: (1998). Data quality measurement and assessment. Unit 100, NCGIA. Available from URL:http://www.ncgia.ucsb.edu/giscc/units/u100/u100_f.html

Chapter 7
LandFragmentS Model

7.1 Introduction

This chapter studies the development and the evaluation of the land fragmentation model, LandFragmentS (Land Fragmentation System). The aim of this module is to quantify the existing situation of land fragmentation using a new index that measures the efficiency of the existing land tenure system and may assist planners in policy decision making, i.e. it can help to decide whether land consolidation should be applied. The chapter contains four main sections. Specifically, the first Sect. 7.2 presents significant aspects of model structure, namely, the methodology for developing the new index, the definition of land fragmentation factors involved in the model, a new method called 'qualitative rating' for assigning weights to factors and standardisation. Thereafter, the module interface is presented in Sect. 7.3 that sequentially follows all the steps for running the model, including the introduction of a new standardisation process called the 'mean standardisation method' (mSM). Then, a new 'parcel shape index' (*PSI*) is outlined in Sect. 7.4, which also includes a review of existing parcel shape indices. In Sect. 7.5, an application of the module is presented using a case study involving the investigation of four weighting scenarios, a comparison of the new index (*GLFI*) with existing indices, a sensitivity analysis focusing on changes to the weights and a comparison of the new *PSI* with existing indices.

7.2 Model Structure Aspects

7.2.1 A New Methodology for Measuring Land Fragmentation

To overcome the deficiencies in existing land fragmentation measures discussed in Sect. 2.2.5, a new methodology has been developed that is comprehensive, flexible and problem specific. It is comprehensive since it is capable of handling any land

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_7, © Springer International Publishing Switzerland 2014

fragmentation factor for which there are available data; it is flexible because the user may select which factors need to be taken into account for a particular project; and it is problem-specific since the planner may decide the weighting given to each component factor for a specific project. The method utilised (MADM) is one that measures how far the existing land fragmentation condition is from that of the 'perfect' status, i.e. an ideal condition which in most cases may be theoretical; or conversely how far the existing land fragmentation is from the 'worst' status. An ideal land tenure system means that all ownerships consist of a unique parcel which has: an adequate size so as to be economically viable; a rectangular shape with a length: breadth ratio of 2:1 (as discussed later); access on a registered road; a unique ownership type, i.e. it belongs only to one landowner and both the trees and the land belong only to that landowner. The proposed process is based on the MADM illustrated in Fig. 5.3 and has four main steps as set out in Fig. 7.1.

Initially the planner selects the land fragmentation factors to be incorporated in the calculations and then assigns a relevant weight to each factor, which represents its importance in a given project. The selection of factors involved in the model is discussed in the next section. Thereafter, the scores associated with each of these factors, e.g. the mean size of parcels and the dispersion of parcels are automatically calculated by the system to create a land fragmentation table (Fig. 7.2). Each row represents an ownership and each column a land fragmentation factor (LFF). Each element of the table represents a score of ownership *i* and factor *j*. These scores are then standardised (if necessary) using appropriate methods (e.g. using

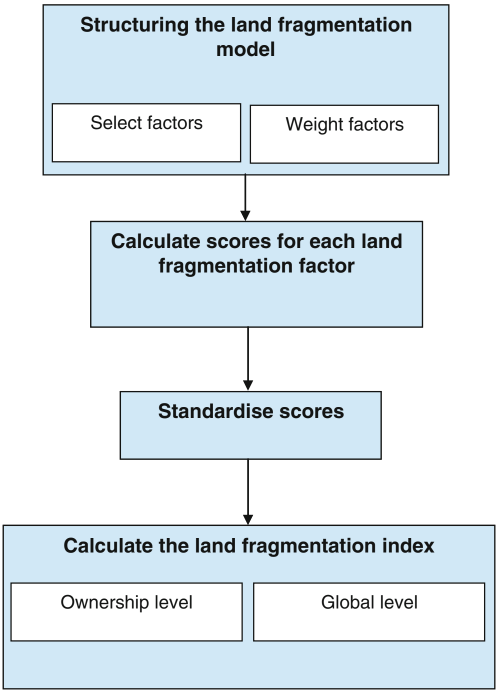


Fig. 7.1 Outline of the LandFragmentS model

	Land fragmentation factors (Weights)							Index
Ownership ID of ownership	F_1 (w_1)	F_2 (w_2)	F_3 (w_3)	..	F_j (w_j)	..	F_m (w_m)	
1	f_{11}	f_{12}	f_{13}	..	f_{1j}	..	f_{1m}	LFI_1
2	f_{21}	f_{22}	f_{23}	..	f_{2j}	..	f_{2m}	LFI_2
3	f_{31}	f_{32}	f_{33}	..	f_{3j}	..	f_{3m}	LFI_3
.	.	.	.	.	.	.	.	.
i	f_{i1}	f_{i2}	f_{i3}	..	f_{ij}	..	f_{im}	LFI_i
.	.	.	.	.	.	.	.	.
n	f_{n1}	f_{n2}	f_{n3}	..	f_{nj}	..	f_{nm}	LFI_n
								GLFI

Fig. 7.2 The typical form of the land fragmentation table

value functions) to create the standardised land fragmentation table. An ownership level land fragmentation index (LFI_i) is computed by multiplying the standardised score of each factor (f_{ij}) by the relevant weight of each factor (w_j) and summing these up for each row or ownership as follows:

$$LFI_i = \sum_{j=1}^{m} f_{ij} w_j \tag{7.1}$$

where m is the number of factors.

Ownerships take values between 0 (full fragmentation or worst system performance) and 1 (no fragmentation or best system performance). A global land fragmentation index (*GLFI*) for the whole study area is then calculated as the mean of the *LFI*s or the mean weighted by the size of the ownerships:

$$GLFI = \sum_{i=1}^{n} LFI_i / n \tag{7.2}$$

A median value could also be considered if the distribution of *LFI*s is skewed. A sensitivity analysis should then follow to assess how robust the outcome is regarding uncertainties and potential errors. It should be noted that the above new index measures the land fragmentation problem itself and it does not quantify the potential current economic, social and environmental impacts.

7.2.2 Defining Land Fragmentation Factors

As noted in Sect. 5.3.2, MADM is utilised for developing both the land fragmentation model and the land redistribution evaluation model. In order to avoid duplicity, the term ‘factors’ is used for the former case whilst the term ‘criteria’ is used for the latter case although both have the same content. When MADM is utilised for its classical purpose, namely, for evaluating a set of alternative solutions against a set of criteria, the assessment of the appropriateness of the criteria involved is crucial since they define the quality of the outcome of the MADM process. The selection of criteria involves two stages: a higher level selection stage and a further filtering stage.

In particular, for the former stage, the relevant literature [1–3] suggests that a number of requirements need to be fulfilled by each criterion and by the whole set of criteria, which will drive the initial selection of the criteria in the higher level stage. Specifically, each criterion should be comprehensive in terms of clearly representing the associated objective and be measurable, i.e. it can be objectively estimated. On the other hand, a set of criteria must be complete since they should cover all aspects of the decision problem, i.e. the efficiency of the plan and the social and environmental impacts and also must be operational because they have clear content, i.e. they can be easily understood by planners and decision makers in terms of the consequences of each alternative. Moreover, they must be decomposable so that the decision problem can be split into smaller parts by grouping criteria based on different themes, e.g. economic, environmental, social, etc. and be parsimonious, i.e. the number of criteria should be kept as small as possible but they should provide an adequate and reliable representation of the decision problem, quantifying the decision makers’ preferences.

In the second stage, the final criteria are chosen from the initial set based on ensuring lack of redundancy or independence. In other words, criteria should be defined in such a way as to avoid duplication of the consequences of the decision since this may act in favour of some alternatives and the outcome may be misleading. In particular, this double counting or duplication must be avoided in the situation where the aggregated performance of each alternative results from an additive value function model, which is used in this research. If the correlation coefficient of a pair of criteria approximates to zero, then the two criteria are independent and hence non-redundant [4] although this situation is rare in spatial decision making [1]. Beinat [5] also utilises the term ‘preferentially independent’ criteria.

Although the MADM employed in this chapter is for a different purpose, the above requirements for selecting criteria (i.e. factors in this case) should be considered as well. In particular, the following seven factors were initially considered for inclusion in the new index: dispersion of parcels; size of parcels/ownerships; shape of parcels; accessibility of parcels; number of parcels per ownership; and type of ownership, which is twofold, i.e. dual ownership and shared ownership.

The most critical requirement is the independence between the factors, i.e. to avoid duplication of associated factors. This can be found by simply calculating the correlation coefficient between two variables. The size of an ownership is directly related to the size of the parcels since the former is the sum of the latter and the number of parcels per ownership is correlated with the mean size of the parcels because the former is used as the denominator for calculating the latter. Similarly, the number of parcels is correlated with the dispersion of parcels since the former is also involved in the relevant Eqs. (7.5), (9.1) and (9.2). All other combinations of pairs of factors do not present any correlation because they inherently represent different aspects. For example, based on the case study data, the values of the correlation coefficient (R) between the shape and size of the parcels, accessibility and the size of parcels, dispersion and size and accessibility and shapeare −0.27, 0.32, −0.08 and −0.08 respectively.

Based on these considerations, the following six variables were chosen: the spatial distribution of parcels, i.e. the dispersion of parcels (F1); the size of parcels (F2); the shape of parcels (F3); the accessibility of parcels (F4); and the type of ownership which is twofold, i.e. dual ownership (the case when land and trees and/or water belong to different landowners) (F5) and shared ownership (where the land belongs to different landowners) (F6). These six factors satisfy all the relevant requirements noted above. In particular, each factor is comprehensive in terms of clearly representing an aspect of the system concerned, and each is measurable, i.e. objectively estimated. Moreover, the whole set of factors is complete since all of the main aspects of the problem are adequately represented. In addition, the factors are operational having a clear content in terms of influencing the performance of the system under consideration. The number of factors is kept as small as possible although they provide adequate and reliable representation of the system. The calculation of each factor is discussed later in Sect. 7.3.3.

7.2.3 A New Method for Assigning Weights to Factors

The purpose of giving different priorities to the evaluation criteria (or factors in this case) by assigning a weight to each is to represent the relative importance of each criterion in the context of the MADM evaluation process [1, 2, 6]. Weighting is a very critical task in decision making because it involves controversy and uncertainty [7] and it influences the final outcome, i.e. the ranking of alternatives (when utilised for the classical purpose) or the index value in the case of the land fragmentation model. Several methods have been developed for this purpose and reviewed by Beinat [5], Malczewski [1] and Sharifi et al. [2]. These include: swing weights; ranking; rating; pairwise comparison; trade off analysis; qualitative translation, etc. Crucial parameters for selecting the most appropriate method for assigning weights to criteria for a certain decision problem or system performance evaluation problem (in this case) are the number of criteria and the grade of uniqueness between them. Two parameters were taken into account when making the decision to choose methods for this module. First, the number of criteria involved in the evaluation process carried out in this model is quite small, i.e. six. This falls within the so called ‘seven plus or minus two’ range that is considered as the maximum number of entities that can be simultaneously processed by the human brain [8] meaning that human can easily process what weights to assign to six factors. Second, given that certain criteria are explicit in terms of their context and meaning, it was judged that two of the most straightforward and popular methods could be utilised: direct ranking and ranking methods.

In particular, direct ranking (or direct estimation) is the most straightforward method to assign values to criteria (that sum up to 1) when the number of criteria is small and manageable. However, even for such a small number of criteria, it is not straightforward when weighting values have two or more decimals. For instance, sometimes is not easy to justify why a criterion has a weight of 0.2 and another criterion has a weight of 0.18; it is even more difficult to differentiate a criterion from another by assigning weights of 0.125 and 0.120. Thus, weighting with this method can be reliable and accurate when values have one decimal, i.e. 0.1, 0.2 or two decimals with the last digit being 5, i.e. 0.15 or 0.25.

On the other hand, ranking methods involve the ordering of criteria to identify the most important to the least important criteria or vice versa. Several procedures (e.g. rank sum, rank reciprocal and rank exponent method) are then utilized for estimating a numerical value of weights based on that rank order [1]. Although these methods are simple, they involve a great disadvantage since they do not provide the potential to rank two or more criteria with equal importance, a fact that is obviously not reasonable in practice. Similar to ranking methods, rating methods, and in particular the point allocation approach, involve allocation across the evaluation criteria of a number of points, e.g. ranging from 0 to 100. The higher the number of points assigned to a criterion, the greater its importance. These scores can then be easily standardized on a scale of 0–1. This method is actually very similar to the direct ranking so it has the same disadvantages and hence is not accurate. In particular, how does one justify assigning say 20 points to a criterion and not 22? The ratio estimation procedure combines the ranking of criteria as employed in ranking methods and the scoring of points carried out in the point allocation method. The difference is that a score of 100 is assigned to the most important criterion and then proportionally smaller scores are assigned to other criteria. Weights are then normalized to a scale from 0 to 1. This method inherits the disadvantages of both methods.

Taking into account that a simple method is still needed for assigning weights to a small number of criteria but overcoming at least some of the disadvantages referred to above, a modified version of the ratio estimation procedure is introduced in this research called ‘qualitative rating’. In particular, this method overcomes the problem of assigning either direct numeric values as weights or scores, which are then transformed into weights by adopting a similar qualitative scale to that used in the pairwise comparison method. In particular, criteria are classified in the following seven classes of importance: extremely high; very high; high; intermediate; moderate; low; and very low. Experience shows that it is easier to ask a decision maker or a planner to intuitively describe the category of importance of a criterion rather than assigning a number or a score. Comparison of the importance of criteria is also easier with this approach. In addition, criteria may have the same importance, which is a reasonable fact in practice.

Similarly with the pairwise comparison method, each class on a scale has a predefined rate, i.e. a score. In particular, the scale is divided into two parts: the upper and the lower range and the subdivision point is the middle class. Each part involves three levels of importance and a differential increase in the scores. More specifically, the rate of increase in the lower part is 10 points whilst in the upper part it is double, i.e. 20 points. This represents an imposed weighting in favour of the upper part and against the lower part. Although this scoring seems arbitrary, in practice this discrimination is realistic since the weight of the classes belonging to the upper range should be more than that of the lower range because planners and decision makers tend to degrade or even ignore the less important criteria in the decision-making process. The scale of importance of each criterion and the corresponding scores are presented in Table 7.1.

After selecting the appropriate scale of importance for each criterion, the weights are standardized based on the score assigned to each criterion so that they sum to 1. As an example, suppose we have seven criteria and each criterion corresponds to a different scale of importance, then Table 7.2 shows the values of the actual weights for seven criteria where each criterion corresponds to a different scale of importance. It is clear that this result cannot be defined directly by a planner in the same way, and if all the criteria have the same importance, then all of the criteria will have the same weight.

Table 7.1 The scale utilised by the qualitative rating method for assigning weights

Rank order	Scale of importance	Score	Classes
1	Extremely high	100	Upper
2	Very high	80	
3	High	60	
4	Intermediate	40	Middle
5	Moderate	30	
6	Low	20	
7	Very low	10	Lower

Table 7.2 An example of the actual weight values with seven criteria

Criterion	Scale of importance	Score	Weight
C1	Extremely high	100	0.294
C2	Very high	80	0.235
C3	High	60	0.176
C4	Intermediate	40	0.118
C5	Moderate	30	0.090
C6	Low	20	0.059
C7	Very low	10	0.029
Total		340	1.000

7.2.4 Standardisation

As noted in Sect. 5.3.2, standardisation is a procedure involved in the MADM. In particular, standardization (or normalization) is the process of transforming the scores of the evaluation criteria into the same scale, which is commonly a dimensionless scale of values from 0 to 1. As a result, the measurement unit is uniform and hence the criteria can be combined and compared. Several standardization methods have been developed and the selection of which one to use depends on the problem concerned and the type of evaluation criteria involved. These methods are classified into two broad categories: linear scale transformation and value/utility function approaches. The former are utilized for deterministic problems whilst the latter are used for both deterministic and probabilistic problems [2].

The most popular linear scale transformation methods are: maximum, interval and goal standardization. The first two methods use the highest and the lowest values of a dataset for the transformation (proportional or not) into a scale, which results in values between 0 and 1. Conversely, the third method utilizes reference points that reflect an ideal point (e.g. a desired value to be achieved) and a minimum point that defines the range of standardization; thus they are independent of the dataset. Malczewski [1] and Sharifi et al. [2] discuss these methods. Although these methods have the advantage of simplicity and predefined behaviour, they have two significant disadvantages: first, they assume a linear association between the original values and the standardised values when, in practice, this relationship is more complex; and secondly, they ignore the judgements of the decision makers as they have no input in the development of the simple linear standardisation function that is commonly used. Both of these limitations are overcome by the use of value functions.

As noted in Sect. 5.3.2, value functions reflect, in mathematical form, human judgement regarding what is desired to be achieved for a certain decision-making problem. In particular, value functions are associated with factual information, human judgement and multiple criteria and they translate a score for a criterion into a value score taking values between 0 and 1. The creation of value functions for a problem is a difficult task and it is crucial for the whole process since it affects the ranking of alternatives or the values of *LFI* and *GLFI* in this case. Therefore, Beinat [5] notes that value functions have to be the result of a specially designed interviewing process, with the decision makers and planners associated with the problem concerned, which is the approach followed here.

A number of methods have been developed for the creation of value functions. The most common are the midvalue method, which has been proposed by Bodily [9], the Evalue method (that combines the assessment of range of scores and weights of evaluation criteria), which has been developed by Beinat [5] and the direct value rating method [5]. The latter has been utilised for the purposes of this research because of its simplicity and flexibility in terms of assigning values not in predefined performance scores (as required in the midvalue method) but depending on the criterion (or factor) concerned. Five land consolidation experts (not having knowledge of value functions) have been involved in the process.

Direct value rating involves the following five steps for each criterion. (i) selection of the score range for a criterion (or factor), i.e. the ideal or goal value (i.e. maximum value) and the minimum value, which correspond to values of 1 (best) and 0 (worst) respectively. Minimum values are all zero. Beinat [5] emphasises the significance of the end points of value functions, and hence the need to be interpreted and defined as accurately as possible. (ii) Definition of the qualitative characteristics of the value function, i.e. monotonicity, shape, etc. (iii) Assignment of values for selected criterion scores that have been defined by dividing the attribute range into 3 to 6 equal intervals resulting in 4 to 7 points, respectively. This task was carried out separately by five land consolidation experts after they were explained the concept and the aim of value functions by the author. (iv) Curve fitting using appropriate software which results in an explicit mathematical equation. (v) Consistency checks to confirm the validity of the functions as representations of preference. This involves examining the intermediate scores given by the five experts in step (iii).

7.3 Module Interface

The LandFragmentS module is operationalised as a toolbar (Fig. 7.3) consisting of seven icons: 'Existing LF indicators'; 'LF factors'; 'LF table'; 'LF value functions'; 'Standardised LF table'; 'LF indices' and 'Sensitivity analysis'. Each icon, which represents a stage of the MADM process, launches a separate window with one or more functionalities. With the exception of the 'Existing LF indicators' and the 'LF function' icons, the remaining icons are in the order in which they must be executed. The functionality of each icon will be described separately in the sections that follow.

7.3.1 Calculate Land Fragmentation Using Existing Indices

As noted in Sect. 2.2.5, the most popular land fragmentation indices are those of Simmons [10] and Januszewski [11] in which a value of 0 indicates the worst possible land fragmentation situation while a value of 1 indicates no land

Fig. 7.3 The LandFragmentS toolbar

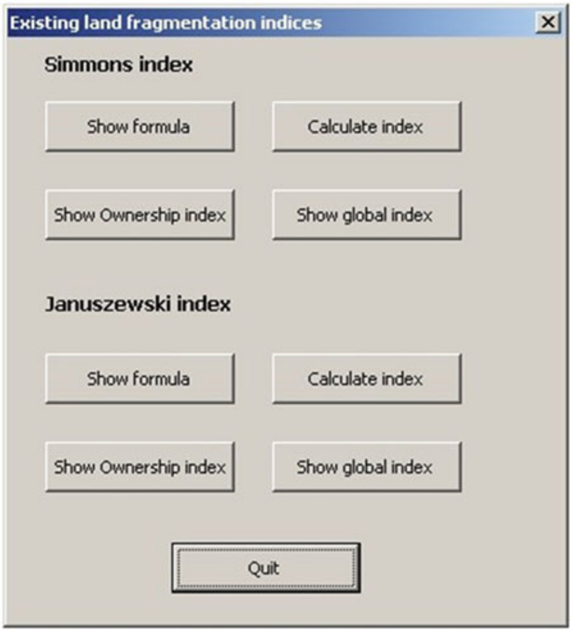


Fig. 7.4 The window for calculating the Simmons and Januszewski indices

fragmentation. To calculate these indices, the first icon on the toolbar shown in Fig. 7.3 is selected, launching the window shown in Fig. 7.4.

The formula for calculating Simmons index is provided in Eq. 2.1. This formula can be displayed by clicking on the ‘Show formula’ button. The remaining buttons are used to calculate the index and display its values by ownership ID in a column called ‘Simmons’ in the LandOwnersEN table, or globally as the mean index of all ownerships. The same options are available for calculating the Januszewski index based on Eq. (2.2).

7.3.2 Selecting and Weighting Factors

The user may select which factors are to be included in the model via the ‘LF Factors’ menu item that launches a window as shown in Fig. 7.5. Selection is made by checking the appropriate boxes or all of the factors can be selected at once. After selection, the structure of the LF table is created. Clicking the OK button completes the process. This window also allows the assignment of weights to factors. In particular, weighting can be carried out by utilising the two methods noted earlier, namely, the direct ranking and the qualitative rating methods. The user selects one of the methods by clicking on the relevant radio button. Then in the case of direct ranking, the user assigns numerical values for the weights in each box, whilst for qualitative rating, the user selects the importance of each factor

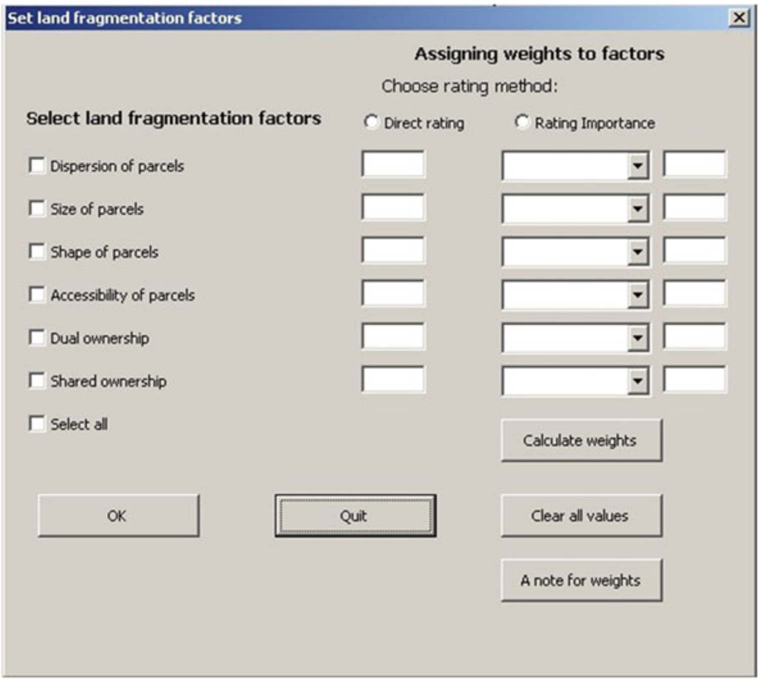


Fig. 7.5 The window for selecting and weighting factors

based on the scale noted in Table 7.1 from the drop down list. Afterwards, the 'Calculate weights' button should be clicked so that the actual weights are calculated as numerical values.

The user may then select the 'LF table' menu item, which appears as a button on the dialogue box shown in Fig. 7.6.

This window provides four main functions (with corresponding buttons): the 'Show LF table structure' (Fig. 7.7) with no scores (a score represents the performance of an ownership associated with a particular factor); 'Pre-calculations' regarding shape analysis factors discussed in a later section; calculation of the scores f_{ij} via the 'Calculate Scores' button; and the final LF table with scores (via the 'Show LF Table' button).

7.3.2.1 Calculate Factor Scores

All of the factors involved in the model are measured per ownership. In particular, the dispersion of parcels by ownership is measured by utilising the dispersion of parcels before land consolidation (DoP) in metres, which is represented by the standard distance. Specifically, standard distance is a basic measure of spatial dispersion [12, 13], which is the spatial equivalent of the standard deviation,

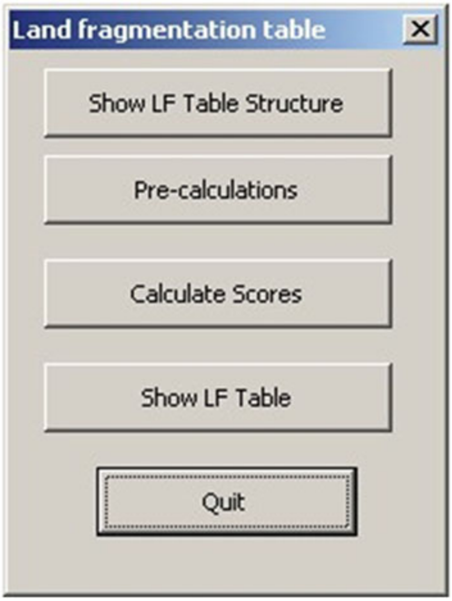
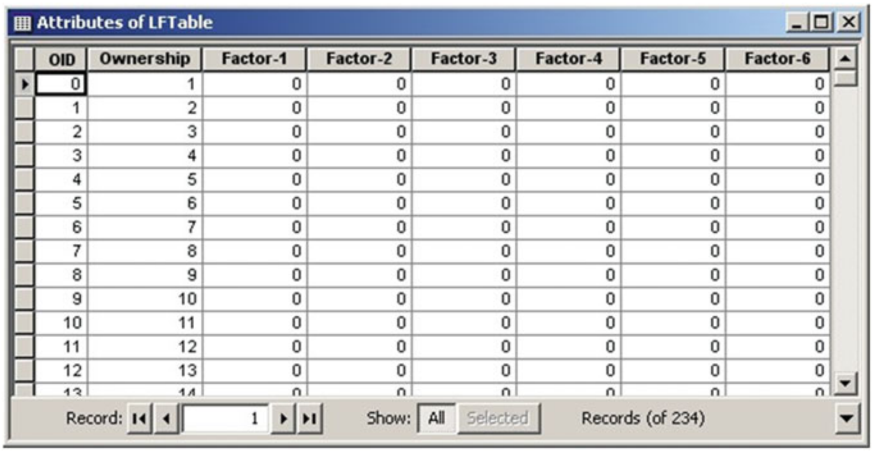


Fig. 7.6 The ‘LF Table’ window


Attributes of LFTable

OID	Ownership	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
0	1	0	0	0	0	0	0
1	2	0	0	0	0	0	0
2	3	0	0	0	0	0	0
3	4	0	0	0	0	0	0
4	5	0	0	0	0	0	0
5	6	0	0	0	0	0	0
6	7	0	0	0	0	0	0
7	8	0	0	0	0	0	0
8	9	0	0	0	0	0	0
9	10	0	0	0	0	0	0
10	11	0	0	0	0	0	0
11	12	0	0	0	0	0	0
12	13	0	0	0	0	0	0
13	14	0	0	0	0	0	0

Record: 1 Show: All Selected Records (of 234)

Fig. 7.7 The structure of LF Table

showing how locations or points are scattered around the spatial mean [13]. The spatial mean or mean centre of gravity is also an important spatial statistical measure of central tendency, which indicates the average location of a set of points defined in a Cartesian coordinate system. Thus, the standard distance measures the degree to which parcels (or more precisely the centroids of parcels) are concentrated or dispersed around their geometric mean. Although, in practice, the dispersion of ownerships is dependent on the location of the farmstead or the village where the farmer resides, the extra information needed is usually not available, so the mean centre of parcels of a ownership is a proxy criterion that gives an adequate representation of the dispersion before and after land consolidation.

An extension of standard distance is the weighted standard distance where centroids may have different attribute values representing the different sizes or land values of each parcel. For instance, if the largest parcels of an ownership are very dispersed in terms of location, this may have more negative effects on productivity than if the smaller parcels are dispersed. Tourino et al. [14] suggest weighting the score of each parcel using its agronomic value, i.e. taking into account the productivity and soil quality of a parcel. Wong and Lee [13] note that the weighted mean centre and the weighted distance should also be utilised when the point locations under study have varying frequencies or occurrences.

Both spatial statistics, i.e. the mean centre and standard distance, are rephrased in this research as the mean centre of the parcels of an ownership and dispersion of parcels (*DoP*) of an ownership, respectively. The mean centre of the parcels of an ownership can be found by calculating the mean of the x co-ordinates (eastings) and the mean of the y co-ordinates (northings) of the centroids of the parcels that belong to an ownership. The two coordinate means define the location of the mean centre of an ownership as shown by:

$$(\bar{x}_{hmc}, \bar{y}_{hmc}) = \left(\frac{\sum_{i=1}^{n} x_i}{n}, \frac{\sum_{i=1}^{n} y_i}{n} \right) \tag{7.3}$$

where $\bar{x}_{hmc}$ and $\bar{y}_{hmc}$ are the co-ordinates of the ownership's mean centre; x_i and y_i are the co-ordinates of the centroid of parcel i; and n is the number of parcels belonging to a ownership.

The larger the size of a parcel, the greater is its importance in terms of its contribution to production, productivity, labour and hence the income of a farmer. Similarly, the land value of a parcel could be also used as weight instead. Thus, the weighted mean centre of a ownership is a better indicator than the simple mean centre because it reflects not only the spatial dispersion of parcels but also the agricultural importance of each parcel. The weighted mean centre of a ownership can be found by multiplying the x and y coordinates of the centroid of each parcel by a weight:

$$(\bar{x}_{whmc}, \bar{y}_{whmc}) = \left(\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \right) \tag{7.4}$$

where $\bar{x}_{whmc}$ and $\bar{y}_{whmc}$ are the co-ordinates of the ownership's weighted mean centre and w_i is the weight of each parcel i. Then the dispersion of parcels (*DoP*) can be calculated by Eq. 7.5. A block of the relevant code is presented in Appendix B.1.1.

$$DoP = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{hmc})^2 + \sum_{i=1}^{n}(y_i - y_{hmc})^2}{n}} \tag{7.5}$$

The weighted *DoP* is then calculated as:

$$DoP = \sqrt{\frac{\sum_{i=1}^{n}w_i(x_i - x_{hwmc})^2 + \sum_{i=1}^{n}w_i(y_i - y_{hwmc})^2}{\sum_{i=1}^{n}w_i}} \tag{7.6}$$

Both simple and weighted measures of parcel dispersion were utilised by Tourino et al. [14]. Although they both constitute a classic measure of spatial dispersion, the disadvantage is that they may result in an unlimited range of values with no explicit extreme values. Therefore, this factor needs standardisation whilst all of the others do not because they already have values between 0 and 1.

In addition to *DoP*, the size of parcels is represented by an ownership size index, which is calculated as the mean value of the size of all parcels belonging to an ownership based on the value functions shown in Figs. 7.8 and 7.9 for arid and irrigated areas, respectively. The reason for having different value functions for each case is that legislation provides different minimum parcel sizes for each case. Value functions have been created based on the methodology described earlier in Sect. 7.2.4. Figure 7.8 presents a fifth order polynomial function (Eq. 7.7) whilst Fig. 7.9 shows a concave benefit fourth order polynomial function (Eq. 7.8).

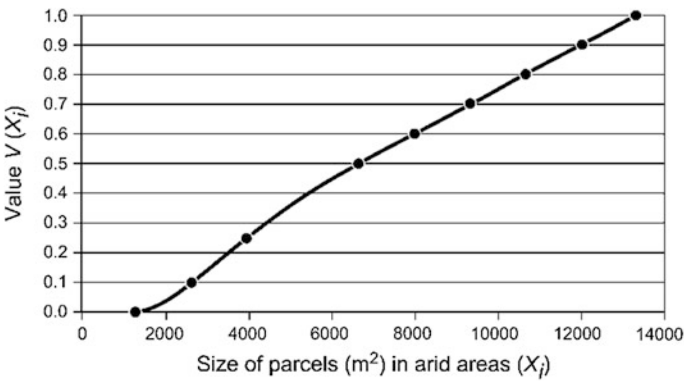


Fig. 7.8 The value function for the size of parcels in arid areas

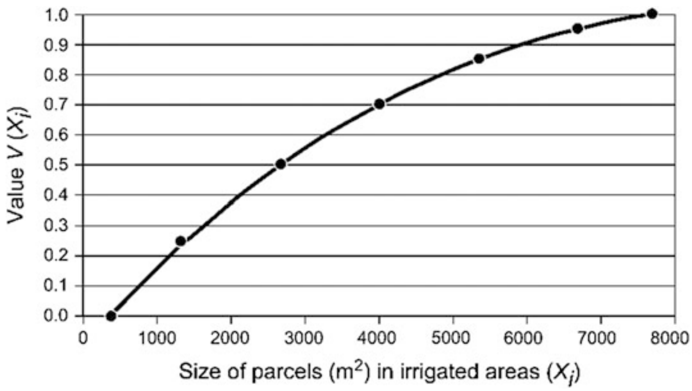


Fig. 7.9 The value function for the size of parcels in irrigated areas

Explanations regarding the rationale for constructing each function is discussed in Demetriou et al. [15].

$$V(x_i) = -1.71 \times 10^{-20} x_i^5 + 6.83 \times 10^{-16} x_i^4 - 9.97 \times 10^{-12} x_i^3 + 6.36 \times 10^{-8} x_i^2 - 7.37 \times 10^{-5} x_i + 5.58 \times 10^{-3} \tag{7.7}$$

$$V(x_i) = -3.24 \times 10^{-17} x_i^4 + 1.10 \times 10^{-12} x_i^3 - 2.74 \times 10^{-8} x_i^2 + 2.82 \times 10^{-4} x_i - 9.68 \times 10^{-2} \tag{7.8}$$

The mean value for each ownership does not require standardisation since the values are already between 0 and 1 due to the pre-processing of input factors via the value functions. In both functions, scores lower than X_{min} are standardised to 0, while scores higher than X_{max} are standardised to 1.

The shape of parcels is represented by a new parcel shape index (*PSI*) introduced in this research. The *PSI* takes into account six factors: the length of the sides; the acute angles; the reflex angles; the number of boundary points; compactness; and regularity. An extensive discussion of this issue is provided later in Sect. 7.4. Furthermore, regarding the accessibility of parcels, the system automatically detects if a parcel has access to a road or not. This is possible by employing the appropriate topology rule. In particular, the esriSpatialRelTouches rule of ArcObjects is utilised to check if a parcel 'touches' a road or not. If this is positive, then 1 is assigned to a special field for the relevant parcel while 0 is assigned if it is negative (a block of the relevant code is presented in Appendix B.1.2).The ownership accessibility index is then calculated as the average value of assigned 1 s and/or 0 s for the parcels that belong to an ownership. A potential weighting of the average accessibility index using the size of a parcel, given that it is more important to have access for a large parcel than a small parcel, is not appropriate because the size of the parcels is a separate land fragmentation factor in the model, which would mean duplication of factors.

Similar to the accessibility of parcels, dual ownership is represented by a binary function that takes values of 1 (not dual ownership) or 0 (dual ownership). This information is included in the original data. Thus, a dual ownership index is calculated as the average value of assigned 1 s and/or 0 s for the parcels that belong to an ownership. Potential weighting of the average ownership index by the size of the parcels is prone to the same limitation as noted earlier. Similar to the two previous factors, shared ownership is represented by a binary function that takes values of 1 if a parcel is not possessed by more than one landowner or 0 if it is. This information is also included in the original data. Thus, a shared ownership index is calculated as the average value of assigned 1 s and/or 0 s for the parcels that belong to an ownership. Similar to the last two factors, the potential weighting of the average shared ownership index is prone to the same limitations as noted earlier.

7.3.3 Generate a Standardised Land Fragmentation Table

As noted earlier, the only land fragmentation factor that needs standardisation in this model is the dispersion of parcels (*DoP*) since it may take any positive value (in metres). There are no factual data available on this index so it is hard for experts to define a value function based on their judgement. In addition, the *DoP* is measured on a ratio scale, i.e. values are real and may vary considerably from project to project. Thus, a more generic standardisation method is recommended below.

In particular, the *DoP* could be standardised using a linear cost function, i.e. the higher the *DoP*, the worse it is. This function presents a proportional increase of standardised values from 0 to 1 based on the minimum and maximum *DoP* scores, respectively. Sharifi et al. [2] review a series of linear standardisation methods. The maximum standardisation appears to be the most appropriate for this factor because the *DoP* is measured on a ratio scale; thus the relative differences must be preserved and hence the standardised values are proportional to the original values. However, maximum standardisation may present a disadvantage in the situation when the minimum and maximum values of the sample are extreme. For example, an ownership with one parcel has a *DoP* of zero while an ownership with several parcels may have a *DoP* of several kilometres. Thus, we introduce the so called mean standardisation method (mSM) by adding 1 to the formula [15] for the calculation of the *PPI* (Sect. 8.3.4, which balances the potential extreme minimum and maximum values by taking into account the mean of the sample. Therefore the modified formulae are:

Table 7.3 Results obtained by the maximum and mean standardisation methods

DoP(m)	Maximum standardisation	mSM
10,000	0.00	0.00
5,000	0.50	0.33
3,000	0.70	0.47
2,500	0.75	0.50
2,000	0.80	0.60
1,500	0.85	0.70
1,000	0.90	0.80
0	1.00	1.00
0	1.00	1.00
0	1.00	1.00

The minimum, maximum and mean values of the sample are 0, 10,000 and 2,500, respectively

$$E_i = 1 - \left(\frac{(S_i - \min S) * 0.5}{meanS - \min S} \right) \quad (\text{if } S_i \le meanS) \tag{7.9}$$

and

$$E_i = 1 - \left(\left(\frac{(S_i - meanS) * 0.5}{\max S - meanS} \right) + 0.5 \right) (\text{if } S_i \le meanS) \tag{7.10}$$

where E_i is the standardized value of score S_i and $\min S, \max S, meanS$ are the corresponding statistical values for all the scores in the sample.

Table 7.3 presents an example of standardisation of values obtained using both methods. This example includes ‘extreme’ values i.e. three 0 s and one 10,000 so as to show the difference between the two methods. It is apparent that the maximum SM assigns a value of 0.75 for the mean score of the *DoP* sample, i.e. 2,500, whilst the mSM assigns the value of 0.5 for the same score which is exactly half, i.e. the mean of the standardization range from 0 to 1. The latter outcome indicates that the mSM balances the standardisation process by precisely assigning values based on the original scores. In accordance with this, the mSM assigns smaller values to the other scores compared to those assigned by the maximum SM. As a result, large scores are not favoured over small scores when standardised because of the way mSM operates.

It is worthwhile to note that the median is not an appropriate measure for this case because usually there are many ownerships that include only one parcel, i.e. the *DoP* is 0. Thus, the *DoP* is skewed towards small values and this fact biases the standardisation. The mSM overcomes this limitation by using the mean value and therefore produces better results. Standardisation is carried out via the ‘Standardised LF table’ menu item that launches a window as shown in Fig. 7.10.

This window provides two operations, i.e. standardise and show the LF table. An example of a standardised LF table is shown in Fig. 7.11. As expected, all values of the factors range between 0 and 1.

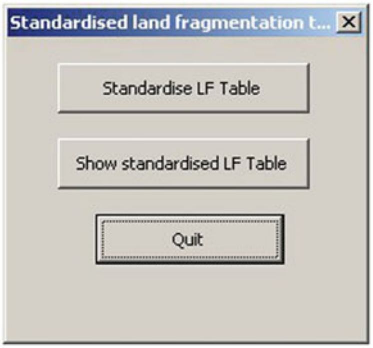
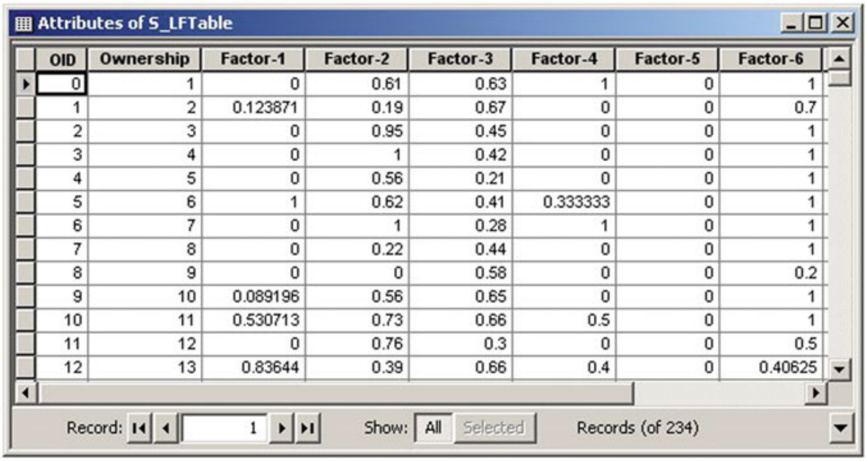


Fig. 7.10 The window for standardising the LF table


Attributes of S_LFTable

OID	Ownership	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
0	1	0	0.61	0.63	1	0	1
1	2	0.123871	0.19	0.67	0	0	0.7
2	3	0	0.95	0.45	0	0	1
3	4	0	1	0.42	0	0	1
4	5	0	0.56	0.21	0	0	1
5	6	1	0.62	0.41	0.333333	0	1
6	7	0	1	0.28	1	0	1
7	8	0	0.22	0.44	0	0	1
8	9	0	0	0.58	0	0	0.2
9	10	0.089196	0.56	0.65	0	0	1
10	11	0.530713	0.73	0.66	0.5	0	1
11	12	0	0.76	0.3	0	0	0.5
12	13	0.83644	0.39	0.66	0.4	0	0.40625

Record: 1 Show: All Selected Records (of 234)

Fig. 7.11 An example of a standardised LF table

7.3.4 Calculate Land Fragmentation Indices

Land fragmentation indices can be calculated by the 'LF indices' icon, which launches a window like that shown in Fig. 7.12 and provides six buttons for calculating and showing: the *LFI* for each ownership; the *GLFI*; and the contribution of each factor to land fragmentation at both the ownership and global levels.

As noted in Sect. 7.2.1, an ownership level *LFI* is computed and stored in the field 'LFindex' in the S_LFTable (standardised land fragmentation table) as shown in Fig. 7.13. The contribution of each factor to the ownership level of land fragmentation is calculated as the percentage of the value $f_j w_j$ relative to the whole LF_i value and is stored in the FPC_LFTable (factor percentage contribution land

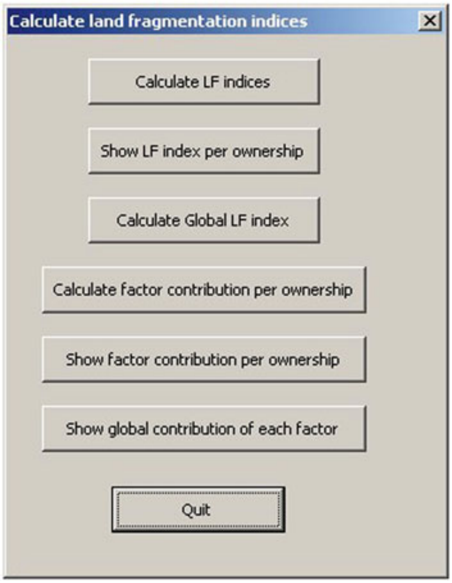
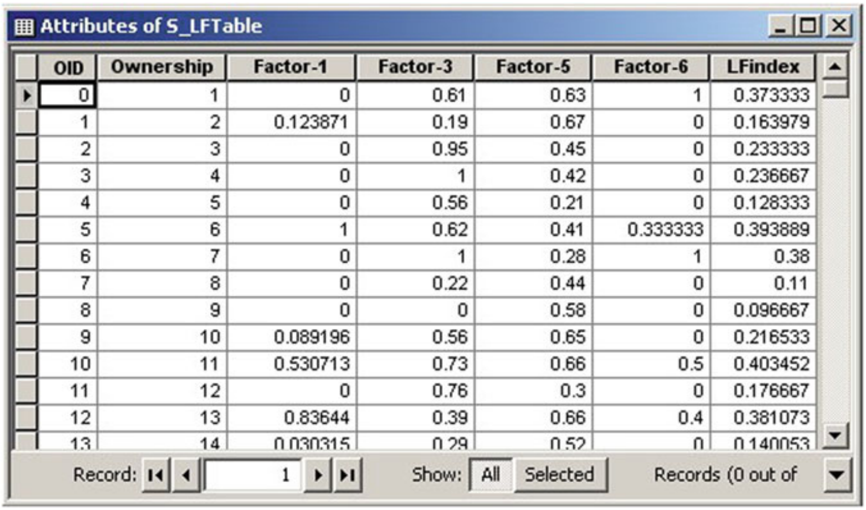


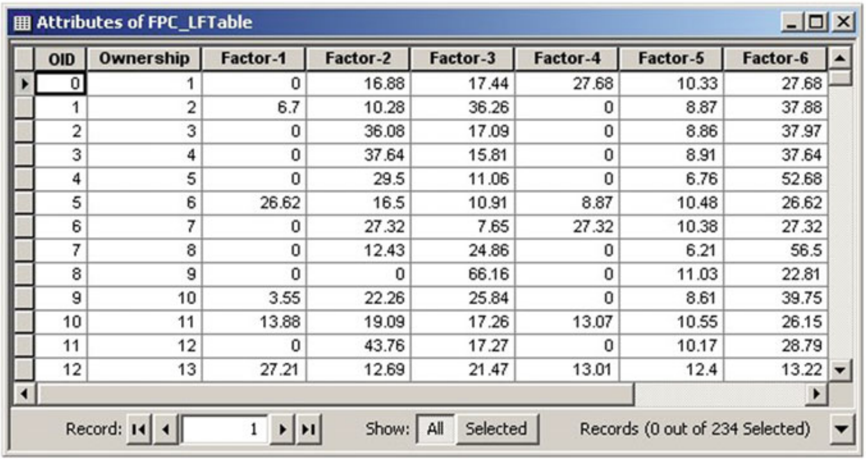
Fig. 7.12 The window for calculating land fragmentation indices



OID	Ownership	Factor-1	Factor-3	Factor-5	Factor-6	LFindex
0	1	0	0.61	0.63	1	0.373333
1	2	0.123871	0.19	0.67	0	0.163979
2	3	0	0.95	0.45	0	0.233333
3	4	0	1	0.42	0	0.236667
4	5	0	0.56	0.21	0	0.128333
5	6	1	0.62	0.41	0.333333	0.393889
6	7	0	1	0.28	1	0.38
7	8	0	0.22	0.44	0	0.11
8	9	0	0	0.58	0	0.096667
9	10	0.089196	0.56	0.65	0	0.216533
10	11	0.530713	0.73	0.66	0.5	0.403452
11	12	0	0.76	0.3	0	0.176667
12	13	0.83644	0.39	0.66	0.4	0.381073
13	14	0.030315	0.29	0.52	0	0.140053

Fig. 7.13 An example of a standardised LF table

fragmentation table) as shown in Fig. 7.14. Hence for each row,the contribution sums to 100 %. The global contribution of each factor is estimated as the mean value of these percentages for all ownerships.



Attributes of FPC_LFTable

OID	Ownership	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
0	1	0	16.88	17.44	27.68	10.33	27.68
1	2	6.7	10.28	36.26	0	8.87	37.88
2	3	0	36.08	17.09	0	8.86	37.97
3	4	0	37.64	15.81	0	8.91	37.64
4	5	0	29.5	11.06	0	6.76	52.68
5	6	26.62	16.5	10.91	8.87	10.48	26.62
6	7	0	27.32	7.65	27.32	10.38	27.32
7	8	0	12.43	24.86	0	6.21	56.5
8	9	0	0	66.16	0	11.03	22.81
9	10	3.55	22.26	25.84	0	8.61	39.75
10	11	13.88	19.09	17.26	13.07	10.55	26.15
11	12	0	43.76	17.27	0	10.17	28.79
12	13	27.21	12.69	21.47	13.01	12.4	13.22

Record: 1 Show: All Selected Records (0 out of 234 Selected)

Fig. 7.14 An example of a factor percentage contribution land fragmentation table

7.3.5 Sensitivity Analysis

Sensitivity analysis (SA) is a process involving the investigation of the impacts in the outcomes of even potentially slight changes and errors in the problem inputs, i.e. data and parameters. As noted in Sect. 5.3.2, sensitivity analysis is the last step of the MADM and it is very critical task that must be carried out in decision-making processes since it reveals how reliable the final decisions are [16]. However, a study carried out by Delgado and Sendra [17], which reviewed how SA has been involved in spatial multi-criteria decision problems, revealed that it is not a common practice. In the case of MADM, two important elements need to be examined in the context of SA: the weights of the evaluation criteria and the criterion scores (or performance measures) [1, 6].

This model inherently involves two sources of uncertainty: the weighting of land fragmentation factors by the planner and the estimation of the performance scores of ownership for three out of six factors (F1, F2 and F3) because of the utilisation of standardisation methods, namely, value functions which are defined by the experts. The model provides an SA operation for the former and not for the latter source of uncertainty. In particular, the model incorporates a SA operation for investigating predefined weighting alterations for various percentages from 10 to 100 % (at increments of 10 %) provided by the 'Sensitivity analysis' menu bar, which launches a window like that shown in Fig. 7.15. On the other hand, it is impossible to systematically investigate the potential sensitivity of performance scores because any standardisation method, especially a different value function, may result in different scores with an irregular pattern. Therefore, standardisation methods need to be applied with awareness and especially value functions need to be carefully considered by experts by analysing their behaviour, i.e. the sensitivity

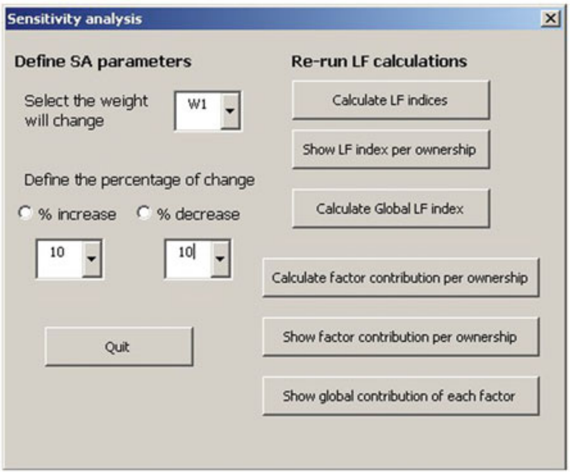


Fig. 7.15 The window for carrying out SA on the weights of the factors

of each function during the process of their definition, which has been done in this research.

The SA window calculates new outcomes regarding the land fragmentation indices defined in the previous section, based on selected increases or decreases in the value of a particular weight and the proportional readjustment of the value of the rest of the weights. Thus, a planner may compare the results for various changes of weights and assess the sensitivity of each factor for all land fragmentation indices.]

7.4 Shape Analysis

7.4.1 Outline

Shape measurement has been one focus of geographical study for many years [18]. Several authors have attempted to develop generic methods for measuring shape (e.g. [18, 19]. MacEachren [20] identifies four approaches: perimeter area ratios; direct comparison to a standard shape; dispersion of elements of an area around a central point; and single parameters of related circles. There are problems with each of the methods and it is sometimes hard to explicitly understand the differences or similarities in index values between various shapes. As a result, there is still no satisfactory method for measuring shape in a standard and explicit manner because of the variety of factors involved for each specific spatial context such as political geography, ecology, agriculture or urban geography.

Therefore, efforts for developing a new method should be focused on analysing shapes in the context of each particular problem [20] and satisfying the following requirements pointed out by Lee and Sallee [19]: (i) each shape should be represented by a unique numerical value. Although this is in general reasonable, two or more different shapes may have very similar values compared to a 'standard shape'; (ii) no two shapes can be represented by the same numerical value unless they are completely the same; the remark made in the previous requirement is also appropriate for this statement; (iii) two similar shapes should be assigned close numbers. Two other requirements are as follows: (iv) a shape index should take values within a predefined dimensionless range so that there is an explicit definition of what is the best and worst shape for the problem concerned, i.e. 1 and 0, respectively; and (v) a shape index needs to be comprehensive, i.e. take into account all possible factors (not only compactness and/or regularity as with generic methods) that are associated with the problem concerned. Moreover, the precision of an index should be chosen for ease of understanding and interpretation by planners. Practice shows that the optimal number of decimal digits to satisfy these conditions is three.

Based on the above considerations, a new shape index should be incorporated as a factor in the land fragmentation model. Several studies have dealt with this issue, some many years ago such as Barnes [21], Lee and Sallee [22], Johnson [23], Witney [24], Landers [25], Gonzalez et al. [26, 27], Aslan et al. [28], Amiana et al. [29], Libecap and Lueck [30]. Despite these studies, there is not yet an index that reliably represents the impact of parcel shape on the effectiveness of cultivation [29] and, more generally, on agricultural development.

7.4.2 Existing Parcel Shape Indices

Only few studies dealt with land parcels shape indices. However, these indices present significant weaknesses. In particular, Aslan et al. [28] have utilised indices that take into account the perimeter (p) and area (a) of parcel i. Such indices are the shape index (SI) shown in Eq. 7.11 [31] and the fractal dimension (FD) shown in Eq. 7.12 [32–35]:

$$SI = \frac{p_i}{2\sqrt{\pi a_i}} \tag{7.11}$$

$$FD = \frac{2 \ln p_i}{\ln a_i} \tag{7.12}$$

Both indices have been developed to represent ecosystem fragmentation, i.e. splitting up contiguous ecosystems into smaller areas called 'patches' [36]. Patches may be classified based on land cover and land use, habitat and vegetation. Thus, these indices are focused on landscape and they are not appropriate for use individually for land parcel shape analysis. In particular, both indices do not meet any of the requirements set out above except for that noted in (iii).

Figures 7.16 and 7.17 show the *SI* and the *FD* for various shapes, respectively. These examples have been picked up from the case study area in Cyprus (Chap. 6) except for the shaded parcels which are simulated. As illustrated in Figs. 7.16e and 7.17c, the shapes are alike and they have similar indices, i.e. requirement (iii) is satisfied. In contrast, requirements (i) and (ii) are not met as illustrated in Figs. 7.16a–d and 7.17a–c, respectively. In particular, the SI for all rectangles equals 1.128 (and not 1 as noted by [28]. Figure 7.16a shows that shapes significantly different from a rectangle may have exact or very similar *SI* values. Similarly, Fig. 7.16b–d indicate that considerably dissimilar shapes may have the same *SI* value when compared to a regular or near regular shape.

Even worse, the *FD* gives different values for different sizes of rectangles (Fig. 7.17a) while similar to the *SI*, the same values emerge from significantly dissimilar shapes with apparent varying quality (Fig. 7.17b). Requirements (iv) and (v) are also not met by either index. Another index that takes into account the

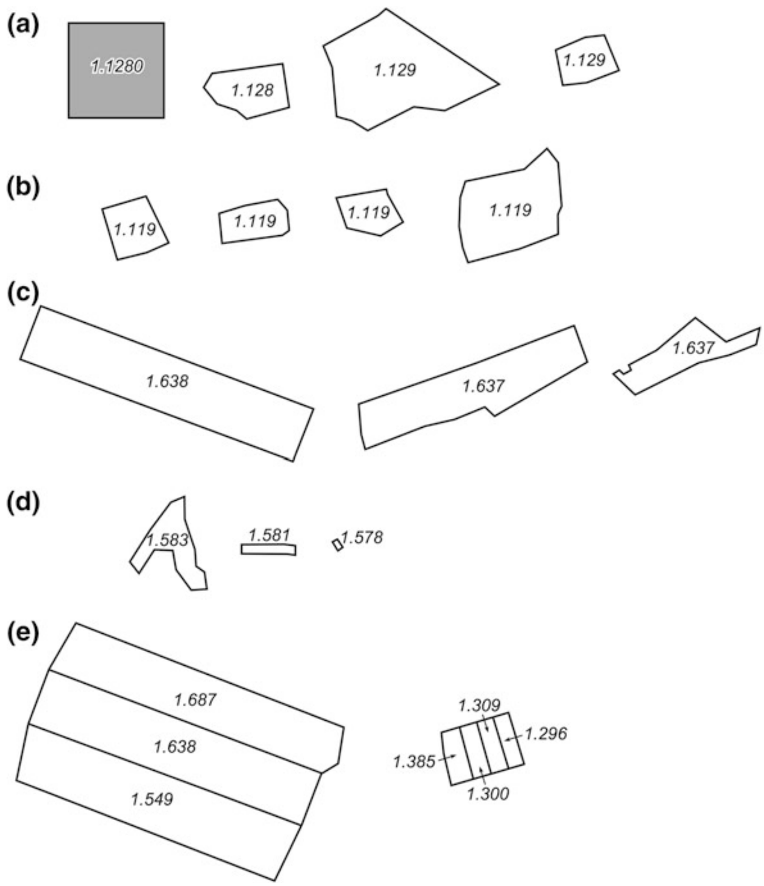


Fig. 7.16 Shape index (*SI*) for various shapes taken from the case study

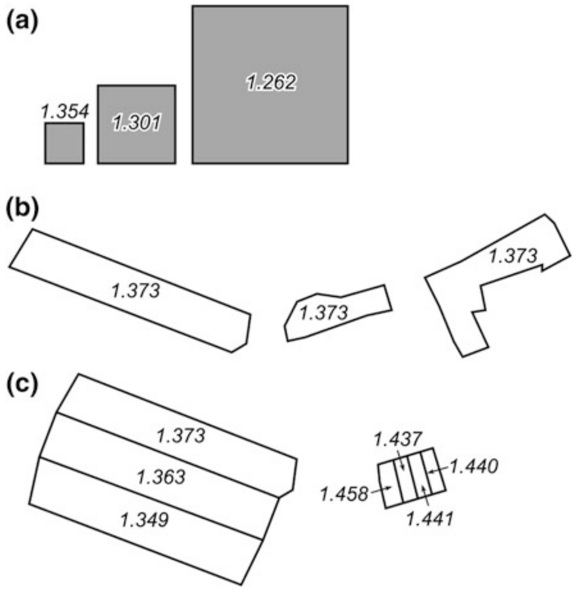


Fig. 7.17 Fractal dimension (*FD*) for various shapes taken from the case study

perimeter and area of a parcel is that utilised by Gonzalez et al. [26, 27] and earlier by Witney [24], which is called the areal form factor (AFF) shown in Eq. (7.13):

$$AFF = \frac{a_i}{p_i^2} \tag{7.13}$$

It is a differentiation of the simple area/perimeter ratio that has the advantage of being independent of parcel size. Witney [24] and Gonzalez et al. [26] demonstrated that the optimal *AFF* for agricultural purposes based on the maximum useful area (i.e. the area that can actually be exploited) is 0.04 and corresponds to a rectangle with a length: breadth ratio of 4:1. This index has been incorporated by Gonzalez et al. [26] into a broader measure called the combined size and shape index (CSSI), which is an estimate of tillage time per useful area based on a predefined set of 36 standard parcel shapes. Similar to the *SI* and *FD* noted above, the *AFF* fulfils only requirement (iii) as shown in Fig. 7.18f. In contrast, Fig. 7.18a–e indicate that completely different shapes, which are clearly very bad for agricultural purposes, may have very close *AFF* values with orthogonal shapes (of various length: breadth ratios) and thus requirements (i) and (ii) are not fulfilled. In other words, while the *AFF* gives certain numbers for rectangular shapes of different length: breadth ratios, the same numbers represent considerably irrelevant and irregular shapes. This is also obvious in the *AFF* values of the 36 standard parcel shapes defined by Gonzalez et al. [26], which is a serious disadvantage of this methodology. Similar to the previous indices, requirements (iv) and (v) are not satisfied.

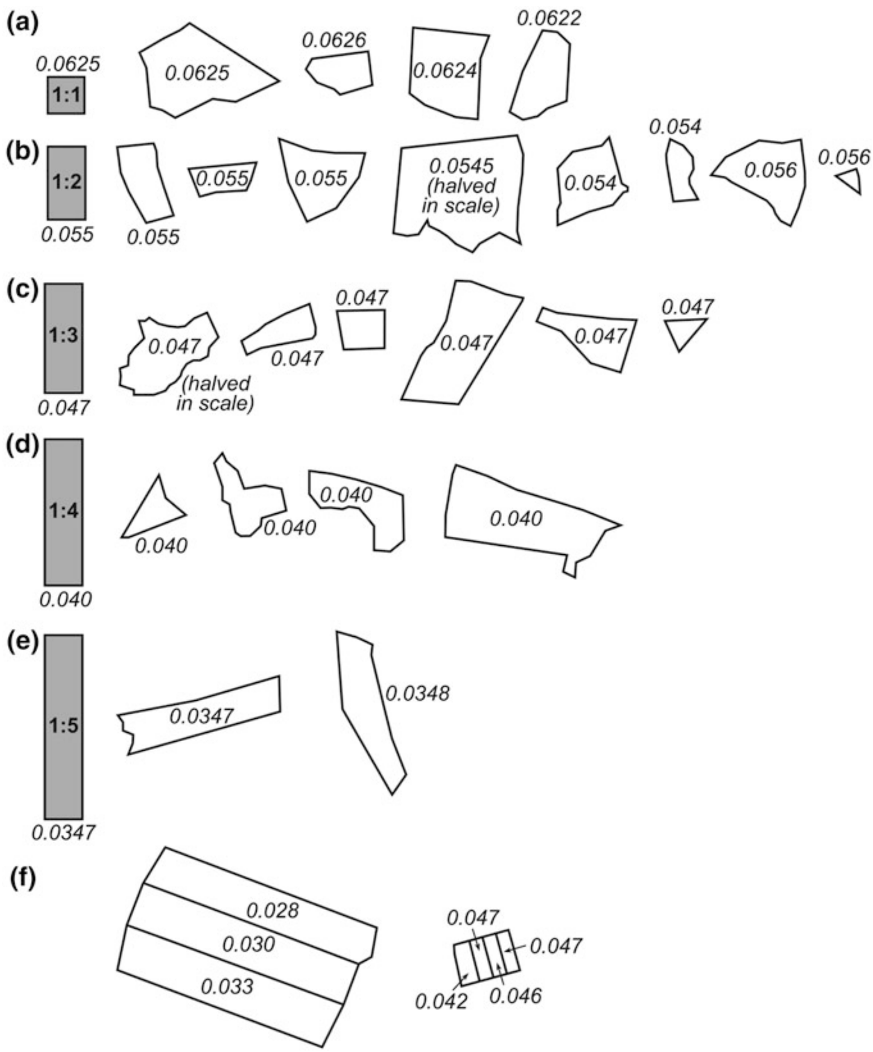
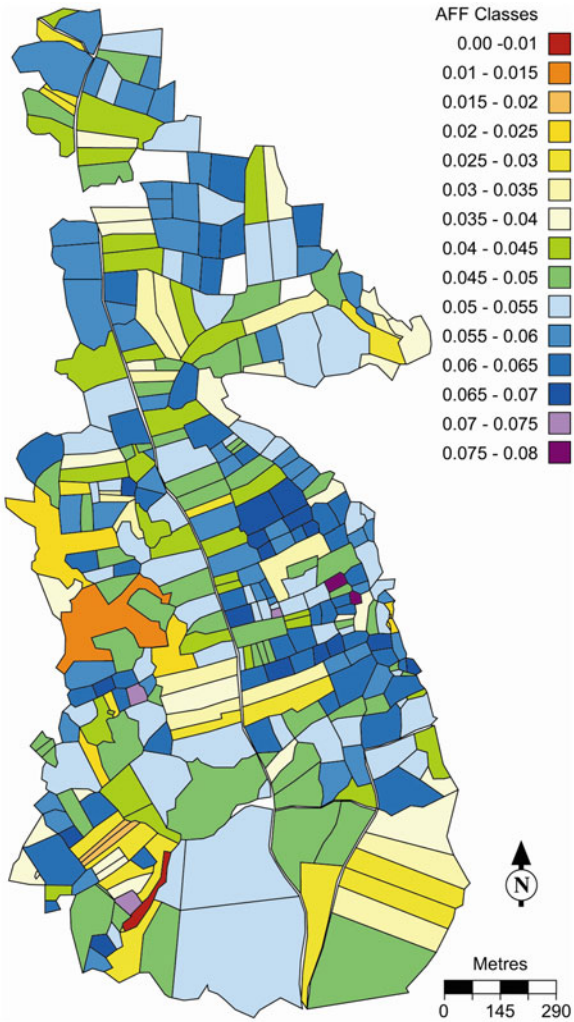


Fig. 7.18 *AFF* values for various parcel shapes taken from the case study

In addition, the *AFF* is poor at representing shapes appropriate for agriculture because it actually measures only the compactness of a shape [20, 29]. In particular, if the relation between the area and the perimeter of a shape is in 'harmony', then the *AFF* takes a value of greater than 0.04; otherwise a shape with a tailed or complex form takes a value of less than 0.04 as shown in the thematic map with *AFF* values for all the parcels in the case study area (Fig. 7.19).

To overcome the deficiencies of existing shapes indices, more factors must be taken into account that will be capable of comprehensively representing all shape

Fig. 7.19 Thematic map classifying *AFF* for the parcels of the case study



parameters, and are able to collectively define what are good and bad shapes for a land parcel. Recent efforts to tackle the disadvantages of the *AFF* have been undertaken by Amiama et al. [29] who proposed two new indices: the first is the highest ratio between the area of a parcel and the area of the quadrilateral with orthogonal sides that best circumscribes the parcel and; the second applies a correction factor that results from comparing the parcel perimeter with the perimeter of the quadrilateral, measured on a scale between 0 and 1. There was insufficient detail in Amiama et al. [29] on which to base any calculation of these indices in order to examine their performance on the case study parcels. However, as the authors were only able to produce results that were slightly better than the

AFF, we surmise that both of these indices will present similar weaknesses to those of the *AFF* noted earlier.

A final relevant study is that of Libecap and Lueck [30], who utilised a variantof the area-perimeter ratio $(p_i/\sqrt{a_i})$ and the number of sides to calculate average values of each quantity based on the parcels in a township. The index was calculated for the case study parcels and revealed the same weaknesses as those of the *SI* and *AFF*. Thus the *SI*, *FD* and *AFF* and other related indices from the literature are currently inappropriate for agriculture because they take only two geometric parameters of parcel shape into account, which is clearly insufficient. More parameters are needed in order to quantify the shape of a parcel while allowing for clear definition of which shapes are good and which are bad. Other studies that have used parcel shape indices include those by Coelho et al. [37], who employed a shape coefficient representing the effect on machine turning time in relation to a rectangular shape without giving any other information, and Tourino et al. [14], who simply used the average perimeter of land parcels as an evaluation indicator.

7.4.3 A New Shape Analysis Index for Land Consolidation

A new parcel shape index (*PSI*) has been developed as part of this research which involves six significant parameters that comprehensively describe the shape of a land parcel compared with an optimum-standard shape. Parcels with irregular shapes present many disadvantages in terms of parcel cultivation, lower crop yields, land wastage, need for increased conservation works (e.g. fencing) or boundary disputes [38]. Therefore, many studies have discussed the advantages provided by rectangular parcels [21, 22, 24, 25, 39, 40]. As noted earlier, Witney [24] and Gonzalez et al. [26] have shown that the most optimal rectangle in terms of cultivation is one with a length: breadth ratio of 4:1. However, this finding is based on the maximum ploughing area, i.e. the minimum dead ground, a parameter relating to cultivation and not to other factors such as irrigation, crop type or the potential land-use changes of a parcel. Thus, in Cyprus, where limited housing development is permitted in agricultural areas, the optimal parcel shape utilised in practice (at least in land consolidation areas) is a rectangle with a length: breadth ratio of 2:1 or alternatively something between 1:1 and 3:1 with the former considered (empirically) as the optimum shape for this research. As a result, the new parcel shape index (*PSI*) compares the shape of a land parcel with this optimum shape.

The *PSI* explicitly defines the best and worst shape for agricultural development, i.e. the shape index equals 1 and 0 respectively. In particular, a *PSI* value of 1 represents the optimum shape where shapes such as a square or a rectangle with a length: breadth ratio of 3:1 will also be assigned values very close to 1, namely, 0.931 and 0.889, respectively. As the length: breadth ratio continues to increase,

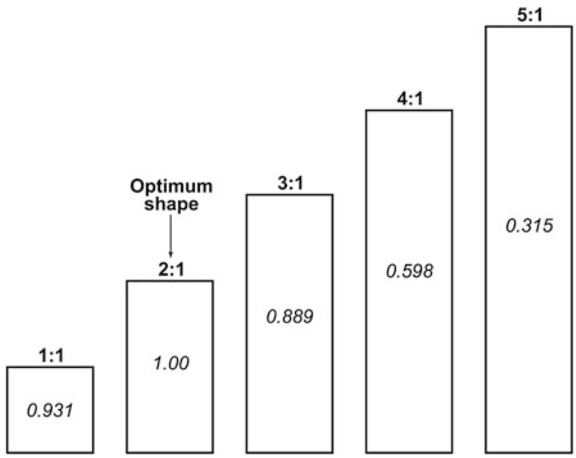


Fig. 7.20 *PSI* values for rectangle with various length: breadth ratios

i.e. to 4:1 and 5:1, the *PSI* decreases to 0.598 and 0.315 respectively, indicating that these shapes are less desirable. These shapes and their *PSI* values are shown in Fig. 7.20.

In particular, the parcel shape index for parcel i (PSI_i) is computed by multiplying the standardised score of each parameter (P_{ij}) by the relevant parameter weight (w_j) and summing these up divided by the number of parameters (m) involved. The relevant equation is shown below:

$$PSI_i = \frac{\sum_{i=1}^{m} P_{ij} w_j}{m} \quad (7.14)$$

Equation (7.14) contains the parameters (m) which can be defined in more detail as: (i) Length of sides (f1): the length of a side of a land parcel should exceed some specified minimum and may theoretically reach any value depending on the length of the other sides and the area. (ii) Acute angles (f2): an acute angle is an angle that is less than 90°. Acute angles constitute a weakness for a land parcel [29] and the more acute angles there are in a parcel shape, the worse this becomes. (iii) Reflex angles (f3): a reflex angle is more than 180° but less than 360°. Similar to acute angles, the presence of reflex angles constitutes a drawback for land parcel exploitation. (iv) Boundary points (f4): the number of corners of a parcel defines the density and complexity of a polygon. Thus, clearly the desirable number of boundary points for a land parcel is four although a slightly higher number of points may not worsen a shape if all other factors are satisfied. (v) Compactness (f5): although problematic if utilised in isolation (for the reasons outlined previously), it is necessary to include this factor in the new shape index because it ensures that a shape has a 'harmonic' area/perimeter ratio. (vi) Regularity (f6): any regular polygon has a rotational symmetry; thus, all of its points circumscribe a common circle. In addition, a regular polygon has all sides and angles equal.

Therefore, this parameter is used to check if a parcel has a regular shape like that of the optimum shape. More details regarding the rationale of defining these parameters are discussed in Demetriou et al. [15]. A block of the relevant code for calculating (i), (ii), (iv) and (vi) is presented in Appendices B.1.3 to B.1.6, respectively.

7.4.4 Standardisation

The first five shape parameters are standardised using value functions, which were defined by five land consolidation experts based on a process explained in Sect. 7.2.4. Value functions and the corresponding equations are indicated in Fig. 7.21(a–e).

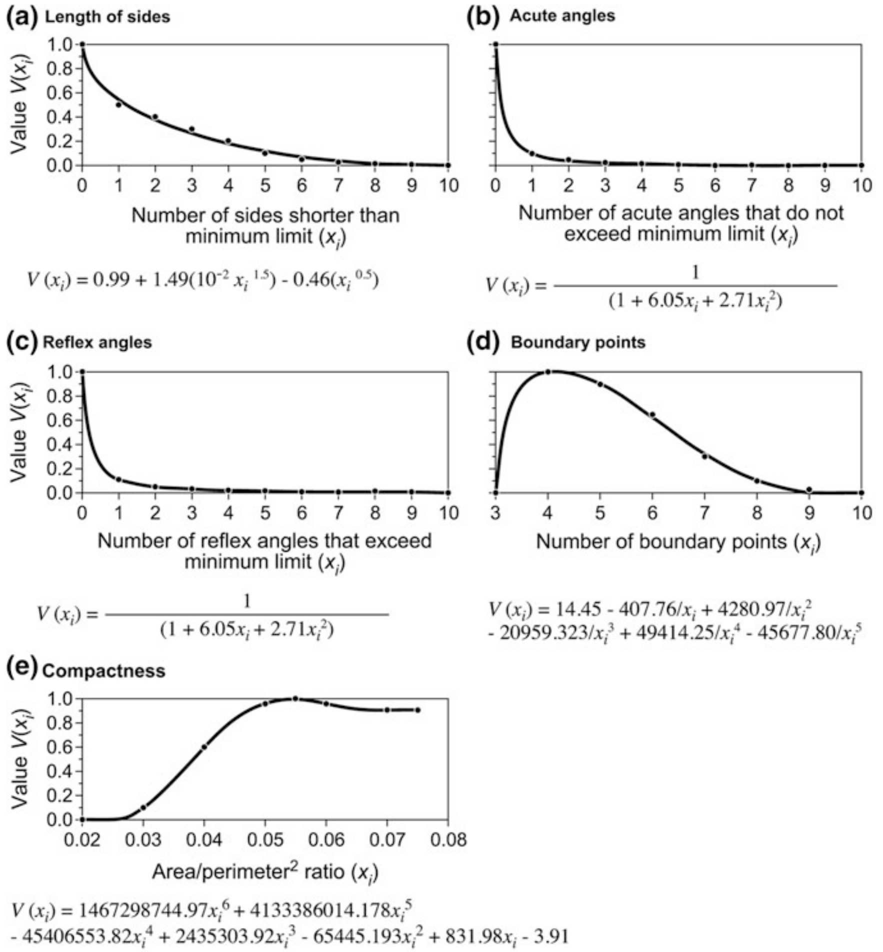


Fig. 7.21 The value functions and the equations for the five shape parameters

In all of the value functions, scores less than X_{min} are standardised to 0, while scores higher than X_{max} are standardised to 1. Further information with respect to the rationale for constructing each value function is provided in Demetriou et al. [15]. The sixth shape parameter (regularity) is not standardised using a value function because the values are case study dependent and are not a function of expert judgement. Thus, it was standardised by employing the mSM already described in Sect. 7.2.3

7.5 Case Study

In this section, LandFragmentS is applied to the case study area. Four issues are investigated: the four weighting scenarios; the comparison of the GLFI with existing indices; a sensitivity analysis focused on changes to the weights; and a comparison of the new *PSI* with existing indices.

7.5.1 The Effect of Changing the Weights of the Factors

Land fragmentation at both levels, i.e. ownership and global, has been calculated based on four scenarios. In scenario 1, all six criteria have been given the same weight. In scenario 2, weights were assigned to each of the first five criteria in the following descending order of importance: extremely high, very high, high, intermediate, moderate and low. In contrast, the weights in scenario 3 have been assigned in ascending order of importance, whilst in scenario 4, they were assigned based on the judgement of the author as: very high, high, extremely high, extremely high, intermediate and high which are then transformed to numerical values based on the qualitative rating method. The *GLFI* and the impact of each factor (%) for each scenario are presented in Table 7.4.

Table 7.4 The *GLFI* and the impact of each factor for four weighting scenarios

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
GLFI	0.512		0.555		0.491		0.515	
	W	C	W	C	W	C	W	C
F1	0.167	26.34	0.303	42.18	0.061	10.98	0.182	28.32
F2	0.167	15.69	0.242	21.25	0.091	9.1	0.136	13.06
F3	0.167	18.92	0.182	18.95	0.121	15.23	0.227	25.33
F4	0.167	6.94	0.121	5.03	0.182	7.66	0.227	9.14
F5	0.167	8.45	0.091	4.38	0.242	13.03	0.091	4.58
F6	0.167	23.66	0.061	8.21	0.303	44.00	0.136	19.57
Sum	1.00	100	1.00	100	1.00	100	1.00	100

W weight, *C* contribution
F1 Dispersion, *F2* Size, *F3* Shape, *F4* Accessibility, *F5* Dual ownership, *F6* Shared ownerships

Table 7.4 reveals firstly, that there is no combination of weights that presents a considerably different picture regarding existing land fragmentation. The maximum difference, i.e. between the minimum and maximum *GLFI* (scenarios 2 and 3, respectively), is not significant, i.e. 13.03 %. As a result, there is no issue regarding the existence or not of a land fragmentation problem for the case study area since the *GLFI* is around 0.50 in all scenarios. That is, the current situation is around 50 % from the optimum situation and this suggests a significant deficiency in the tenure system. Land fragmentation is therefore a problem in this area. Empirically, it could be said that a *GLFI* of greater than 0.70 could imply a satisfactory situation where 1 means no land fragmentation problem at all and 0 suggests very serious land fragmentation. This assumption could be investigated in more detail by considering other economic indices regarding agricultural production, farmer income, etc.

Secondly, although the impact of each factor in the land fragmentation problem is influenced by the weight assigned to each factor, it seems that some factors achieve the highest or among the three highest contributions to this problem, independent of the weight. In particular, F1 (the dispersion of parcels) has the highest negative impact in three out of four scenarios followed by F6 (shared parcels) with the highest, second highest and third highest contribution in scenarios 3, 1 and 4 respectively; F3 (parcel shape) has the second highest contribution in scenarios 3 and 4 and the third highest contribution in scenarios 1 and 2. Other factors have less influence. This outcome suggests that factors F1, F6 and F3 magnify and are responsible for the land fragmentation problem in the case study area compared to factors F2, F4 and F5 that have less influence in this particular context.

7.5.2 Comparison of the LandFragmentS Indices with Existing Indices

The comparison of the land fragmentation index that resulted from LandFragmentS and the formulas of Simmons and Januszewski are presented in Fig. 7.22. It is obvious that the Simmons and Januszewski indices present similar patterns. As a result, the correlation coefficient is very high indeed (r = 0.98). The difference between the indices is that the Januszewski index gives higher values with a minimum of 0.364, an average of 0.841 (maximum value is 1 for both indices) and a narrow spectrum of values (standard deviation of 0.186). In contrast, the Simmons index gives lower values with a minimum of 0.160, an average of 0.785 and a wider range of values (standard deviation equals 0.262). On the other hand, the new index (*LFI*) clearly results in considerably lower values compared to both existing indices (although the minimum value of the Simmons index is lower) as revealed by the values of the basic statistics: minimum 0.216; maximum 0.839; and average 0.512. It is also noteworthy that around 50 % of ownerships achieved

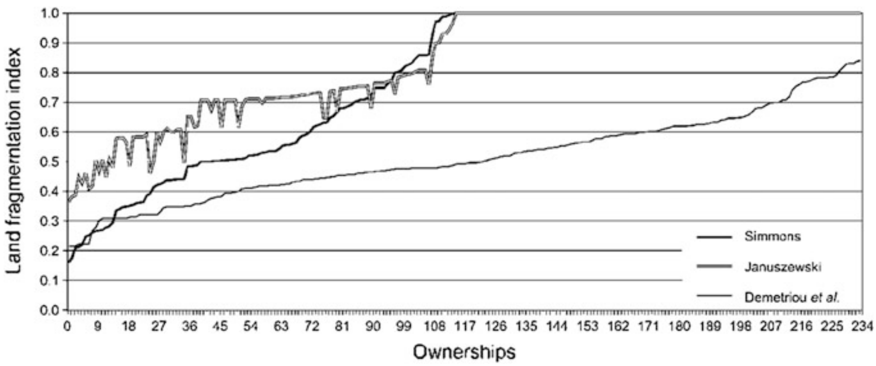


Fig. 7.22 Comparison of Simmons, Januszewski and Demetriou et al. indices

the maximum index value for both existing indices whilst in contrast no ownership achieved the maximum in the new method.

The above outcomes clearly indicate that both of the existing indices can be misleading because they underestimate the problem of land fragmentation giving significantly higher average values, i.e. around 0.8 in both cases compared to the *GLFI* (0.5); hence the policy decisions made from these indices will be wrong. In contrast, the *GLFI* outcome is more reliable because it takes into account six land fragmentation factors while only two are considered by the existing indices, suggesting that the area concerned has a significant land fragmentation problem since the global value is around the middle of the scale between 0 (worst land fragmentation) and 1 (least land fragmentation). It is interesting to note that land consolidation was carried out in this study area, which is a decision closer to the *GLFI* and not to both existing indices.

7.5.3 Sensitivity Analysis

Table 7.5 shows the *GLFI* values and percentage changes (compared with the *GLFI* when the weights are equal) for either an increase or decrease in the weight of each factor by 10–100 %. The last row of the table shows the maximum percentage difference of the *GLFI* values for the minimum to maximum change, i.e. 10–100 %. A general outcome is that the *GLFI* is not significantly sensitive to changes in the weights because even for a 100 % weight change, the maximum change in the index is around ±8.90 %, i.e. the *GLFI* equals 0.462 and 0.563 in the case of an increase and decrease in the weight for F5. This reveals stability in the outcomes and hence reliable policy decisions can be taken based on these indices. The percentage is shown in the bottom row of each panel of the table and reveals that factors F4 and F5 are equally the most sensitive for both increases and decreases in weight; F6 is a little bit less sensitive; F1 is sensitive only to a

Table 7.5 Sensitivity analysis of the weights of factors

Weight	W1				W2			
Change (%)	Increase		Decrease		Increase		Decrease	
10	0.517	−0.77	0.507	−0.99	0.512	0.00	0.512	0.00
20	0.523	0.38	0.502	−1.99	0.512	0.00	0.512	0.00
30	0.528	1.33	0.497	−3.02	0.512	0.00	0.512	0.00
40	0.533	2.25	0.492	−4.07	0.512	0.00	0.512	0.00
50	0.538	3.16	0.487	−5.13	0.512	0.00	0.512	0.00
60	0.543	4.05	0.482	−6.22	0.512	0.00	0.512	0.00
70	0.549	5.10	0.477	−7.34	0.512	0.00	0.512	0.00
80	0.543	4.05	0.472	−8.47	0.512	0.00	0.512	0.00
90	0.537	2.98	0.467	−9.64	0.512	0.00	0.512	0.00
100	0.531	1.88	0.462	−10.82	0.512	0.00	0.512	0.00
Max ch. (%)	2.71		−8.88		0.00		0.00	

	W3				W4			
	Increase		Decrease		Increase		Decrease	
10	0.513	0.19	0.512	0.00	0.507	−0.99	0.517	0.97
20	0.513	0.19	0.511	−0.20	0.502	−1.99	0.522	1.92
30	0.513	0.19	0.511	−0.20	0.497	−3.02	0.527	2.85
40	0.514	0.39	0.510	−0.39	0.492	−4.07	0.532	3.76
50	0.514	0.39	0.510	−0.39	0.487	−5.13	0.537	4.66
60	0.515	0.58	0.510	−0.39	0.482	−6.22	0.542	5.54
70	0.515	0.58	0.509	−0.59	0.477	−7.34	0.547	6.40
80	0.516	0.78	0.509	−0.59	0.472	−8.47	0.552	7.25
90	0.516	0.78	0.508	−0.79	0.467	−9.64	0.557	8.08
100	0.516	0.78	0.508	−0.79	0.462	−10.82	0.562	8.90
Max ch. (%)	0.58		−0.78		−8.88		8.70	

	W5				W6			
	Increase		Decrease		Increase		Decrease	
10	0.507	−0.99	0.517	0.97	0.517	0.97	0.508	−0.79
20	0.502	−1.99	0.522	1.92	0.521	1.73	0.503	−1.79
30	0.497	−3.02	0.528	3.03	0.526	2.66	0.499	−2.61
40	0.492	−4.07	0.533	3.94	0.53	3.40	0.494	−3.64
50	0.487	−5.13	0.538	4.83	0.535	4.30	0.490	−4.49
60	0.482	−6.22	0.543	5.71	0.539	5.01	0.485	−5.57
70	0.477	−7.34	0.548	6.57	0.544	5.88	0.480	−6.67
80	0.472	−8.47	0.553	7.41	0.548	6.57	0.476	−7.56
90	0.467	−9.64	0.558	8.24	0.553	7.41	0.471	−8.70
100	0.462	−10.82	0.563	9.06	0.558	8.24	0.467	−9.64
Max ch. (%)	−8.88		8.90		7.93		−8.07	

decrease and F2 and F3 are not sensitive. Hence, factors F4, F5 and F6 are the most critical.

However, in this case, the sensitivity has two opposite directions, i.e. factors F4 and F5 have a positive impact on the problem; hence by increasing their importance, the global index *GLFI* is reduced and vice versa. On the other hand, factors F1, F3 and F6 present a negative impact because, by increasing their importance, the *GLFI* is increased and *vice versa*. The *GLFI* for F2 does not change under any change of weight, indicating an independence of this factor from the weights. This finding is in accordance with the finding in Sect. 7.5.1 that factors F1, F3 and F6 have the highest negative impact in this case study context (although they may not be sensitive, e.g. F3), whereas F2, F4 and F5 have less influence.

7.5.4 Shape Analysis

The thematic map in Fig. 7.23 presents a classification of the *PSI* based on 10 categories and provides an overview of the evaluation of the shapes. In particular, going from category 1 with values around 0 to category 10 with values around 1 represents the worst (irregular-complex shapes) and best (i.e. regular rectangles) parcel shapes respectively. An overall visual inspection of each category reveals that there are common geometric characteristics of the parcel shapes that belong to each category, indicating that the index offers good consistency, reliability and accuracy. For a deeper investigation, parcels that belong to each class have been isolated in separate maps (Fig. 7.24 for *PSI* categories 1–6 and Fig. 7.25 for *PSI* categories 7–10).

Category 1 includes the parcels with the worst shape. All shapes are highly irregular and complex. It seems that there is a consistency in the value of the index since all shapes have similar geometric features. Similarly, categories 2 to 5 comprise highly irregular shapess in varying grades. The grade of irregularity or more precisely how far a shape is from the optimum varies, and different shapes may have a similar *PSI* because of different undesirable geometric characteristics. However, it should be noted that it may seem that some shapes, which are not irregular along the whole of their perimeter (namely a couple of their sides are straight lines), are disfavoured compared to shapes that are completely irregular along their whole perimeter. This happens because the model examines each shape as a whole compared to the optimum shape. Thus, even a shape with a few (or even all) straight sides is essentially irregular with several disadvantages for agricultural purposes. In addition, in classes 2 to 5, it seems that the accuracy of the *PSI* is very sensitive to small changes in the geometric features and the relevant value functions so that a shape may be in one of these four groups because it is better or worse than another in just one geometric feature.

In contrast to the first five categories, the other categories involve better shapes with more accuracy and consistency among them. As the *PSI* increases, the shapes begin to look more acceptable. In particular, categories 6 and 7 contain parcels with irregular shapes but these are definitely better than the shapes found in the previous groups. Both categories have shapes with common characteristics and most of them could be in either group. Category 8 includes shapes that are quite

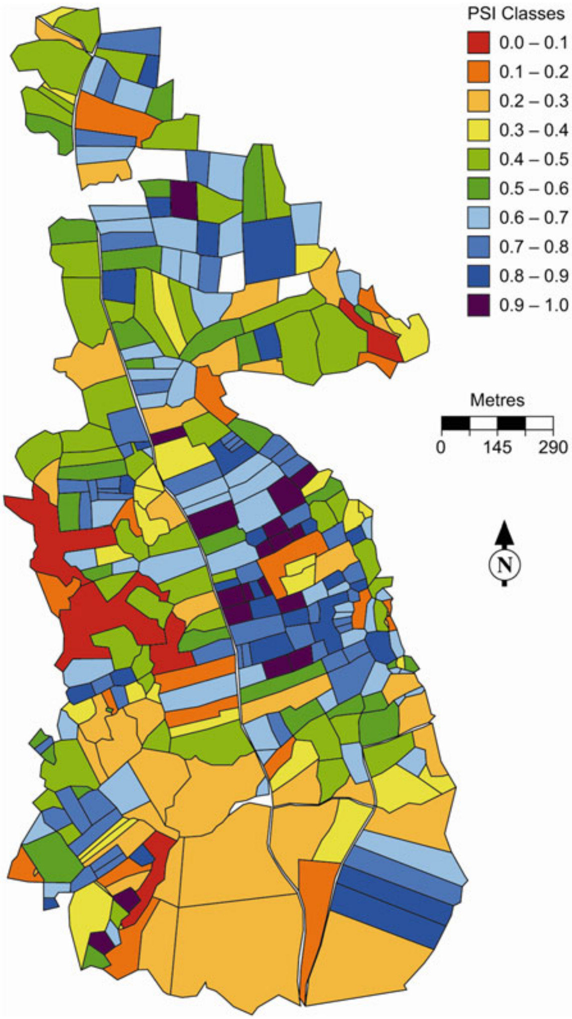


Fig. 7.23 Classification of the *PSI* based on ten categories

close to being regular. The similarities in the shapes illustrate the accuracy and consistency of the index. Similarly, category 9 involves almost regular shapes. Some of them are absolutely regular although they do not meet all the requirements of the optimum shape; for instance, the length: breadth ratio is different from the optimum. Finally, in category 10, almost all the parcels are optimum or close to optimum. The category also illustrates that the index is able to discern optimum shapes.

Based on the above analysis, the 10 categories were collapsed into four groups as shown in Fig. 7.26.

In particular, the four groups are as those with: highly irregular shapes (categories 1, to 5); irregular shapes (categories 6 and 7); regular or near regular shapes

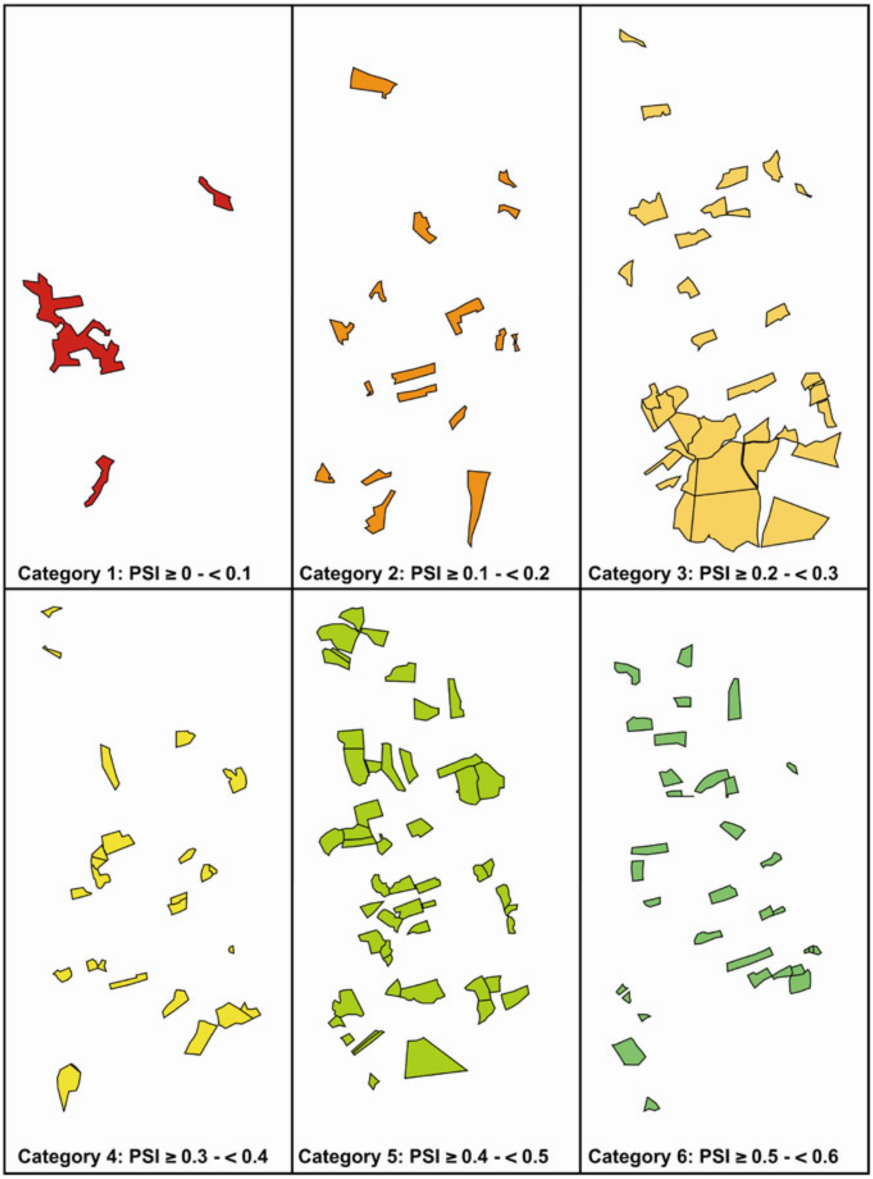
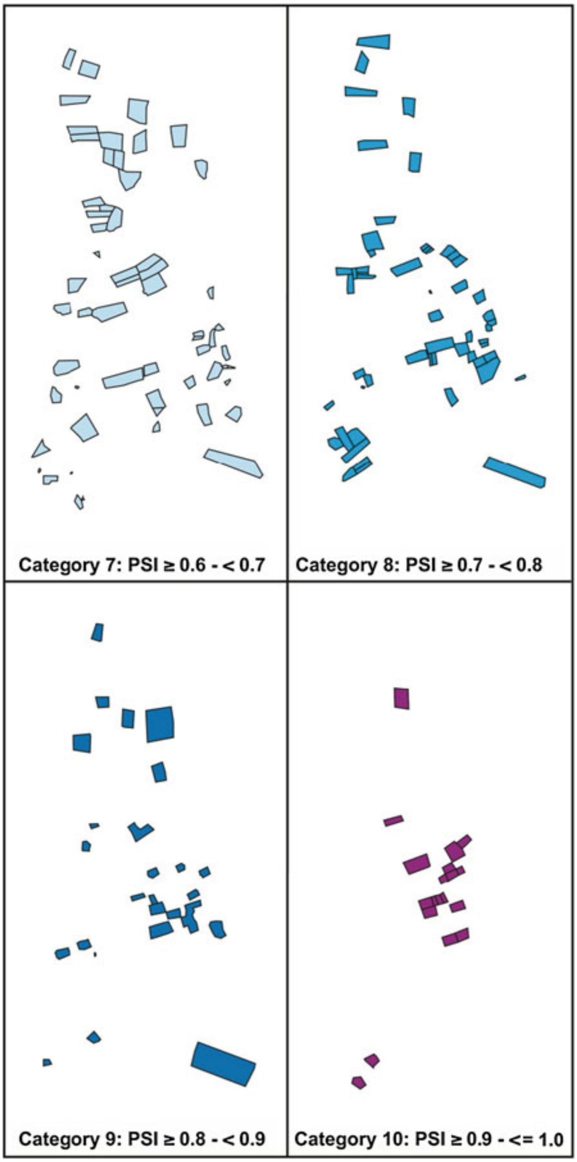


Fig. 7.24 Parcel shapes with PSI≥ to <0.6

(categories 8 and 9) and; optimum or near optimum shapes (category 10). It is logical that the majority of parcels (65.9 %) have either highly irregular shapes or irregular shapes, which is in accordance with the previous finding that the factor F3 (parcel shape) had the biggest negative impact on land fragmentation for the

Fig. 7.25 Parcel shapes with *PSI* ≥ 0.6 to ≤1.0



four weighting scenarios discussed earlier. Moreover, a small minority of parcel shapes (5.3 %) have optimum or near optimum shapes whilst a significant number (28.8 %) have regular or near regular shapes.

Based on the above results, a qualitative evaluation of the *PSI* can be undertaken by checking its ability to satisfy the five requirements noted in Sect. 7.4.1. In particular, requirements (iv) and (v) are satisfied by the *PSI* because it ranges from

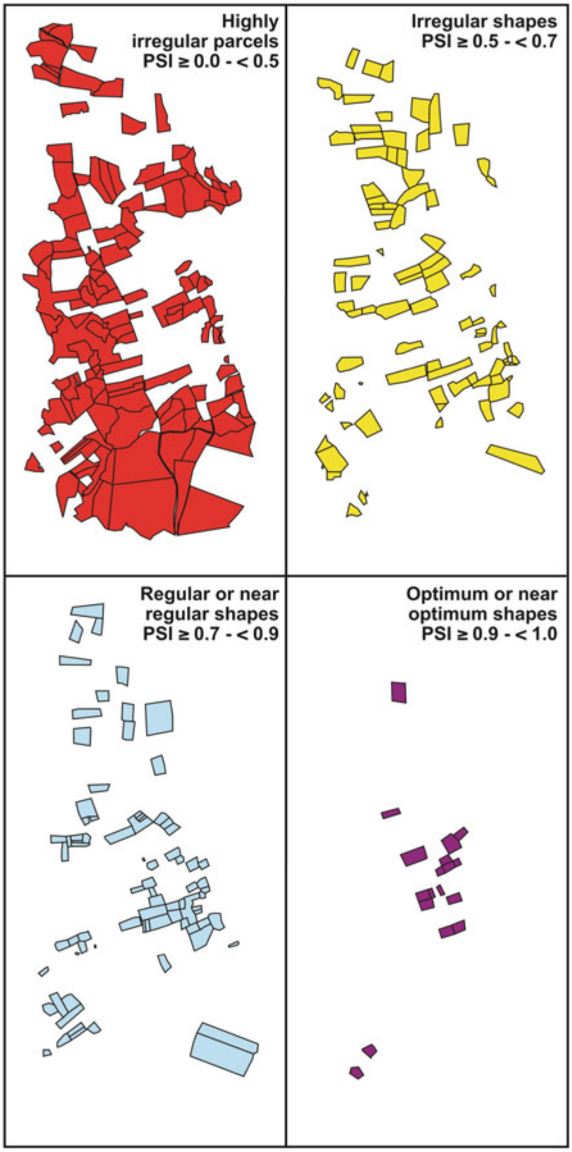


Fig. 7.26 Classification of parcel shapes based on four groups

0 to 1 and it takes into account six geometric parameters that comprehensively describe a shape. In addition, requirement (i) that each shape should be represented by a unique number is also satisfied, especially if comparison is made with a precision of three of four decimal places. However, some shapes may have very close indices either because they are similar (as noted in requirement (iii) or because they differ by the same distance in terms of quality compared to the

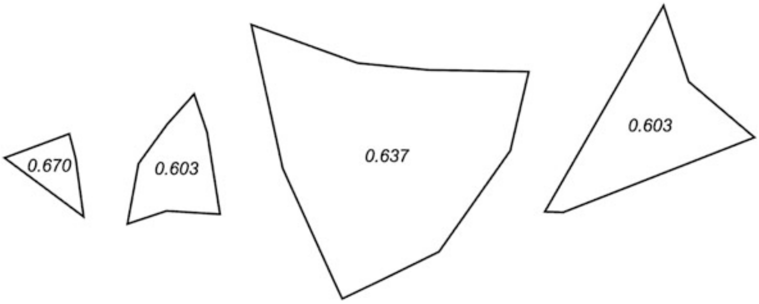


Fig. 7.27 Shapes which are favoured in terms of the *PSI*

optimum shape. This may seem as if requirement (ii) is not satisfied. However, this is possible when a method compares each shape with the optimum one as used here. As a result, two dissimilar shapes may have a similar index because they differ by almost the same distance in terms of quality from the optimum shape but for different undesirable geometric parameters.

Two weaknesses of the index are that: symmetrical shapes are favoured and hence they may have a higher index than expected, e.g. shapes with a triangular form as shown in Fig. 7.27 have a relatively high PSI; and shapes with a general regular form, i.e. those having some straight sides and some not straight, as shown in Fig. 7.28, are perhaps penalised more compared to shapes that have a completely irregular shape along their entire periphery. These weaknesses could be improved by either investigating a different form of the relevant value functions or by adding new value functions, e.g. for obtuse angles or by penalising symmetrical shapes with angles different than the limits suggested.

Furthermore, comparisons of the *PSI* with the *SI*, *FD* and *AFF* based on the same parcel shapes as shown in Figs. 7.16, 7.17 and 7.18 are provided in Figs. 7.29, 7.30 and 7.31. The PSI values are within parentheses while the values of the index with which they are being compared are not. The shaded parcels are simulated. In all these cases, the *PSI* overcomes the deficiencies of the existing indicators (noted in Sect. 7.4.2).This is evident through a visual inspection from the gradual way in which the index increases as the shapes improves towards the optimum. Hence, the *PSI* clearly outperforms existing indices. Based on all of the

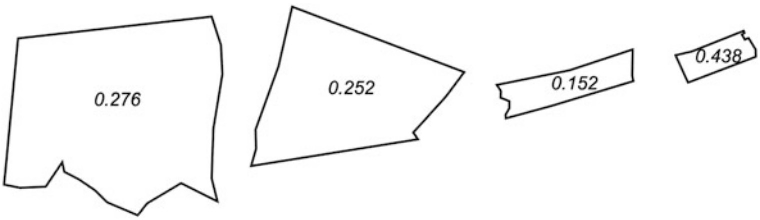


Fig. 7.28 Shapes which are disfavoured in terms of the *PSI*

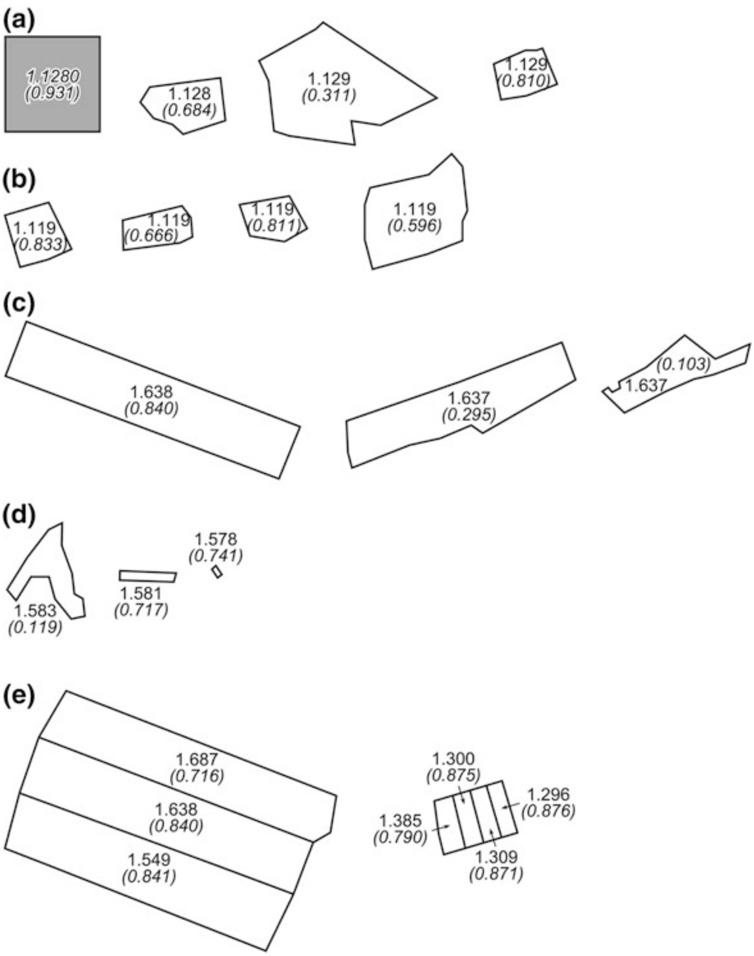


Fig. 7.29 Comparison of the *PSI* with *SI*

above considerations, a qualitative comparison of the existing indices with the *PSI*, based on whether they satisfy the five requirements, is presented in Table 7.6.

In addition to the above methods, it could be said with confidence that the indices developed by Amiama et al. [29] and Libecap and Lueck [30] also present the weaknesses of the three existing methods shown in the above table indicating the superiority of the *PSI* when compared against them.

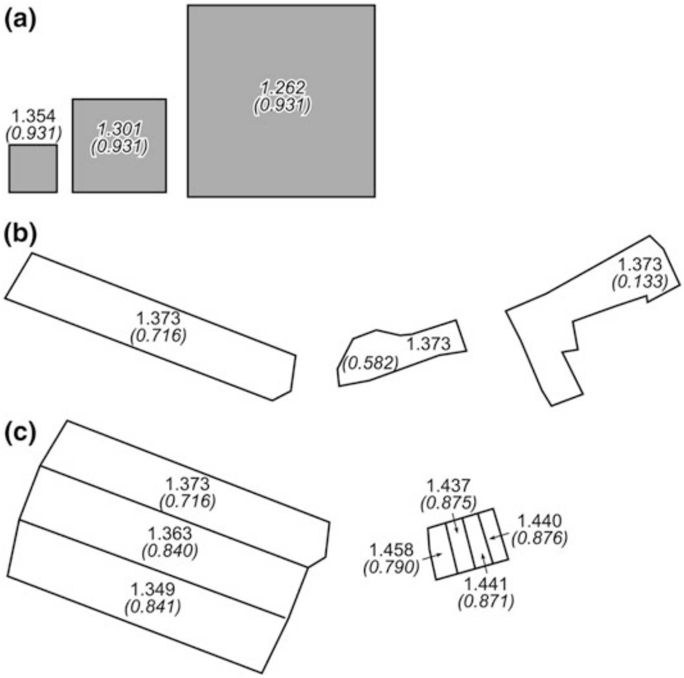


Fig. 7.30 Comparison of the *PSI* with the *FD*

Table 7.6 Comparison of existing indices with the *PSI*

Indices	AFF	SI	FD	PSI
Criterion				
I	×	×	×	✔
II	×	×	×	×✔
III	✔	✔	×	✔
IV	×	×	×	✔
VI	×	×	×	✔

✔ criterion satisfied, × criterion not satisfied, ×✔ criterion satisfied with preconditions

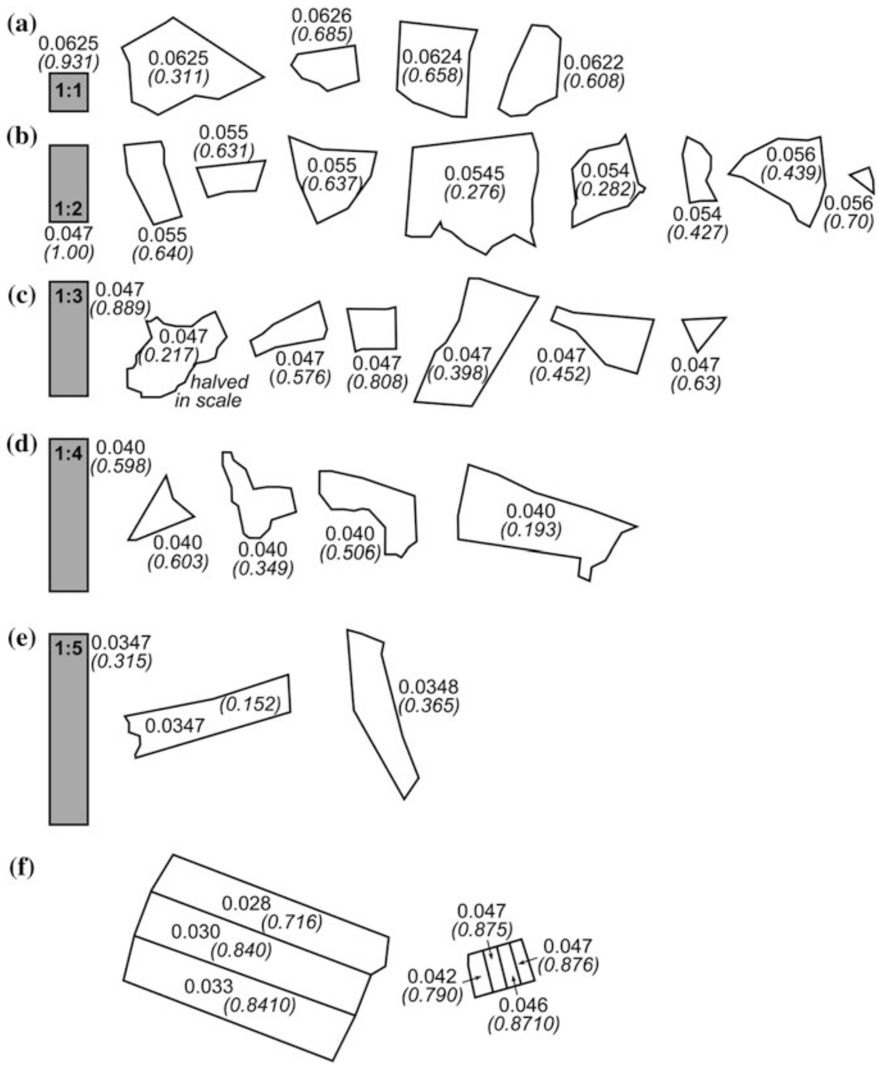


Fig. 7.31 Comparison of the *PSI* with the *AFF*

7.6 Conclusions

This chapter has presented a new land fragmentation index which overcomes the weaknesses of existing indices. In particular, the *GLFI* has the following features: it is comprehensive since it integrates six core land fragmentation factors; it is flexible because the user may select which factors should be taken into account for a particular project; and it is problem-specific since the planner may decide the weighting given to each factor for a specific project. The application of this new model using a case study and the comparison with the results produced by two popular existing indices showed that the latter indices underestimate the problem of land fragmentation, because they ignore several important variables, and hence they may be misleading in terms of the consequent decision making that might ensue. In comparison, the *GLFI* has been shown to be a more reliable and robust measure of land fragmentation and significantly outperforms the existing indices.

Furthermore, some other innovations should be highlighted. In particular, similar to the land fragmentation indices, existing shape analysis methods and especially parcel shape indices also suffer from some basic deficiencies. A new measure called the parcel shape index (*PSI*) has been developed based on six variables: length of sides; acute angles; reflex angles; number of boundary points; compactness and regularity. The case study showed that the *PSI* overcomes the problems of the existing indices and considerably outperforms the other indices. In particular, it is fairly accurate and reliable so as to classify shapes in four groups: highly irregular shapes; irregular shapes; regular or near regular shapes and optimum or near optimum shapes. Some minor weaknesses of the *PSI* have been identified and could be investigated in further research.

In addition to the above, a new transformation process called the 'mean standardisation method' (mSM) has been introduced. The mSM is better than similar existing methods such as maximum standardisation because the former may produce more balanced values compared to the latter since it takes into account not only the minimum and maximum scores but also the mean score of a sample. Thus, it is appropriate in cases when a sample includes extreme values. Furthermore, the 'qualitative rating method', which is a slightly modified version of the ratio estimation procedure, overcomes the problem of assigning either direct numerical values as weights or scores, which are then transformed as weights, by adopting a similar qualitative seven level scale of importance to that used in the pairwise comparison method. This chapter has also shown that MADM can be used not only for assessing a discrete number of alternative solutions as applied more conventionally, but also for exploring and measuring the performance of an existing system compared to an ideal system or evaluating the shape of an object compared to an optimum standard.

Once the new index suggests that land fragmentation is a problem, then the planner may proceed to run the land redistribution model, which is presented in the next chapter.

References

1. Malczewski, J. (1999). *GIS and multi-criteria decision analysis*. New York: Wiley.
2. Sharifi, A., Herwijnen, M., & Toorn, W. (2004). Spatial Decision Support Systems. Lecture Notes. ITC, International Institute for Geo-Information Science and Earth Observation, The Netherlands.

3. Keeney, R., & Raiffa, H. (1993). *Decision with multiple objectives: Preferences and value trade-offs*. Cambridge: Cambridge University Press.
4. Easton, A. (1973). *Complex managerial decisions involving multiple objectives*. New York: Wiley.
5. Beinat, E. (1997). *Value functions for environmental management*. Dordrecht: Kluwer Academic Publishers.
6. Triantaphyllou, E. (1997). A sensitivity analysis approach for some deterministic multi-criteria decision making methods. *Decision Sciences, 28*(1), 151–194.
7. Chen, Y., Yu, J., Shahbaz, K., & Xevi, E. (2009). A GIS-based sensitivity analysis of multi-criteria weights. In: *Proceedings of 18th World IMACS/MODSIM Congress*, 13–17 July, Cairns, Australia. Available from URL: http://www.mssanz.org.au/modsim09/I2/chen_y.pdf.
8. Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *The Psychological Review, 63*, 81–97.
9. Bodily, S. E. (1985). *Modern decision making: a guide to modelling with decision support systems*. New York: McGraw-Hill.
10. Simmons, A. J. (1964). An index of farm structure, with a Nottingahmsire example. *East Midlands Geographer, 3*, 255–261.
11. Januszewski, J. (1968). Index of land consolidation as a criterion of the degree of concentration. *Geographia Polonica, 14*, 291–296.
12. Ebdon, D. (1985). *Statistics in Geography*. Oxford: Blackwell Publishing.
13. Wong, D., & Lee, J. (2005). *Statistical analysis of geographic information: With ArcView and ArcGIS*. New Jersey: Wiley.
14. Tourino, J., Boullon, M., & Gonzalez, X. (2003). A GIS-embedded system to support land consolidation plans in Galicia. *International Journal of Geographical Information Science, 17*(4), 377–396.
15. Demetriou, D., Stillwell, J., & See, L. (2011). LandSpaCES: A spatial expert system for land consolidation. In S. Geertman, W. Reinhardt, & F. Toppen (Eds.), *Advancing geoinformation science for a changing world* (pp. 249–274). Berlin: Springer Verlag.
16. Pannell, D. (1997). Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. *Agricultural Economics, 16*, 139–152.
17. Delgado, M. G., & Sendra, J. B. (2004). Sensitivity analysis in multi-criteria spatial decision making: A review. *Human and Ecological Risk Assessment: An international Journal, 10*(6), 1173–1187.
18. Boyce, R., & Clark, W. (1964). The concept of shape geography. *Geographical Review, 54*(4), 561–572.
19. Lee, D., & Sallee, T. (1970). A method of measuring shape. *Geographical Review, 60*(4), 555–563.
20. MacEachren, A. (1985). Compactness of geographic shape: comparison and evaluation of measures. *Geografiska Annaler. Series B, Human Geography, 67*(1), 53–67.
21. Barnes, C. P. (1935). Economies of the long lot farm. *Geographical Review, 25*, 298–301.
22. Lee, D., & Sallee, T. (1974). Theoretical patterns of farm shape and central place location. *Journal of Regional Science, 14*(3), 423–430.
23. Johnson, H. B., (1976). *Order upon the land: The U.S. rectangular land survey and the upper mississippi country.* Oxford University Press, New York.
24. Witney, B. (1995). *Choosing and using farm machines*. Edinburgh: Land Technology Ltd.
25. Landers, A. (2000). *Resource management farm machinery: Selection, investment and management*. Farming Press, Tonbridge.
26. Gonzalez, X. P., Alvarez, C. J. & Crecente, R. (2004). Evaluation of land distributions with joint regard to plot size and shape. *Agricultural Systems, 82*, 31–43.
27. Gonzalez, X. P., Marey, M. F., & Alvarez, C. J. (2007). Evaluation of productive rural land patterns with joint regard to the size, shape and dispersion of plots. *Agricultural Systems, 92*, 52–62.
28. Aslan, T., Gundogdu, K., & Arici, I. (2007). Some metric indices for the assessment of land consolidation projects. *Pakistan Journal of Biological Sciences, 10*(9), 1390–1397.

29. Amiama, C., Bueno, J., & Alvarez, C. J. (2008). Influence of the physical parameters of fields and the crop yield on the effective field capacity of a self-propelled forage harvester. *Biosystems Engineering, 100*, 198–205.
30. Libecap, G., & Lueck, D. (2009). *The demarcation of land and the role of coordinating institutions*. NBER (The National Bureau of Economic Research) Working Papers Series. Working Paper No. 14942.
31. McGarical, K. & Marks, B. J. (1995). FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Washington, D.C., U.S. Department of Agriculture, Forest Service, General Technical Report No PNW-GTR-351.
32. Krummel, J. R., Gardner, R. H., Sugihara, G., O'Neill, R. V., & Coleman, P. R. (1987). Landscape pattern in a disturbed environment. *Oikos, 48*, 321–324.
33. O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L,, Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988). Indices of landscape pattern. *Landscape Ecology*, *1*, 153–62.
34. Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988). Indices of landscape patterns. *Landscape Ecology, 1*(3), 153–162.
35. Milne, B. T. (1991). Lessons from applying fractal models to landscape patterns. In M. G. Turner & R. H. Gardner (Eds.), *Quantitative methods in landscape ecology* (pp. 199–235). New York: Springer-Verlag.
36. Rutledge, D. (2003). *Landscape indices as measures of the effects of fragmentation: Can pattern reflect process? DOC Internal Series 98*. Wellington: Department of Conservation.
37. Coelho, C., Pinto, P. A., & Silva, M. (2001). A systems approach for the estimation of the effects of land consolidation projects (LCPs): A module and its application. *Agricultural Systems, 68*, 179–195.
38. Bentley, W. (1987). Economic and ecological approaches to land fragmentation: In defence of a much-maligned phenomenon. *Annual Review of Anthropology, 16*, 31–67.
39. Heady, E. O., & Jensen, J. R. (1954). *Farm management economies*. Prentice-Hall: Englewood Cliffs.
40. Hagget, P. (1966). *Locational analysis in human geography*. St. Martin's Press, New York.

Chapter 8
LandSpaCES Model (Design Module)

8.1 Introduction

This chapter deals with the development of the Design module of the land redistribution model called LandSpaCES (Land Spatial Consolidation Expert System). This module is the key component of LACONISS since it is capable of automatically generating a set of alternative land redistributions, which are then used as inputs to the next two modules. The chapter is divided into three main sections. In particular, Sect. 8.2 discusses considerable system design issues such as system definition, knowledge acquisition and representation, knowledge-base building and definition of inputs and outputs. Thereafter, Sect. 8.3 considers classical system development issues such as the selection of the appropriate development tool and the description of the system architecture and interface. In addition, the two basic concepts of development are set out and discussed, i.e. the 'No-Inference Engine Theory (NIET)' that differentiates the system development from conventional expert system (ES) development, and the parcel priority index (*PPI*), which constitutes the basic parameter that defines the redistribution of land in terms of location. Finally, system evaluation using a case study that involves verification and validation is carried out in Sect. 8.4. In addition, the system was run with ten different sets of inputs to generate ten alternative land redistribution solutions and was compared with TRANSFER, which is well-known, similar software developed and used by the Dutch Cadastre.

8.2 System Design

The design of knowledge-based systems consists of some tasks other than those followed in conventional software systems. This differentiation is due to the knowledge component that is embedded in the former systems. In particular, conventional computer programs perform tasks using conventional decision-making logic, which contains little knowledge other than the basic algorithm for

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_8, © Springer International Publishing Switzerland 2014

solving that specific problem and the necessary boundary conditions. On the other hand, knowledge-based systems collect the small fragments of human know-how into a knowledge base, which is then used to reason through a problem, searching for a solution. This task, i.e. the design of an ES, usually consists of the following steps: system definition, knowledge acquisition, knowledge representation, knowledge-base building and the definition of the inputs and outputs.

8.2.1 System Definition

The name of the system is LandSpaCES (Land Spatial Consolidation Expert System) Design module representing the Design phase in the LACONISS operational framework (Fig. 5.6). The aims of this module are: to automate the process of land redistribution so as to generate a complete problem solution that will be close to the solution of human experts or be better than that; to be used as a decision support tool by generating alternative land redistributions by changing facts; to enhance the land redistribution process by structuring it in a systematic, standardised and transparent way using an appropriate model; to considerably diminish the time needed by a human expert (which may last from several weeks to months) to carry out the land redistribution process.

This module is the key component of LACONISS because its outputs will be used as inputs to the next modules, i.e. the LandSpaCES Evaluation module and LandParcelS. In addition, the output can be used as an input to the ex-ante evaluation framework discussed in Sect. 4.5.1 to predict results and impacts of a land consolidation project. Lastly, the system may be used as a trainee tool for new and expert land consolidation technicians to understand and analyse the reasoning process of land redistribution.

8.2.2 Knowledge Acquisition

Liou [1] p. 2–1), who discussed extensively knowledge acquisition methods, defines knowledge acquisition as *the process of extracting, structuring and organizing knowledge from several knowledge sources, usually human experts so that the problem solving expertise can be captured and transformed into a computer readable form.* A variety of knowledge acquisition methods were suggested by several authors [2–5], which tend to be a combination of a few basic approaches. The literature suggests the following four main knowledge acquisition methods: documentation (like manuals, guidelines and legislation); studying past cases (e.g. past projects) and their subsequent shortcomings; discussing cases with experts via personal or collaborative interviews; and watching/observing experts applying their knowledge to current problems.

The selection of an appropriate knowledge acquisition method depends on many factors, namely, the problem domain, the availability of knowledge resources and the time/cost constraints. In this research, in which the author acts both as one of the experts involved and the knowledge engineer, knowledge is collected through the following resources: the author's fifteen-year personal experience in working on land consolidation projects; informal discussions/interviews with land consolidation technicians (i.e. the prospective main users of the system) who have carried out the land consolidation process for two to three decades; documentation, such as the Land Consolidation Law, formal Departmental guidelines and instructions, legal advice etc.; and analysis of the solution given by experts in the case study used in this research.

8.2.3 Knowledge Representation

In order to model the land redistribution decision-making process, the problem has been split into seven sub-problems represented by decision trees to facilitate the analysis and make the decision trees effective and understandable through visual representation. One is the basic tree (shown in Fig. 8.1) called the Main Flowchart and the other six trees (Flowcharts B1, B2, C1, C2, D1 and D2), which are

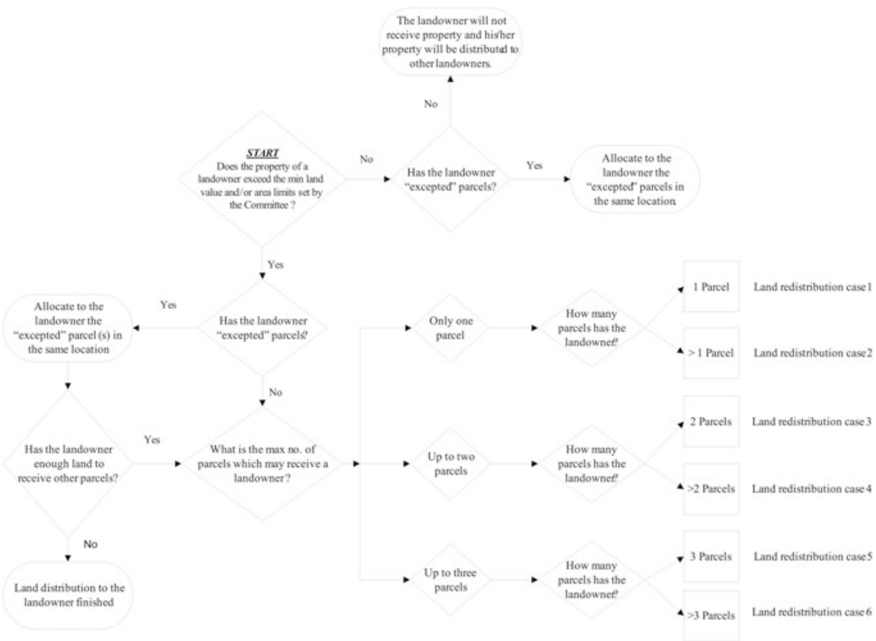


Fig. 8.1 The main decision tree for the design module of LandSpaCES

presented in Demetriou et al. [6], represent corresponding land redistribution cases that can be grouped according to the original number of parcels owned by a landowner and the maximum number of parcels that may be allocated to a landowner in the new plan.

In particular, the following six land reallocation groups can be distinguished: (1) the landowner originally has 1 parcel and he/she may receive only 1 parcel in the new plan; (2) the landowner originally has more than 1 parcel and he/she may receive only 1 parcel in the new plan; (3) the landowner originally has 2 parcels and he/she may receive up to 2 parcels in the new plan; (4) the landowner originally has more than 2 parcels and he/she may receive up to 2 parcels in the new plan; (5) the landowner originally has 3 parcels and he/she may receive up to 3 parcels in the new plan and; (6) the landowner originally has more than 3 parcels and he/she may receive up to 3 parcels in the new plan.

Each tree is composed by nodes, branches and leaves. Nodes are represented by a diamond-shaped decision symbol containing certain questions, i.e. the premise of a rule. Branches are either, 'Yes' or 'No' answers to these questions and leaves contain conclusions. The question-answer-conclusion chain may be split into a number of relevant sub-sets. This form of tree is called a binary tree. Although the process of land reallocation and land redistribution in particular was presented in a structured way in Sect. 4.2.2, the process is not documented as a sequence of steps. Therefore, although the problem is driven by many fundamental and complementary principles as discussed in Sect. 4.3, reasoning and decision making may vary from one planner to another. As a result, the most difficult task is to formulate a process that is able to synthesise the expertise of many experts and which will simultaneously be systematic, standardised and transparent. These decision trees seem to satisfactorily represent the land redistribution decision-making process for the majority of cases and the majority of experts' knowledge. However, it is impossible to model all the land redistribution conditions. Some of them may be unique for a certain project. For this reason, the expert needs to intervene accordingly to adjust the land redistribution and hence have the final say, at the planning stage, for the decisions taken.

8.2.4 Knowledge Base Building

A knowledge base contains a collection of IF-THEN rules that have been extracted from each decision tree. Decision trees and their rules follow the statement in Sect. 5.4.1 suggesting that the appropriate inference approach (control process) for solving the land redistribution problem is forward chaining (i.e. data driven); hence rules search the solution from data and facts to conclusions. Rules are grouped in ten *rule clusters,* i.e. groups of rules that represent the decision-making process for a certain land redistribution sub-problem. Later, in system development, each rule cluster will be transformed to a computer language procedure to incorporate rules and other necessary operations to solve a certain problem.

Two examples of rule clusters, one for the Main Flowchart and one for the Flowchart B2, containing rules in plain language, are presented in Tables 8.1 and 8.2 respectively.

Rule clustering is important in the design and the efficiency of the system. The entire knowledge base consists of 74 rules. Among them, 22 are *generic rules*, which are included only once in the Main rule cluster and 38 are *specific rules*, which are included in more than one rule cluster. Generic rules have a broad scope regarding decisions taken, e.g. a landowner may or may not receive property in the new plan or what is the maximum number of parcels that can be allocated to each landowner? On the other hand, specific rules focus on decisions taken for each land redistribution case, e.g. create a new parcel or not? Displace a new parcel in another location or not? An example of a generic and specific rule is shown below.

Generic Rule: IF [The total area OR value of a landowner's property is < than the minimum completion limits set by the Committee AND the examined parcel is not "exempted"] THEN [The landowner will not receive any parcel in the new plan AND he/she will receive as pecuniary compensation the land value of the property AND the property will be available to be distributed to other landowners]

Specific Rule: IF [The area of the new parcel is > = the minimum parcel area set by the Committee AND the area of the new parcel is < the minimum area set by the Law] THEN [Set the new area equal to the minimum limit set by the Law AND create the new parcel]

Compared to an ES with hundreds or even thousands of rules, the knowledge base of LandSpaCES is small. However, most rules involve complex spatial operations and some may call procedural algorithmic subroutines.

8.2.5 Definition of the Inputs and Outputs

The system requires two kinds of inputs: GIS data and facts. GIS data, which are stored in the long-term memory, are those involved in Dataset 1 as discussed in Sect. 6.4. Facts, which are stored in the working memory, are the users' inputs, which are used by the rules to infer new facts or conclusions or actions. The necessary facts for this system, in question form, are as follows.(1) What are the minimum new parcel area limits according to the law for this land consolidation area? (2) What are the minimum area and land value limits set by the Land Consolidation Committee in order to receive a landowner property in the new plan? (3) What are the area limits for small-medium-large property sizes? (4) What are the weights for the Parcel Priority Index (*PPI*)? (5) What is the minimum area limit to create a new parcel (for landowners that may receive more than one parcel)? The facts are decision variables that may result in alternative land

Table 8.1 Rules in plain language for the main flowchart cluster

Rule no.	IF	THEN
1	The total area OR value of a landowner's property < the corresponding minimum completion limits set by the Committee AND the examined parcel is not "excluded"	The landowner will not receive any parcel in the new plan AND he will receive expiate the land value of the property AND the property will be available to be distributed to others
2	The total area OR value of a landowner's property >= the corresponding minimum completion limits set by the Committee AND the parcel examined is not "exclusive" AND the landowner has not applied to be completed	The landowner will not receive any parcel in the new plan AND he will receive expiate the land value of the property AND the property will be available to be distributed to others
3	The total area OR value of a landowner's property >= the corresponding minimum completion limits set by the Committee AND the total area is >= minimum area limit set by the Law	The landowner will receive property in the new plan
4	The total area of a landowner's property >= the corresponding minimum completion limit set by the Committee AND the total area is <= minimum area limit set by the Law and the landowner has applied "to be completed"	The landowner will receive property in the new plan
5	The total value of a landowner's property >= the corresponding minimum completion limit set by the Committee AND the total area is <= minimum area limit set by the Law and the landowner has applied "to be completed"	The landowner will receive property in the new plan
6	The total area of a landowner's property >= the corresponding minimum completion limit set by the Committee AND the total area is <= minimum area limit set by the Law and the landowner has not applied "to be completed"	The landowner will not receive any parcel in the new plan AND he will receive expiate the land value of the property AND the property will be available to be distributed to others
7	The total value of a landowner's property >= the corresponding minimum completion limit set by the Committee AND the total area is <= minimum area limit set by the Law and the landowner has applied not "to be completed"	The landowner will not receive any parcel in the new plan AND he will receive compensation equal to the land value of the property AND the property will be available to be distributed to others
8	A landowner will not receive property in the new plan	His property will be available to be distributed to others

Table 8.2 Rules in plain language for the Flowchart B2 rule cluster

Rule no.	IF	THEN
1	The new area will be allocated to a landowner < the minimum area limit set by the Law	The new area will be equal to the minimum area limit set by the Law
2	The area of the new parcel <= available land in the block of that parcel	Create the new parcel
3	The number of parcels already allocated to a landowner = the maximum number of parcels may received by the certain landowner	Do not allocate him any other parcels
4	The area of the new parcel > the available area of the block of the parcel AND the parcel priority Index > the minimum of the parcels of that block	Search and allocate the examined parcel in that block and "move" the parcel(s) with less PPI in another block
5	Rule 4 can not be satisfied	Search and allocate the examined parcel in another block in which the landowner posses a parcel
6	Rule 5 can not be satisfied	Allocate the new parcel in none block to decide the user

redistribution solutions. System outputs that include both database tables and maps are provided later in Sect. 8.3.3.

8.3 System Development

8.3.1 Development Tools

It was noted that the available software for developing an ES can be divided into three main categories: expert system shells (e.g. EXSYS or XpertRule), high level or AI programming languages (e.g. LISP, OPS5 or PROLOG) and knowledge engineering tools (e.g. CLIPS or KEE). It has also been emphasised that the selection of the most appropriate and efficient tool for developing an ES is a crucial matter. Thus, a literature search was carried out for this purpose which showed that, on the one hand, undoubtedly the easiest and most efficient way to develop an ES is to use an ES shell, then use a knowledge engineering tool and then an AI language. On the other hand, a remarkable finding of the above search is that there is a lack of specialised ES development tools capable of easily integrating ES and proprietary GIS in the environment of the latter, despite the fact that some efforts have been made in this direction [7, 8]. Thus, the question raised is: Is it appropriate to use a generic ES tool to integrate ES and GIS? The literature review showed that these specialised ES development tools are efficient for developing standalone ES applications and not hybrid systems. In particular, the ES development tools have limitations in their flexibility and in their communication with non-ES applications, e.g. GIS [9]. In addition, these tools permit only loose or tight coupling integration architecture and they cannot create fully integrated systems. Thus, an alternative is to use a conventional programming language that provides greater development flexibility even though it is a time consuming task for developing an ES from scratch [10].

Indeed, there are cases, either standalone or hybrid systems, which have been developed using procedural languages. Recent research carried out by Hicks [11] discusses 'the no-inference engine theory (NIET)' and argues that this method outperforms traditional ES development tools. Other authors [12, 13] have developed ES using a conventional language. Moreover, it is very interesting for this research project that some researchers have integrated ES and GIS using conventional languages or GIS languages such as Avenue, VBA and ArcObjects [9, 14–16]. Such geotechnology tools have been widely used in the development of planning support systems [17]. Although conventional languages have been rarely employed for developing ES, they may be appropriate for a hybrid ES with a small knowledge base and a straightforward reasoning engine [18].

Table 8.3 ES development tools vs. conventional GIS programming tools

ES development tools	
Advantages	Disadvantages
Ease of ES development	Time needed to learn something new
Provides all the components of a typical ES (i.e. knowledge acquisition module, explanation facility, etc.)	Cost
	Programming limitations
	Impossible to have full integration with other systems
	Slower hybrid systems
	A lot of development tools have been retracted
	Some tools have limited support
Conventional GIS programming tools	
Advantages	Disadvantages
Flexibility of programming	Time consuming
Capability for fully integrated hybrid systems	Difficult to develop all the facilities of an ES (i.e. explanation facility, editable knowledge base, etc.)
System development only in one environment	
More familiar to GIS experts	
Creation of faster hybrid systems	

Based on the previous discussion, a comparison of the advantages and disadvantages of specialised ES development tools and conventional GIS programming tools (e.g. VBA and ArcObjects) for developing integrated GIS-ES is summarised in Table 8.3. This review suggests that it is better to sacrifice some of the advantages provided by ES development tools to gain the advantages offered by conventional programming languages under a common GIS development environment, that is, VBA and ArcObjects in ArcGIS, to fully integrate GIS with ES techniques. However, this integration needs to be based, in terms of development, on robust theoretical foundations. This requirement is provided by the NIET.

8.3.2 The 'No-Inference Engine Theory'

Giarratano and Riley [19] make some very important remarks regarding the design of an ES. They emphasise that when dealing with un-structured problems, it is possible to reach a solution using an algorithm, i.e. a step-by-step process. Such a case involves a rigid control structure, i.e. the rules are forced to execute in a certain sequence, i.e. every rule fires another rule and so on. In such a case, a major advantage of an ES is negated, i.e. dealing with unexpected inputs that do not follow a predetermined pattern and hence there is no need for an inference engine and an ES, because a procedural programming language is a more appropriate approach. Ideally, an ES is a balanced mix of strongly and weakly coupled rules, just as humans may use deductive, inductive, probabilistic and other methods to reach a conclusion.

In contrast to the above remarks, Hicks [11] suggests The 'No-Inference Engine Theory—NIET'. Conventionally, the major task performed by an inference engine is *conflict resolution*, which determines the sequence of consultation based on a predefined priority assignment in a rule, when multiple rules are activated simultaneously. However, a disadvantage of this strategy is that most of the execution time of a program is spent in performing this process. In NIET, conflict resolution is performed during the development stage, by ordering rules in a logical flow sequence. In addition, in the case of rules that present the so called 'bartender problem' (i.e. two or more rules have at least the first condition of their premise part in common), the conflict resolution is solved by sequencing first the most specific rules, i.e. rules with the greater number of conditions, so they can be tested first. This is a rule ordering strategy or more precisely a conflict resolution strategy which is common in the ES industry and is the default for most products. This strategy is also recommended in the manuals of some ES shell/tools such as CLIPS and M.4 [11], in which the user assigns a priority value for a rule (e.g. in CLIPS this is referred to as salience).

The central concept of this approach is that it transforms the traditional declarative inference engine into a procedural solution involving a sequence of IF-THEN statements with other conventional programming operations and inputs to instantiate conditions. Inference is still performed but the components are distributed between the development and the delivery environments. In other words, in contrast to typical ESs, a rigid control structure and strong coupled rules are the characteristics of NIET-based systems in which all the inference components are performed at run-time, where a NIET system performs only inputs and logic at run-time and not conflict resolution. As noted earlier, Hicks [11] demonstrated, using EZ-Xpert, that this simplification of the run-time task results in significant performance improvements. In addition, the concept of NIET has also been employed by other researchers [12, 13].

Another significant differentiation of NIET is that the knowledge base and inference engine are not kept separated as in conventional ES. In NIET, there is no inference engine and the reasoning (rule base) and process (inference engine) are combined into a single unit. Separation of the two basic components of ES constitutes an advantage in terms of ease and efficiency to edit the knowledge base. However, this advantage is not such an important matter for this module since the number of rules used (i.e. 74) is small and it is not expected that the knowledge base will be updated very frequently, given that modifications to legislation and new circulars regarding the process are rare. Therefore, NIET has been adopted as the development methodology of this module. For instance, the two cases of rule clusters provided earlier in plain language, i.e. the Main Flowchart (Table 8.1) and the Flowchart B2 (Table 8.2), are presented in computer language in the two blocks of code that appear in Appendices B.2.1 and B2.2, respectively.

8.3.3 System Architecture and Interface

The overall architecture of the Design module of LandSpaCES is illustrated in Fig. 8.2. Similar to other knowledge-based GIS (KBGIS), LandSpaCES consists of three main parts: (1) a database management system (DBMS) through ArcGIS, which can accommodate all the necessary information as noted in Sect. 4.2.4 about a land consolidation plan. Basic database management functions can be carried out in ArcView. (2) the land redistribution expert system mechanism (ES), which contains the rule base (reasoning) and the process (inference engine). It is the heart of the system, which implements the land redistribution decision making and (3) a graphical user interface (GUI) through which the user can input data and facts, run land redistribution process and display the system outputs.

The User interface involves a toolbar embedded in the ArcView environment that consists of five icons as is shown in Fig. 8.3.

Each icon launches a separate window with a title, text boxes and command buttons. The window of each icon is shown in Figs. 8.4 to 8.8. The Input Data window (Fig. 8.4) is used to input the shapefiles and databases provided/created for the case study. The Input Facts window (Fig. 8.5) is used to input the problem's basic facts (F1-F8) in the eight text boxes. The Run Land redistribution Model window (Fig. 8.6) is used to run the land redistribution model assuming that the previous windows have been used appropriately. The planner also has to

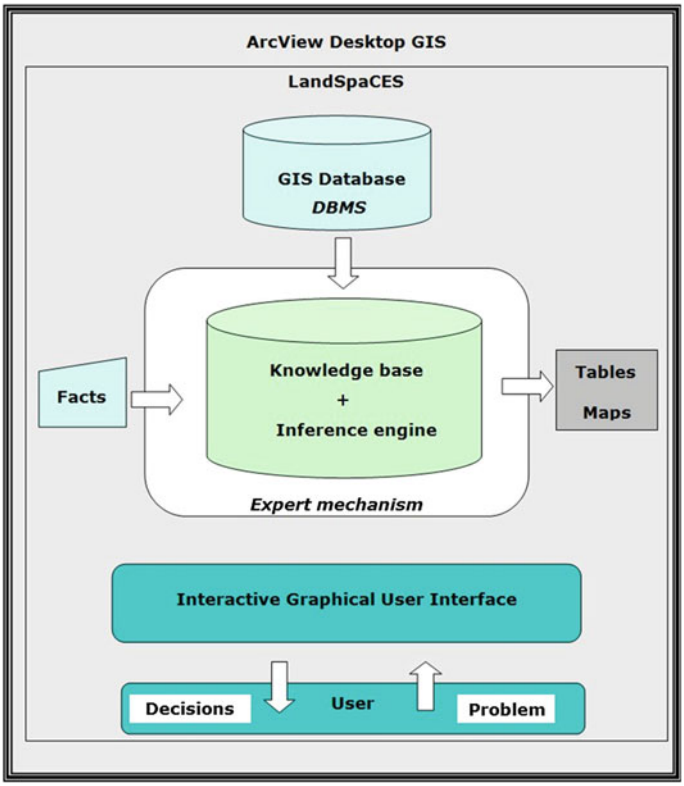


Fig. 8.2 The overall architecture of LandSpaCES (design module)

Fig. 8.3 The LandSpaCES design module toolbarModule toolbar

define three facts (F9-F11), namely, two weights for the *PPI* calculation and a minimum area limit for the creation of a new parcel for those landowners who may receive more than one parcel. The Display outputs/decision window (Fig. 8.7) presents the system results. In particular, there are two output tables: New-ParcelsLS.dbf, which includes the attributes of the newly created parcels and NewOwnershipLS.dbf, which includes the attributes of the owners. A part of each of these tables is shown in Figs. 8.9 and 8.10, respectively. The two tables can be joined with a one-to-one relationship using the Parcel_ID as the key field.

In addition, there is an output map called ParcelsCentroids layer, a part of which is illustrated in Fig. 8.11. Each point represents the centroid (i.e. the approximate location) of each new parcel. The numerator and the denominator of

Fig. 8.4 The 'input data' window

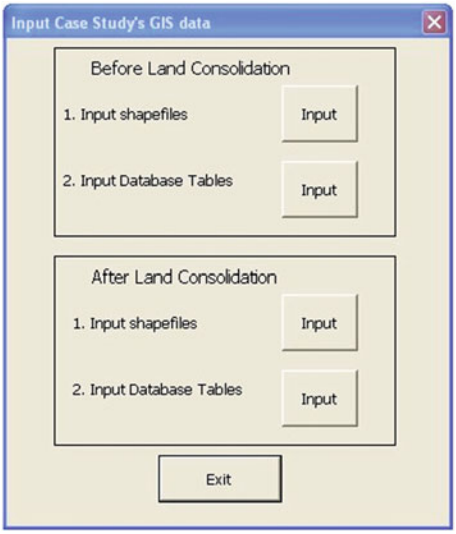
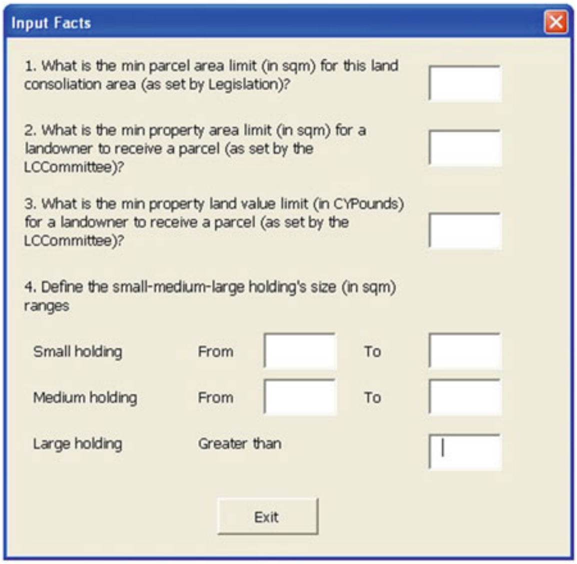


Fig. 8.5 The 'input facts' window



the fraction shown above each centroid represent the Owner_ID and Parcel_ID for a new parcel, respectively. Red underlined numbers are the Block_IDs. A part of the attribute table of the output map is shown in Fig. 8.12.

The System Evaluation window (Fig. 8.8) executes various calculations used for system validation (see Sect. 8.4.2), i.e. the comparison of the results from the system and the human expert.

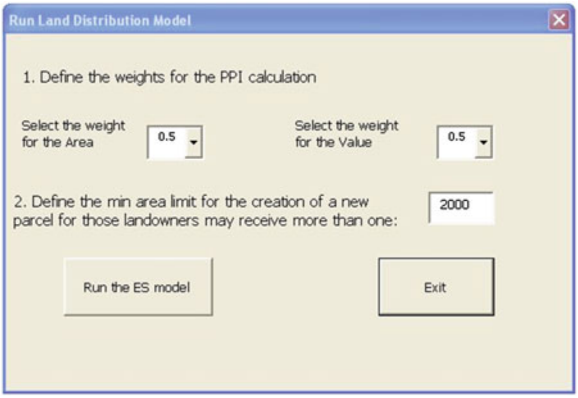


Fig. 8.6 The 'run land redistribution model' window

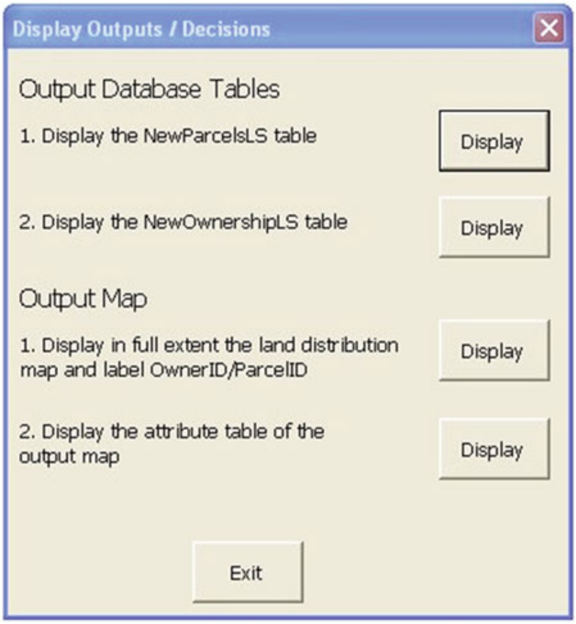


Fig. 8.7 The 'display outputs/decisions' window

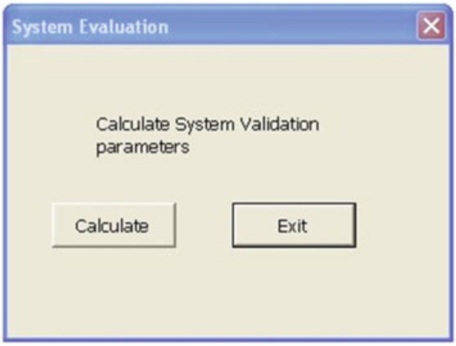


Fig. 8.8 The 'system evaluation' window

Attributes of NewParcelLS

OID	Parcel_ID	Area	Value	X_Centroid	Y_Centroid	Block	PPI
0	1	3267.23	535.49	144928.16	352915.18	8	0.324893
1	2	6535.44	923.26	145424.05	351810.65	19	0.512819
2	3	8822.7	1377.6	144995.97	353021.67	8	0.546201
3	4	2940.9	415.47	145537.59	352893.32	7	0.270247
4	5	8822.7	1446.12	145009.81	352743.21	12	0.550143
5	6	4411.35	754.4	145201.49	353051.63	7	0.55375
6	7	7841.75	1107.91	144798.5	352601.23	10	0.527578
7	8	5554.49	1171.08	145235.75	351924.33	17	0.523973
8	9	3267.23	510.22	145453.67	351990.21	19	0.316531
9	10	3021.99	809.07	145237.53	352875.09	7	0.390352
10	11	9476.34	1129.78	144998.63	353476.69	4	0.53401
11	12	3920.87	102.04	145613.08	352933.42	7	0.324038
12	13	5228.16	816.36	145343.09	351967.56	17	0.491692
13	14	8822.7	1471.87	145540.78	351941.7	18	0.551625
14	15	5881.8	481.07	144866.67	351908.01	25	0.531603
15	16	9476.34	1479.65	145291.3	353023.41	7	0.554141

Record: 1 Show: All Selected Records (0 out of 259

Fig. 8.9 A part of the NewParcelsLS.dbf table

Fig. 8.10 A part of the NewOwnershipLS.dbf table

Attributes of NewOwnershipLS

OID	Parcel_ID	Owner_ID	Share_N	Share_D
0	1	1	1	1
1	2	3	1	1
2	3	4	1	1
3	4	5	1	1
4	5	7	1	1
5	6	12	1	1
6	7	21	1	1
7	8	27	1	1
8	9	29	1	1
9	10	31	1	1
10	11	36	1	1
11	12	38	1	1
12	13	40	1	1
13	14	41	1	1
14	15	42	1	1
15	16	45	1	1

Record: 1 Show: All electe

8.3.4 The Parcel Priority Index

The conventional approach used for land reallocation, of which land redistribution is a part, is described in Sect. 4.2.2. One of the crucial matters considered for building the land redistribution model is the way in which the preferences of the landowners are incorporated. It is accepted that the most important matter for

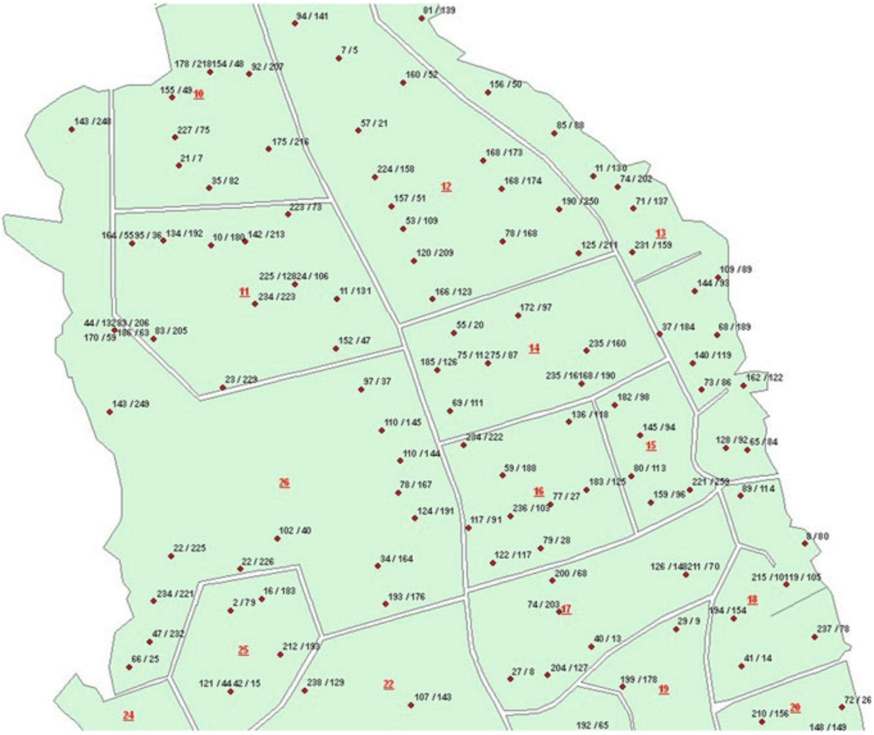


Fig. 8.11 A part of the output map

Fig. 8.12 A part of the attribute table of the output map

Attributes of ParcelsCentroids

FID	Shape	Parcel_ID	Owner_ID
0	Point	1	1
1	Point	2	3
2	Point	3	4
3	Point	4	5
4	Point	5	7
5	Point	6	12
6	Point	7	21
7	Point	8	27
8	Point	9	29
9	Point	10	31
10	Point	11	36
11	Point	12	38
12	Point	13	40
13	Point	14	41
14	Point	15	42
15	Point	16	45

Record: 1 Show:

landowners in a land consolidation project is the location of the new parcels which they will receive. It is also well known by land consolidation planners that each landowner wishes to receive his/her property in the location of his/her 'best parcel', then to the next 'best parcel' and so on (Sonnenberg 1998; [20, 21]).

Thus, the question focuses on what parcel is considered to be 'best' for a landowner. Practice has shown that the 'best parcel' for a landowner is perceived as that with the largest area and/or the highest land value per hectare or a combination of these two factors. A parcel with these characteristics may contain the farm buildings as well. Area and land value (either market price or agronomic value) are the two fundamental factors commonly used as the basic land reallocation criteria. Consequently, a measure that takes into account these two factors may satisfactorily represent the preference of a landowner in terms of the location he wishes to receive his/her new parcels. For these reasons, a measure called the parcel priority index (*PPI*) has been introduced (Demetriou et al. [22]) in this research and will operate as a factor:

- representing the preference of landowners by setting in rank order all the parcels of a project and then separately the parcels of each landowner defining preferences regarding the location they wish to receive the new parcels; that is, those parcels of a landowner with the greatest area and/or land value are ranked first;
- representing the priority of a pair landowner-parcel in the land redistribution process in terms of allocating a parcel in a certain location or not. In other words, the higher the *PPI* the higher the priority, hence the higher possibilities for a landowner to receive his property in the desired location(s). Thus, the *PPI* is a crucial factor that determines if a parcel (and hence its landowner) will be 'displaced', during land redistribution, in another location so as to satisfy the first, second etc. preference of a landowner; and
- ensuring equity, transparency and standardisation of the process since the redistribution of parcels in a new location is based exclusively on this factor.

The power of *PPI* is that it treats the two basic entities of reallocation, i.e. landowners and parcels, as one common entity, the parcel-landowner. In particular, the *PPI* combines the characteristics of the entity parcel-landowner and defines the entity's priority for reallocation into a single number between 0 and 1. Currently, it is calculated based on two factors: the area and the land value of the parcel. Initially, the *PPI* is calculated separately for each parcel based on the mSM noted in Sect. 7.3.4 if the value of 1 is omitted in both formulas 7.9 and 7.10. Thus, the noted formula can be restated for calculating *PPI* for area [Eqs. (8.1) and (8.2)] and land value [Eqs. (8.3) and (8.4)]. Afterwards, the overall *PPI* [Eq. (8.5)] is calculated based on the relevant weight assigned by the user for each factor. Weights represent the importance of each factor in the land redistribution process and influence the location of the new parcels. The relevant formulas are given below:

PPI* for *Area

$$PPIa_i = \frac{(A_i - MinA)^{*}0.5}{MeanA - MinA}\ (\text{if}\ A_i \leq MeanA) \tag{8.1}$$

$$PPIa_i = \frac{(A_i - MeanA)^{*}0.5}{MaxA - MeanA} + 0.5\ (\text{if}\ A_i > MeanA) \tag{8.2}$$

where $PPIa_i$ is the *PPI* based on the area of parcel *i*, A_i is the area of parcel *i*, and *MinA*, *MaxA*, and *MeanA* are the corresponding area values for all the parcels in the dataset.

***PPI* for Land Value**

$$PPIv_i = \frac{(V_i - MinV)^{*}0.5}{MeanV - MinV}\quad (\text{if}\quad V_i \leq MeanV) \tag{8.3}$$

$$PPIv_i = \frac{(V_i - MeanV)^{*}0.5}{MaxV - MeanV} + 0.5\quad (\text{if}\quad V_i > MeanV) \tag{8.4}$$

where $PPIv_i$ is the *PPI* based on the land value of parcel *i*, V_i is the land value of parcel *i*, and *MinV, MaxV and MeanV* are the corresponding land values for all the parcels in the dataset.

Overall *PPI*

$$PPI_i = Wa * PPIa_i + Wv * PPIv_i \tag{8.5}$$

where PPI_i is the overall *PPI* for parcel *i*, and *Wa*, *Wv* are the weights for area and land value respectively that should sum to 1.

Ideally, the *PPI* may take into account more reallocation criteria (than parcel area and land value) regarding a parcel and a landowner. For example, other criteria that may be used for parcels are land use and morphology. Similar to parcels, the characteristics of a landowner can be the profession (farmer or not farmer, full-time or part-time farmer etc.), age, residence (in the village or not), number of children, and so on. Then, the overall *PPI* may be calculated in a similar manner.

8.4 System Evaluation

In general, system quality issues are hierarchically ranked as follows: *evaluation, assessment, credibility, validation* and verification [23–25]. Evaluation reflects the benefits in terms of value for money to the users, sponsors and the organization more generally [26]. Assessment is the set of issues that consider the 'fit' between the system and the user independently and the quality of decisions made. Credibility is defined as the extent to which a system is believable or the confidence in the system results [27]. Validation involves the correctness of the software with respect to the user needs and requirements, i.e. building the right system. Thus, validation is more concerned with the quality of the decisions made by the system. On the other hand, verification is defined by Adrion et al. [28] as the consistency, completeness and correctness of the software. In other words, verification means building the system correctly in terms of eliminating errors and making sure that it corresponds to the predefined specifications.

In practice, software developers rarely deal with more than verification and validation, the so called 'V&V' [23]. Verification and validation are part of an iterative process in the system development. Verification is generally carried out during the development of a system component and during the composition of various system components, while validation can be performed for each system component and detailed efforts can be carried out for the complete system. Taking into account that the system under development is a prototype, it is considered adequate to test the system quality based on two these aspects: verification and validation.

8.4.1 Verification

Normally, in the case of an ES, verification is focused on the knowledge base and not on the inference engine since it is usually provided (and hence verified) by an ES shell. However, in this research, the knowledge base and inference engine are not separated so they are both verified. Usually verification involves the following checks: *consistency, completeness, correctness and redundancy*. Consistency generally means to use consistent variable names across all of the rules. Completeness refers to problems that are related to the structure of a rule such as unreferenced and illegal attributes and conclusions or unreachable premises and dead end conclusions. Correctness focuses on the violation of the structure of the rule-base and in particular in conflicting rules, i.e. two or more rules have the same if attributes, but come to contradictory conclusions; subsumed rules, i.e. two or more rules have the same conclusions but one contains additional constraints on the situations in which it will succeed [29]; and circular rules, i.e. a chain of reasoning that begins with some condition and then returns to that same condition. Redundancy occurs when two or more rules succeed in the same situation and have the same conclusions [29] or the reasoning chain contains a redundant rule.

The fact that this module was developed using conventional programming tools and not an ES shell considerably alters the anomalies that can occur with rules and introduces other anomalies that need to be considered. Since this module consists of Procedures, Functions and Rule Cluster Procedures, the verification process is separated into two parts: one for the Procedures and Functions that carry out customised and necessary tasks such as calculations, creation of tables, fields, etc. and one for the Rule Cluster Procedures, which comprise the system's expert mechanism, i.e. the rules and the inference engine. The verification process followed is shown graphically in Fig. 8.13.

Verification of Procedures and Functions is an iterative process, which is initially carried out individually for each Procedure-Function to verify that it works properly and it produces the correct results. Afterwards, Procedures and Functions, which are called by other Procedures, are also verified when the calling procedure is verified. As shown in Fig. 8.13, after the initial coding, the next step is testing and debugging. Testing is the process of finding errors in a program and debugging is the process of correcting errors that are found. The last step is to investigate the results. If the results are not correct, then a detailed review and inspection of the code is necessary to detect and correct the errors by modifying the code. This is an iterative process until the code runs properly and produces the correct results.

Furthermore, verification of Rule Cluster Procedures as shown in Fig. 8.10, involves two more components than the process followed for the Procedures-Functions: rule verification structure and line reasoning (inference engine) verification. As noted earlier, rule verification structure consists of four aspects: consistency, completeness, correctness and redundancy. The structure of rules in a Rule Cluster Procedure has to be consistent with the rules written in plain

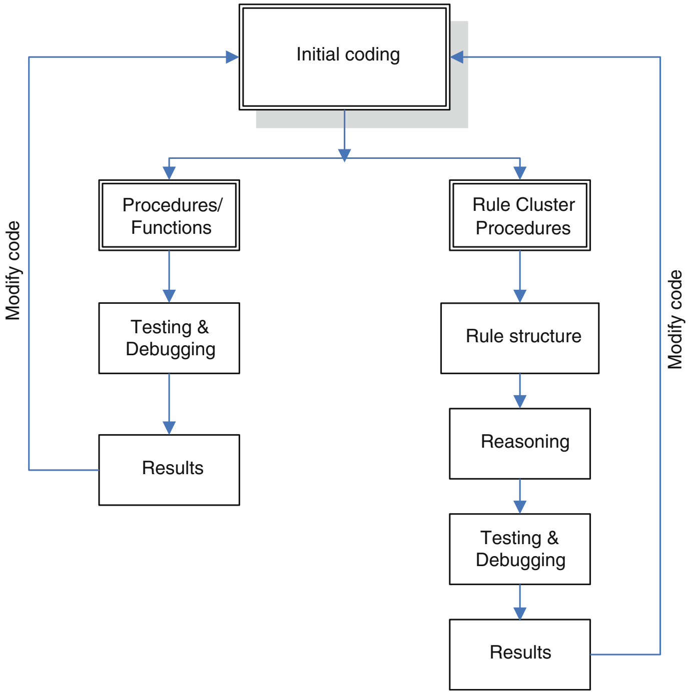


Fig. 8.13 Verification process for the LandSpaCES design module

language, which in turn have to be consistent with the decision trees. Thus, a cross-verification is carried out among them to assure that the four aspects of rule structure verification are satisfied. Because the total number of rules is relatively small (i.e. 74 rules) and because development is via conventional programming tools rather than an ES shell (which may provide rule checking facilities), all checks were carried out by careful inspection, review and comparison of the system results with the known or expected results.

Verification of reasoning was carried out by careful cross-reviews and inspection of the order of the rules in the code (conflict resolution strategy) and the order of the rules in the decision trees. Afterwards, the exploration of the system results compared with the results from human experts revealed a possible line of reasoning problem. Common errors detected by the process of Rule Cluster verifications were: wrong numbering of the new parcels; parcel allocation to the wrong landowner; allocation of more parcels than the maximum permissible to a land owner; landowners with no allocated parcel while they should have been allocated; generation of an inappropriate number of parcels for a rule cluster; and allocation carried out in an unexpected manner. All these errors were corrected. Verification ensures that the code works and produces correct outputs.

8.4.2 Validation

Validation is inherently more complex than verification; hence it should be properly structured at the outset of the process. O'Keefe et al. [23] propose a framework consisting of several approaches to structure validation (e.g. establishing criteria, criterion versus construct validity, maintaining objectivity and reliability) and methods (components validation, test case, Turing tests, simulation, control groups, sensitivity analysis, etc.) for carrying out system validation. Similarly, Sojda [30] reviews a number of validation methods such as Gold Standard, real time-historical datasets, panel of experts, sensitivity analysis and component validation. Also, among various system validation methods, a survey of ES developers (O'Leary [31] showed that the 'test case' is the dominant method for the systematic validation of ES. Based on this literature, the 'establishing criteria' approach and the 'test case' method have been selected as the most appropriate to structure and carry out the validation, respectively.

Specifically, the establishing validation criteria approach involves defining the output level of expertise that the system should perform. A system, for example, may perform at the level of an expert, better than an expert or at the level of a good trainee. As laid out in the system definition, the aim of the module is to perform as near as possible to a human expert and if possible perform better than an expert. A common method used to determine the level of expertise of a system is to get the system to 'sit an exam', i.e. test it with a case study (test case method) and measure (as a percentage) its success in solving the specific problem. Given the issues discussed above, the following nine performance criteria were defined for evaluation: number of landowners who received property (C1); number of common landowners who received property (C2); number of landowners who received a "completed" parcel (C3); number of common landowners who received a "completed" parcel (C4); total number of new parcels created (C5); number of new parcels created per owners' group (C6); number of new parcels received by each landowner (C7); number of new parcels received by each landowner in common blocks (C8); and number of new parcels received by each landowner in a common location (C9). These validation criteria cover the most important decisions made by the expert regarding the new land redistribution plan. Thus, they can really be used to evaluate the overall system performance when compared to the human expert solution. Results which involve calculations and not decisions are not included in the validation criteria (e.g. area and land value of new parcels).

After defining the evaluation criteria, the system performance can be measured based on a case study described in Chap. 6. Namely, the level of expertise of the system is measured for each validation criterion by comparing the decisions made by the system and the human expert. Figure 8.14 shows the system performance for each validation criterion and Table 8.4 shows the system performance for each land redistribution group. In particular, the results are very encouraging because the system reproduced the human expert decisions from 62.55 to 100 % for the nine validation criteria. More specifically, the system allocated property to 210 landowners whereas the human expert allocated property to 204 (CR1). The difference of 6 more landowners that have been allocated property by the system is in accordance with the difference of 7 more 'completed parcels' created by the system (CR3). This is due to the fact that these landowners presumably had not applied (as regulations require) to receive a 'completed parcel'; that is, they did not wish to be allocated a property in the new plan and they received a compensation. However, the system was not provided with this information since it was unknown and a relevant procedure to take this into account will be developed in a future system enhancement. Despite these slight differences, the system and the human expert fully agreed with 'completed parcels' in 204 (CR2) and 24

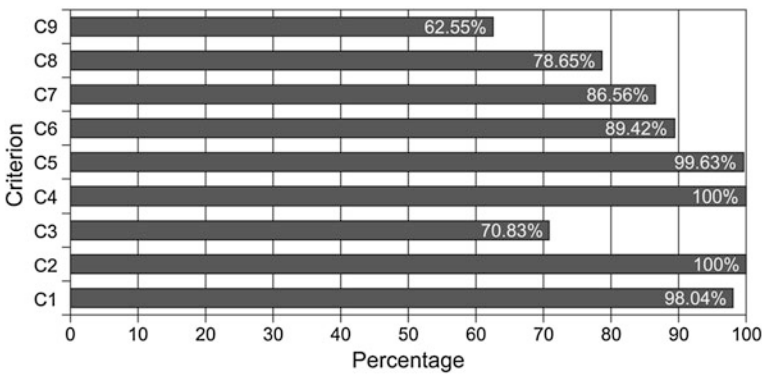


Fig. 8.14 System performance against nine validation criteria

Table 8.4 Number of new parcels created per land redistribution group

Land redistribution group	LandSpaCES	Human expert	Difference	System performance (%)
Completed parcel	31	24	+7	70.83
B1	80	79	+1	98.73
B2	26	26	0	100.00
C1	32	32	0	100.00
C1b*	18	16	+2	87.50
C2	18	26	−8	69.23
D1	26	24	+2	91.67
D2	37	38	1	97.37
Total	268	265 + 2** = 267		

*Group C1 has been programmatically split into two parts for efficiency reasons
**Human expert allocated 2 exempted parcels from rules that are not classified in the land redistribution groups

(CR4) common landowners, respectively. CR5 shows that the system and the expert created almost exactly the same number of new parcels, i.e. 268 and 267 respectively, although there was a variation in the number of parcels created for each land redistribution group.

The system performance for each land redistribution group (CR6) ranges from 69.23 to 100 %. The difference of 7 or more 'completed parcels' created by the system has already been explained. The difference of 8 or more parcels allocated by the human expert compared to the system for group C2 is due to the fact that some landowners have been allocated more parcels than the maximum number provided by the principle of 'small-medium-large' holdings size, since the Head of the Department may accept some exceptions from this rule in some justified cases. Again, the system had not been fed with this information and hence strictly applied the rules. The differences for the other land redistribution groups are small (i.e. ranging from 0 to 2 parcels) and due to the same reason. Also, 2 parcels allocated by the expert cannot be classified in any distribution group because they have been allocated as exceptions from rules.

CR7 shows that for 219 out of 253 (i.e. 86.56 %), the system and the expert agreed to allocate the same number of parcels, i.e. from 0 to 3 in the new plan. CR8 and CR9 refer to the location of the new parcels. In particular, 210 out of 267 parcels (i.e. 78.65 %) allocated by the system for each landowner in common blocks agreed with those allocated by the expert. In addition, 167 out of 267 parcels (i.e. 62.55 %) have been allocated by the system in exactly the same location (as shown in a part of the output map in Fig. 8.15) as that allocated by the expert. The same location means that the centroid of a new parcel falls within the boundaries of the block of the same parcel allocated by the expert.

Further to the system performance in terms of outputs, the one area where the system considerably outperforms the human expert is on the amount of time taken to complete the process. A small survey carried out based on ten expert land consolidation technicians showed that an individual expert needs about 30 working

Fig. 8.15 The common generated parcels by the system and the experts

days to solve this particular case study land redistribution problem. On the other hand, the system solves the same problem in around 6 min, which is really an impressive result. System superiority over the human expert is even greater if it is taken into account that currently the system is lacking significant data such as landowners' preferences, land use and the landowners' personal data (residences, age, and occupation). In addition, evaluation of ten alternatives carried out in the next chapter showed that the system may produce a better solution than that of the human experts.

Despite the remarkable performance of this module, there are some limitations. In particular, as expected, it is very difficult to model all of the land redistribution reasoning of a human expert. Investigation into the differences between the system and human expert results showed that some more rules may be added into the model to improve its performance. However, some of these rules involved the combination of complex operations that required further programming tasks and extra time, which is not available in the context of this research. Another system limitation is the lack of some facilities offered in a typical ES. In particular, since the knowledge base is not separated by the inference engine, it cannot be edited (e.g. new rules cannot be added easily or existing rules cannot be edited) by a user. Instead, programming skills are necessary to carry out this task. Also, the system does not offer an explanation facility, which is a very important part of a decision making system in order to explain step by step its decisions. Both limitations can be overcome by further research and work. Also, testing with more case studies may extract more robust conclusions.

8.4.3 Generation of Alternative Solutions

As noted, among the aims of this *module* is to be able to generate alternative land redistributions by changing facts. Thus, the system ran for ten different sets of facts generating ten alternative land redistributions. Facts, which involve eleven different land redistribution variables and the results for three main land redistribution criteria, are shown in Table 8.5. It should be noted that the values of facts need to be feasible regarding a certain project; otherwise results may be infeasible or unrealistic. Each alternative is described briefly by comparing its facts with those of alternative 1 which is the solution given by experts: (1) Experts' solution (Irrigated project); (2) Medium area and land value minimum limits; (3) High area and land value minimum limits; (4) Unequal *PPI* weights for area and land value; (5) Low small-medium-large holdings sizes; (6) High minimum area of new parcels with high area and land value minimum limits; (7) Low minimum area of new parcels with high area and land value minimum limits; (8) Low area and land value minimum limits with low small-medium-large holdings sizes; (9) Inverse unequal *PPI* weights for area and land value (comparing to alt-4); (10) Arid project.

A general picture derived from Table 8.5 is that changing facts can generate quite different solutions. A1's facts are those used by the expert for the case study used earlier to test the system. By changing F2 and F3 slightly in A2 compared to A1, the three basic outputs changed, that is, they were reduced because the higher F2 and F3 are, the less parcels that are created, the less landowners that receive property and the less landowners that are 'completed'. This result is absolutely expected and it is also confirmed in A3. By only changing F9 and F10, i.e. the *PPI* weights in A4 compared to A1, no change in results occurred (except in C1 with one less landowner receiving property) because the *PPI* influences the location of the new parcels. This result is also expected. A5 involves modifying facts (compared to A1) F4 to F8 representing the 'small-medium-large' holdings rule, that in turn, defines the maximum number of parcels that may be allocated to each landowner. Thus, this change causes an increase (14 parcels) in the number of parcels created (output C1). Outputs C2 and C3 remain stable since they are not affected by facts F4 to F8 but are only affected by fact F1.

A6 involves a tremendous modification to the project variables by changing all the facts except F9 and F10. F1 decreased to half the value (i.e. 1 donum) compared to A1, which is by itself a big change. The other facts (F2 to F8 and F11) change appropriately taking into account the new value of F1. Results showed a significant increase (34 parcels) in the number of new parcels created (C1) and a remarkable decrease (22 parcels) in the number of landowners who received a 'completed' parcel (C3). This result is also feasible because fact F1 is crucial for

Table 8.5 Facts and outputs for ten alternative land redistributions

Alternative no	Facts											Outputs/Criteria		
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	C1	C2	C3
A1	2676 (2)	1000	100	2676 (2)	5351 (4)	5352 (4)	10702 (8)	10703 (8)	0.5	0.5	2000	268	210	31
A2	2676 (2)	1500	150	2676 (2)	5351 (4)	5352 (4)	10702 (8)	10703 (8)	0.5	0.5	2000	264	206	27
A3	2676 (2)	2000	200	2676 (2)	5351 (4)	5352 (4)	10702 (8)	10703 (8)	0.5	0.5	2000	259	201	22
A4	2676 (2)	1000	100	2676 (2)	5351 (4)	5352 (4)	10702 (8)	10703 (8)	0.3	0.7	2000	267	210	31
A5	2676 (2)	1000	100	1338 (1)	4014 (3)	4015 (3)	6690 (5)	6691 (5)	0.5	0.5	2000	282	210	31
A6	1338 (1)	750	75	1338 (1)	4014 (3)	4015 (3)	6690 (5)	6691 (5)	0.5	0.5	1000	302	210	9
A7	1338 (1)	500	50	1338 (1)	4014 (3)	4015 (3)	6690 (5)	6691 (5)	0.5	0.5	1000	305	213	12
A8	1338 (1)	500	50	1338 (1)	2676 (2)	2677 (2)	5352 (4)	5353 (4)	0.5	0.5	1000	314	213	12
A9	2676 (2)	1000	100	2676 (2)	5351 (4)	5352 (4)	10702 (8)	10703 (8)	0.7	0.3	2000	268	210	31
A10	6690 (5)	4000	350	6690 (5)	9366 (7)	9367 (7)	14718 (11)	14719 (11)	0.5	0.5	4500	204	182	89

Facts
F1 The minimum parcel area limit (in m^2) for this land consolidation area as set by legislation
F2 The minimum holding's size limit (in m^2) for a landowner to receive a parcel in the new plan as set by the Committee
F3 The minimum holding's land value limit (in CyP) for a landowner to receive a parcel in the new plan as set by the Committee
F4 The lower limit (in m^2) of a "small" holding size
F5 The upper limit (in m^2) of a "small" holding size
F6 The lower limit (in m2) of a "medium" holding size
F7 The upper limit (in m^2) of a "medium" holding size
F8 The lower limit (in m^2) of a "large" holding size
F9 The weight for parcel area for the calculation of the PPI(Parcel Priority Index)
F10 The weight for parcel land value for the calculation of the PPI (Parcel Priority Index)
F11 The minimum residual area limit (in m^2) for the creation of a new parcel for those landowners may receive more than one Note: the number in brackets represents the area in donums (1 donum = 1,338 m^2)
Outputs/Criteria
C1 Total number of new parcels created
C2 Number of landowners received property in the new plan
C3 Number of landowners "completed"
Note the number in brackets represent the are in donums (1 donum = 1,337.78 m^2)

outputs C1 and C3. C2 remains stable because facts F2 and F3 are almost the same in the alternative concerned and A1.

In addition, by slightly changing F2 and F3 (A7) compared to the previous solution (i.e. A6), all outputs were also slightly changed (increased by 3, C1, C2 and C3) compared with the previous results. This indicates that F2 and F3 are also crucial in the land redistribution process because they may change the basic outputs. Changing F4 to F8 and keeping the same facts as in A7, only C1 is changed as happened between A5 and A1. A9 involves inversely changing facts F9 and F10 compared to A4. No change occurred since as mentioned earlier, *PPI* affects only the location of the new parcels, which is not represented in certain outputs.

Finally, A10 involves great changes since it considers that the area under consolidation is non-irrigated (i.e. the minimum acceptable F1 is 5 donums), whereas in all the previous solutions based on the fact that the case study refers to an irrigated land consolidation area (i.e. the F1 can be at minimum either 2 or 1 donums). Thus, dramatically changing all the facts, except for F9 and F10, results in a completely different picture since all outputs are significantly changed: C1 (decreased by 64), C2 (decreased by 28) and C3 (increased by 58) compared with the base alternative i.e. A1.

The above results indicate that the system is robust in generating various alternative land redistributions by using different sets of facts. These solutions are then passed to the Evaluation module (Chap. 9) for assessment using MADM methods and more than the three criteria used in this section.

8.4.4 LandSpaCES versus TRANSFER

As noted in Chap. 4, TRANSFER is land redistribution software evolved after many years of research, which is currently used in practice by the Dutch Cadastre. The author had the opportunity in April 2010 to attend a demonstration of this software in the Head Offices of Dutch Cadastre that followed by a presentation about LandSpaCES and a relevant discussion with a group of Dutch land consolidation experts. The comparison of the two programs revealed that LandSpaCES has some advantages over TRANSFER which are outlined below:

1. LandSpaCES defines a centroid for each new parcel representing the approximate location of each new parcel with detailed attributes while TRANSFER just decides in which land block to allocate each land holding/landowner and whether or not the parcels of a land owner will be joined around or contain the farm buildings.
2. LandSpaCES utilises the *PPI* for assigning a priority of each landowner/parcel pair while TRANSFER estimates a general priority index for each landowner for the whole project.

3. LandSpaCES utilises the *PPI* for ranking (predicting) the preferences of landowners in terms of locating the new parcels while TRANSFER directly accepts as input three preferences for each landowner regarding the location of new parcels. Although this capability is an advantage, on the other hand, the system cannot reach a solution without these preferences because it cannot predict them.
4. LandSpaCES may generate many alternatives by changing facts, i.e. decision variables, while TRANSFER produces a very limited number of alternatives, i.e. 3 to 5 (or perhaps some more) and some that were exactly the same without a justification by experts.
5. LandSpaCES validation showed very high performance in terms of reproducing human experts' decisions, i.e. from 63 to 100 % for nine criteria, while TRANSFER gave poor performance regarding this issue as explainedby experts.
6. LandSpaCES provides a powerful Evaluation module while TRANSFERdoes not and the ranking is done empirically by experts and the local land consolidation committee.
7. LandSpaCES is fully integrated in an ArcGIS environment thus all GIS functionalities are available while TRANSFER has limited GIS functionalities since it is a standalone system developed from scratch in the 1990s.
8. TRANSFER is just a module while LandSpaCES is a sub-system of an IPDSS, which fully supports the land reallocation process, i.e. from exploring land fragmentation and the need to apply land consolidation to the automated decision making, design, evaluation and generating the final land reallocation plan.

8.5 Conclusions

Evaluation based on a real case study proved that the Design module of LandSpaCES is a robust and reliable system that has fulfilled its aims. In particular, it can efficiently solve the problem of land redistribution by producing results that are very close to human expert decisions and hence the outcome is realistic and applicable in contrast to existing studies. In addition, it can easily generate a set of alternative land redistributions for various sets of facts, some of which were better than the solutions from the human experts. Furthermore, the time performance was shown to be impressive, and tremendously diminished the time needed by a human expert to carry out the land redistribution process; this contributes to alleviating two of the significant problems of the land consolidation process, i.e. the long duration of projects and the high operational costs. LandSpaCES transforms the land redistribution process, which is semi-structured, complex and time consuming, into an efficient, systematic, standardised and transparent methodology. In addition to this internal evaluation, the system seems to outperform in several ways the well-known Dutch program for land reallocation (TRANSFER), which has been developed over many years and is currently implemented in practice by the Dutch Cadastre. Despite the remarkable performance of the module, some limitations have been identified regarding the need to add more rules to the knowledge base and the lack of an editing facility for the knowledge base and an explanation facility that can be overcome by further research.

The above encouraging results are accompanied by the negative fact that the integration of GIS with ES is not an easy task, since there is a lack of specialised external or embedded tools in proprietary GIS for incorporating knowledge for this purpose, which is a pressing need for spatial planning processes. Thus, as indicated, the employment of VBA and ArcObjects with NIET provides an alternative way for integrating GIS with ES. Another innovation regarding the land redistribution process is the introduction of the parcel priority index (*PPI*), which is a powerful measure representing both the preferences of landowners regarding the location they wish to receive their new parcels and the priority of the dual entity landowner-parcel in the land redistribution process in terms of allocating a parcel to a certain location or not. As a result, the *PPI* ensures equity, transparency and standardisation of the process, which contributes to alleviating the problem of conflicts between the stakeholders involved.

The next chapter involves the development of the Evaluation module of LandSpaCES that is tested by feeding it the ten alternative land redistributions generated earlier by the Design module.

References

1. Liou, Y. (1998). Expert system technology: Knowledge acquisition. In J. Liebowitz (Ed.), *The handbook of applied expert systems* (Vols. 2–1 pp. 2–11). USA: CRC Press.
2. Breuker, A., Wielinga, J. (1983). *Analysis techniques for knowledge based systems*. Part 2: Methods for knowledge acquisition, report 1.2, ESPRIT Project 12, University of Amsterdam.
3. Grover, D. (1983). A pragmatic knowledge acquisition methodology. *International Journal on Computing and Artificial Intelligence, 1*, 436–438.
4. Hart, A. (1986). *Knowledge acquisition for expert systems*. London: Kogan Page.
5. Kidd, L. (1987). *Knowledge acquisition for expert systems: A practical handbook*. New York, London: Plenum Press.
6. Demetriou, D., Stillwell, J., See, L. (2010). *LandSpaCES: A design module for land consolidation: Methods and application*. Working paper 10/07. School of geography, University of Leeds (p. 77). Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/10-07.pdf.
7. Leung, Y., & Leung, K. (1993). An intelligent expert system shell for knowledge-based GIS: 1. The tools. *International Journal of Geographical Information Systems, 7*(3), 189–199.
8. Leung, Y., & Leung, K. (1993). An intelligent expert system shell for knowledge-based GIS: 2. Some applications. *International Journal of Geographical Information Systems, 7*(3), 201–213.
9. Jin, Z., Sieker, F., Bandermann, S., & Sieker, H. (2006). Development of a GIS-based expert system for on-site storm water management. *Water Practice & Technology, 1*, 1.

10. Lukasheh, A., Droste, R., & Warith, M. (2001). Review of ES, GIS, DSS and their applications in landfill design management. *Waste Management and Research, 19*, 177–185.
11. Hicks, R. (2007). The no inference engine theory-performing conflict resolution during development. *Decision Support Systems, 43*(2), 435–444.
12. Wilson, L. (2007). Rule based programming in C. Dr. Dobb's Portal: The world of software development. CMP Technology. Available from URL:http://www.drdobbs.com/rule-based-programming-in-c/199702471.
13. Griffin, N., Lewis, F. (1989). A rule-based inference engine which is optimal and VLSI implementable. In *Proceedings of IEEE International Workshop, Tools for Artificial Intelligence: Architectures, Languages and Algorithms* (pp. 246–251) IEEE, 23–25 October.
14. Vlado, V. (2002). *Knowledge based GIS for site suitability assessment*. ESRI library. Available from URL: http://proceedings.esri.com/library/userconf/proc02/pap1185/p1185.html.
15. Howard, H. (2003). *Development of an expert system for cartographic design education*. PhD thesis. Department of Geography, University of Kansas.
16. Choi, J., & Usery, E. (2004). System integration of GIS and a rule-based expert system for urban mapping. *Photogrammetric Engineering and Remote Sensing, 70*(2), 217–224.
17. Geertman S., Stillwell J. (2000). *Geoinformation, Geotechnology and Geoplanning in the 1990s*. Working paper 00/01. School of Geography, University of Leeds, Leeds. Available from URL:http://eprints.whiterose.ac.uk/5027/1/00-1.pdf.
18. Choi, J. (2002). *A rule-based expert system using an interactive questions-and-answer sequence*. Department of Geography, University of Georgia, USA. Available from URL:http://www.ucgis.org/summer2002/choi/choi.html.
19. Giarrantano, J., & Riley, G. (2005). *Expert systems: Principles and programming*. Canada: Course Technology.
20. Cay, T., Ayten, T., Iscan, F. (2006). An investigation of reallocation model based on interview in land consolidation. In *Proceedings of the XXIII FIG Congress, Shaping the Change,* Munich, Germany, 8–13 October. Available from URL:http://www.fig.net/pub/fig2006/papers/ts89/ts89_02_cay_etal_0429.pdf.
21. Ayranci, Y. (2007). Re-allocation aspects in land consolidation: A new model and its application. Asian network for scientific information. *Journal of Agronomy, 6*(2), 270–277.
22. Demetriou, D., Stillwell, J., See, L. (2011). LandSpaCES: A spatial expert system for land consolidation. In S. Geertman., W. Reinhardt., F. Toppen (Eds.), *Advancing geoinformation science for a changing world* (pp. 249–274). New York: Springer, Verlag Berlin Heidelberg.
23. O'Keefe, R., Balci, R., & Smith, E. (1987). Validating expert systems performance. *IEEE Expert, 2*(4), 81–89.
24. O'Keefe, R., & O'Leary, D. (1993). Expert System verification and validation: A survey and tutorial. *Artificial Intelligence Review, 7*(1), 42–73.
25. Vermesan, A. (1997). Foundation and application of expert system verification and validation. In J. Liebowitz (Ed.), *The handbook of applied expert systems* (Vol. 5–1 pp. 5–32). MA, USA: CRC Press.
26. Metaxiotis, K., Askounis, D., & Nikolopoulos, K. (2006). Identifying the characteristics of successful expert systems: An empirical evaluation. *International Journal of Information Technology and Management, 5*, 21–36.
27. Balci, O. (1987). Credibility assessment of simulation results: The state of the art. In *Proceedings of the Conference on Methodology and Validation*. ESC, Orlando, FL, 6–9 April. Available from URL:http://eprints.cs002Evt.edu/archive/00000038/01/TR-86-31.pdf.
28. Adrion, W., Branstad, M., & Cherniavsky, J. (1982). Validation, verification and testing of software. *ACM Computing Surveys, 14*(2), 159–192.
29. Nguyen, T., Perkins, W., Laffery, T., & Pecora, D. (1987). Knowledge base verification. *AI Magazine, 8*(2), 65–79.

30. Sojda, R. (2006). Empirical evaluation of decision support systems. *Environmental Modelling & Software, 20*(2), 269–277.
31. O' Leary, D. (1991). Design, development and validation of expert systems: A survey of developers. In M. Ayel., J.-P. Laurent (Eds.), *Verification, validation and testing of expert systems* (pp. 3–19). New York: John Wiley. Available from URL:https://msbfile03.usc.edu/digitalmeasures/doleary/intellcont/Design-Development-and-Validation-of-Expert-Systems-A-Survey-of-Developers-1.pdf.

Chapter 9
LandSpaCES Model (Evaluation Module)

9.1 Introduction

This chapter outlines the development of the land redistribution Evaluation module of LandSpaCES. This module aims to assess alternative land redistribution solutions generated by the Design module as described in the Chap. 8 and determines the best solution to be input to the next module of LACONISS, i.e. the land partitioning (LandParcelS) module. The structure of the chapter is as follows. Section 9.2 discusses model structure issues by setting out the problem, selecting the evaluation criteria involved in the model and introducing the concepts of (1) the parcel concentration coefficient (*PCC*) for measuring the dispersion of holdings; and (2) the landowner satisfaction rate (*LSR*) for estimating the acceptance of the new land redistribution plan by the landowners in terms of the location(s) of the new parcels they receive. Thereafter, Sect. 9.3 presents the module interface including the basic elements of the evaluation process step by step. Sections 9.4 and 9.5 report an application using case study alternatives generated in the previous chapter, based on two scenarios: changing the weights of the criteria and the project objectives, respectively.

9.2 Model Structure Aspects

9.2.1 Problem Definition

Multi-criteria decision methods (MCDM), both multi-attribute (MADM) and multi-objective (MODM), have been described in Chap. 5. The Evaluation module of LandSpaCES (Choice phase I) follows the MADM process which is illustrated in Fig. 5.3, where a planner or a decision maker is confronted with a discrete number of alternative solutions but it is not clear, *a priori*, which solution is the best, i.e. one solution that dominates all the other alternatives across all the evaluation criteria. Thus, in this case, the aim is to find the best alternative land

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_9, © Springer International Publishing Switzerland 2014

redistribution plan among those generated by the Design module and to rank alternatives based on their ability to achieve the objectives. This MADM problem can be defined as having i = 1, 2, 3…, N criteria and j = 1, 2, 3…, M alternatives. Alternatives and criteria are combined in a table with the former as rows and the latter as columns to create an 'Impact table' (or effect or analysis table) of N × M dimensions. The preference of the planner at this stage of the process is incorporated by assigning a weight (or scaling constant), w_i, to each criterion, C_i, representing the relative importance of that criterion for the problem concerned, where the sum of the weights always equals 1. Each element α_{ij} of the Impact table represents a score which indicates the performance, i.e. the outcome of alternative j for criterion i. The typical form of an Impact table is illustrated in Fig. 9.1 and the aggregate performance of each alternative across all weighted criteria defines the ranking of the alternative. Once the problem has been articulated, the alternative land redistributions plans must be determined and the evaluation criteria must be identified.

9.2.2 Selecting Evaluation Criteria

The selection of the appropriate criteria begins with the definition of a hierarchical objective tree specified via the goal, aims and objectives of the land consolidation problem. In particular, based on the discussion of the land consolidation and land reallocation problems in Chaps. 3 and 4 respectively, such a hierarchical objective tree is illustrated in Fig. 9.2. The goal is an expression of the reason to take action

	Alternatives						
Criteria	A_1	A_2	A_3	.	A_j	.	A_M
C_1 (w_1)	α_{11}	α_{12}	α_{13}	.	α_{1j}	.	α_{1M}
C_2 (w_2)	α_{21}	α_{22}	α_{23}	.	α_{2j}	.	α_{2M}
C_3 (w_3)	α_{31}	α_{32}	α_{33}	.	α_{3j}	.	α_{3M}
.	.	.	.	.	.	.	.
C_i (w_3)	α_{i1}	α_{i2}	α_{i3}		α_{ij}	.	α_{iM}
.	.	.	.	.	.	.	.
C_N (w_N)	α_{N1}	α_{N2}	α_{N3}	.	α_{Nj}	.	α_{NM}

Fig. 9.1 The typical form of an impact table

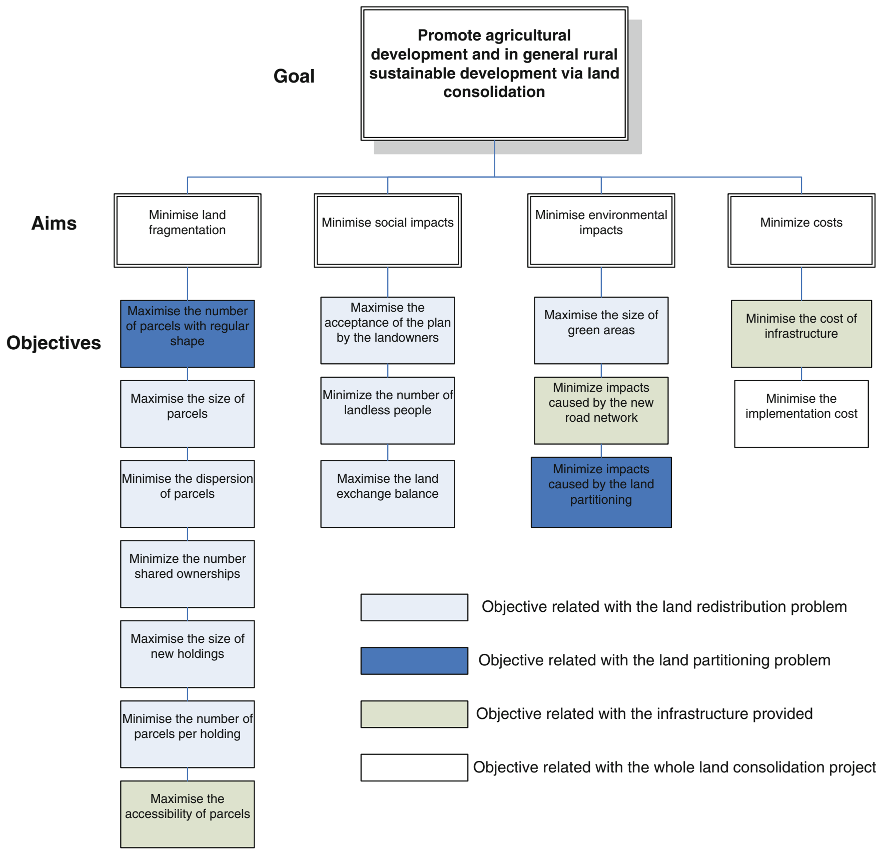


Fig. 9.2 The objective tree for land consolidation

and what needs to be achieved, i.e. sustainable rural development [1, 2]. The aims are the broader changes to be achieved for a specific aspect of the problem and the specific objectives set out how each aim will be fulfilled. The objective tree classifies objectives in groups that correspond to the critical issues, i.e. land fragmentation, social concerns, environmental concerns and costs. This research has broken down land consolidation into two sub-processes: land reallocation and the planning/provision of infrastructure, and the former is then split into land redistribution and partitioning. Thus, each objective is classified (using different colours) in the objective tree based on the problem concerned. Since this model focuses on the land redistribution problem, the associated objectives with the corresponding criteria/attributes are separately presented in Fig. 9.3. Further analysis of the latter Figure is provided in Demetriou et al. [3].

An assessment process, which was carried out in Demetriou et al. [3] for selecting which of the nine criteria included in Fig. 9.3 should be involved in the land redistribution Evaluation model, showed that all the requirements noted in

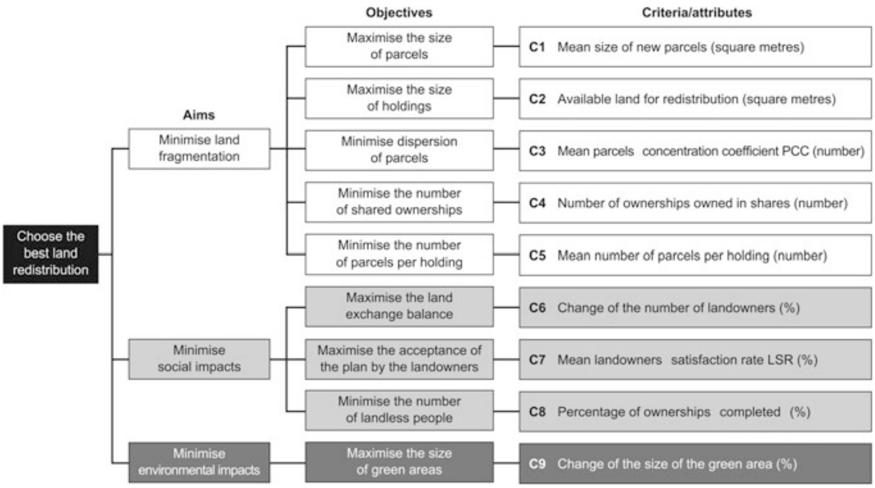


Fig. 9.3 The objective tree for the land redistribution problem

Sect. 7.2.2 are fulfilled by the following five criteria: mean size of new parcels (C1); mean parcel concentration coefficient (C3); change in the number of landowners (C5); mean landowner satisfaction rate (C7); and percentage of ownerships 'completed' (C8). The calculation of the scores of C1, C5 and C8 is straightforward since they involve simple statistical measures directly extracted from the output table of the Design module. Thus, the next two sections explain criteria C3, the mean parcel concentration coefficient (*PCC*) and C7, the mean landowner satisfaction rate (*LSR*), which are new criteria introduced in this research.

9.2.3 Parcel Concentration Coefficient

A new indicator is developed called the *parcel concentration coefficient* (*PCC*) which is measured on a scale between 1 and −1. A zero value means there is no change in the dispersion of a holding's parcel before and after land consolidation. The value of +1 refers to the situation of 'perfect concentration' and −1 represents 'worst concentration'. The dispersion of parcels can be calculated for each holding twice, i.e. before (DoP_{b}) and after (DoP_{a}) land consolidation based on Eq. 7.5 and then combined to calculate the *PCC* such that:

(1) If $DoP_b = DoP_a$ then $PCC = 0$ (for both Eqs. 9.1 and 9.2 that follow) means that the dispersion of parcels has not changed and the land consolidation has not achieved any concentration of parcels for the holding concerned. This occurs independently for either the number of new parcels allocated to a landowner or the number of original parcels owned by the landowner because the purpose of *PCC* is to calculate the difference in the dispersion of parcels

and not to compare the difference in the number of parcels (before and after a project) which is included in another criterion.

(2) If $DoP_b > DoP_a$ then

$$PCC = \frac{\left(\frac{DoP_b - DoP_a}{DoP_b}\right)}{n'} \quad (9.1)$$

where n' is the number of new parcels allocated to a holding after land consolidation. In this situation, an improvement has taken place in the dispersion of parcels and thus the PCC may take values that are somewhat more than 0. The extreme value of 1 means that parcels have been concentrated after land consolidation into a single parcel, i.e. $n' = 1$ and hence a perfect concentration has been achieved. This happens when the $DoP_{\mathrm{a}} = 0$ and consequently $n' = 1$. The numerator in Eq. 9.1 represents the change of dispersion before and after land consolidation for a holding. The denominator, i.e. the number of parcels allocated to a holding after land consolidation, adjusts the proportional change in dispersion, i.e. the level of concentration, since the PCC increases as n' decreases. In other words, the more the number of parcels allocated after land consolidation, the less the concentration of new parcels and hence the PCC reduces towards zero.

(3) If $DoP_b < DoP_a$, then

$$PCC = -\frac{\left(\frac{DoP_a - DoP_b}{DoP_a}\right)}{n} \quad (9.2)$$

where n is the original number of parcels belonging to a holding before land consolidation. In this situation, deterioration in dispersion of parcels has occurred and thus the PCC will take values between 0 and -1. Actually, this may occur either when the number of parcels allocated to a holding after land consolidation is greater than the original number of parcels and/or when the parcels have been allocated at greater distances. The extreme value of -1 means that the concentration of parcels after land consolidation is the worst independently of the number of new parcels allocated because in this case clearly the basic aim of concentrating parcels via land consolidation completely fails. This happens when the $DoP_{\mathrm{b}} = 0$ and consequently n = 1.

The numerator in Eq. 9.2 represents the change of dispersion before and after land consolidation of a holding. The denominator, i.e. the number of original parcels belonging to a holding, adjusts the proportional change in dispersion, i.e. the level of concentration, since the PCC increases as n increases. In other words, the greater the number of original parcels owned by a landowner, the less bad the difference (before and after a project) in parcel concentration is; hence PCC

Table 9.1 Calculation of *PCC* for various set of values

DoP_b	DoP_a	n′	n	*PCC*
Applying Eq. 9.1 (If $DoP_b \geq DoP_a$)				
500	500	1		0
1,000	1,000	2		0
1,500	1,500	3		0
2,000	1,500	1		0.25
2,000	1,500	2		0.13
2,000	1,500	3		0.08
5,000	1,000	1		0.80
5,000	1,000	2		0.40
5,000	1,000	3		0.27
2,000	0	1		1
1,000	0	1		1
500	0	1		1
Applying Eq. 9.2 (If $DoP_b \leq DoP_a$)				
500	500		1	−1
1,000	1,000		2	0
1,500	1,500		3	0
1,500	2,000		1	−1
1,500	2,000		2	−0.13
1,500	2,000		3	−0.08
1,000	5,000		1	−1
1,000	5,000		2	−0.40
1,000	5,000		3	−0.27
0	2,000		1	−1
0	1,000		1	−1
0	500		1	−1

reduces towards zero because the dispersion was already bad. For example, it is a worse situation if a landowner had only one parcel, i.e. perfect dispersion and is then allocated more than one parcel compared with a landowner having three parcels, which means that the holding was already dispersed, and is then allocated four parcels that cause an even worse dispersion. However, it should be noted that allocating a landowner more parcels than those originally owned is a very rare case in land consolidation projects. The above considerations are clarified by utilising an example which applies formulas 9.5 and 9.6 for various ranges of values that are illustrated in Table 9.1. The basic code for calculating *PCC* is presented in Appendix B.3.1.

9.2.4 Landowner Satisfaction Rate

The *landowner satisfaction rate* (*LSR*) is an indicator showing the satisfaction of the landowners' preferences for the whole project in terms of the location of their new parcels. It is based on the parcel priority index (*PPI*) introduced in Chap. 8, which ranks the preferences of landowners regarding the locations of the new parcels they wish to receive. For instance, a landowner with five parcels is assigned a *PPI* index for each parcel, which defines the rank order of parcels representing the preference of the landowner, i.e. first, second, third, fourth and fifth in terms of the new parcel locations. Thus, the *LSR* searches for the solutions in which the preferences of each landowner have been satisfied and assigns a proportional percentage of satisfaction depending on the ranking of the preference satisfaction, with a maximum of 100 %.

In particular, each new parcel is assigned a partial satisfaction rate (*PSR*), with a maximum of 100 %, based on the rank order of the preferences satisfied. A critical point in this process is that the original parcels of a landowner (n) which are already in a preference ranking order (based on *PPI*s) are divided in two parts. The first covers the situation up to $n = n'$ (where n is the number of original parcels owned by a landowners and n' is the number of new parcels held by a landowner) whilst the other part covers the situation for the rest of the parcels i.e. from $n' + 1$ to n. Then each new parcel is examined to identify in which part the preference falls. Thus, if it falls in the first part then the partial satisfaction rate of the landowner will be 100 % whereas if it falls in the second part, then the partial satisfaction is assigned proportionally, namely reduced, depending on the number of original parcels and the number of new parcels. This can be expressed mathematically as follows:

If $n \geq n'$, then the *PSR* for each new parcel i allocated to a landowner can be calculated as:

$$PSR_i = m_i P \tag{9.3}$$

where m_i is a variable that takes into account the number of parcels originally owned by a landowner (n) and the ranking order of the preference of each original parcel i (RO_i) and P is a linear function that expresses decreasing satisfaction for each landowner. The two variables, m_i and P are computed as:

$$m_i = n - RO_i + 1 \tag{9.4}$$

Maxm is the m_i value assigned to those new parcels that fall in the first part of original parcels as explained earlier. In this case, the parameter (RO_i) in Eq. 9.4 is replaced by the number of new parcels (n') as:

$$Maxm = n - n' + 1 \tag{9.5}$$

P, which is a constant percentage for the redistribution of each holding, is calculated based on the two parts mentioned earlier. In particular, the parcels belong in the count in the first part as one sub-part whilst the parcels belong in the count in the second part individually as a separate sub-part. Thus, *P* is determined by dividing 100 % by the total number of sub-parts which always equals $n-n' + 1$. Therefore, *P* can be computed as:

$$P = \frac{100}{n - n' + 1} \tag{9.6}$$

Combining Eqs. (9.3), (9.4) and (9.6) yields:

$$PSR_i = \frac{100(n - RO_i + 1)}{n - n' + 1} \tag{9.7}$$

The total *LSR* for each landowner *j* is then calculated as the mean value of the *PSR*:

$$\bar{LSR_j} = \sum_{i=1}^{n'} \frac{PSR_i}{n'} \tag{9.8}$$

Similarly, the average *LSR* for the whole land consolidation area, i.e. the whole project, can be calculated as the mean *LSR* of all landowners, *l*, who received property in the plan as:

$$LSR = \sum_{j=1}^{l} \frac{LSR_j}{l} \tag{9.9}$$

The above assumptions become clearer by utilising an example for calculating *PSR* and *LSR*. Table 9.2 involves a landowner who originally had five parcels (i.e. n = 5) and after land consolidation receives either 1, 2 or 3 parcels (i.e. n′ = 1, n′ = 2, n′ = 3). Each cell of the table contains the *PSR* value for each combination of n and n′.

Table 9.2 An example for the calculation if the partial satisfaction rate

	Number of new parcels (n′) allocated to the landowner		
n	1 (%)	2 (%)	3 (%)
1	maxM × P = 5 × 20 = 100	maxM × P = 4 × 25 = 100	maxM × P = 3 × 33.33 = 100
2	M_2 × P = (5 − 2 + 1) × 20 = 80	maxM × P = 4 × 25 = 100	maxM × P = 3 × 33.33 = 100
3	M_3 × P = (5 − 3 + 1) × 20 = 60	M_3 × P = (5 − 3 + 1) × 25 = 75	maxM × P = 3 × 33.33 = 100
4	M_4 × P = (5 − 4 + 1) × 20 = 40	M_4 × P = (5 − 4 + 1) × 25 = 50	M_4 × P = (5 − 4 + 1) × 33.33 = 66.66
5	M_5 × P = (5 − 5 + 1) × 20 = 20	M_5 × P = (5 − 5 + 1) × 25 = 25	M_5 × P = (5 − 5 + 1) × 33.33 = 33.33

The interpretation of the *PSR* values shown in Table 9.2 is straightforward. In particular, if the landowner who originally had five parcels has been allocated one parcel (i.e. first column) in the same location as its fourth preference (i.e. fourth row), then he/she will have partial satisfaction of 40 %. Similarly, if the landowner has been allocated two parcels (i.e. second column), say in the same location as the first (i.e. first row) and fourth preference (i.e. fourth row), then he/she will be satisfied partially by 100 % for the location of the first parcel and by 50 % for the location of the second parcel. As a result, the average *LSR* can be easily calculated as 75 %. In the same vein, if the landowner has been allocated three parcels (i.e. third column), say in the same location as the second (i.e. second row), third (i.e. third row) and fifth preference (i.e. fifth row), then he/she will be satisfied partially by 100 % for the location of the first parcel, by 100 % for the location of the second parcel and by 33.33 % for the location of the third parcel. As a result, the average *LSR* will be 77.78 %.

Based on the above, it is clear that if $n' \geq n$, it is examined if the n' up to n new parcels fall in the first part and in such case the *PSR* is estimated as above. The remainder of the new parcels, i.e. a number $n' - n$ fall definitely outside the ranked preferences of landowners because preferences coincide exactly with the number of original parcels, i.e. n; hence *PSR* is 0 % for those new parcels. The basic code for calculating *LSR* is presented in Appendix B.3.2.

9.3 Module Interface

9.3.1 The Module Toolbar

The toolbar of the Evaluation module illustrated in Fig. 9.4 follows the process shown in Fig. 5.3, which is described in Chap. 5. The toolbar consists of seven menu items: Alternatives; Criteria; Impact Table; Value Functions; Decision Table; Ranking Alternatives; and Sensitivity Analysis. Each menu item represents a stage of the MADM process and launches a separate window with one or more functionalities. The menu items are organised in the order in which they must be executed in the process. The functionality of each menu item will be described separately in the sections that follow.

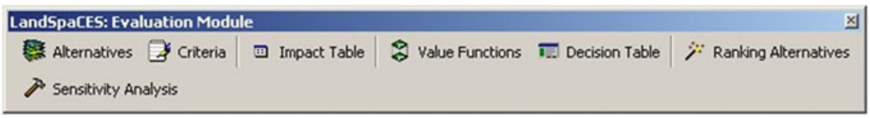


Fig. 9.4 The toolbar of the Evaluation module of LandSpaCES

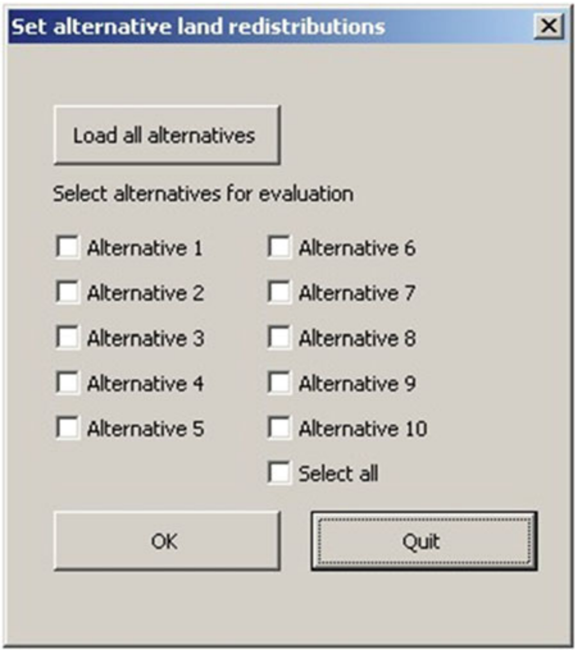


Fig. 9.5 The 'set alternative land redistributions' window

9.3.2 Selecting Alternatives

The Alternatives menu item allows the user to select alternative land redistribution solutions and launches a window entitled 'Set alternative land redistributions' (Fig. 9.5). The user first loads all the alternative land redistributions generated by the Design module of LandSpaCES by pressing the button 'Load all alternatives'. Then the user selects which alternative solutions to use in the evaluation process by checking the appropriate boxes, or all alternatives can be selected at once. Clicking the OK button completes this process.

9.3.3 Selecting and Weighting Criteria

The user then selects which criteria to include via the 'Criteria' menu item. The selection of the criteria works in the same way as selecting the alternatives (Fig. 9.6). This window also allows the assignment of weights to factors. In particular, weighting can be carried out by utilising the two methods noted in Sect. 7.2.3, namely, the direct ranking and the qualitative rating methods.

Once the alternatives and criteria are selected, this creates the structure of the 'Impact table' as shown in Fig. 9.1. If the user selects the Impact table menu item, the dialogue box is shown (Fig. 9.7). This window provides four main functions

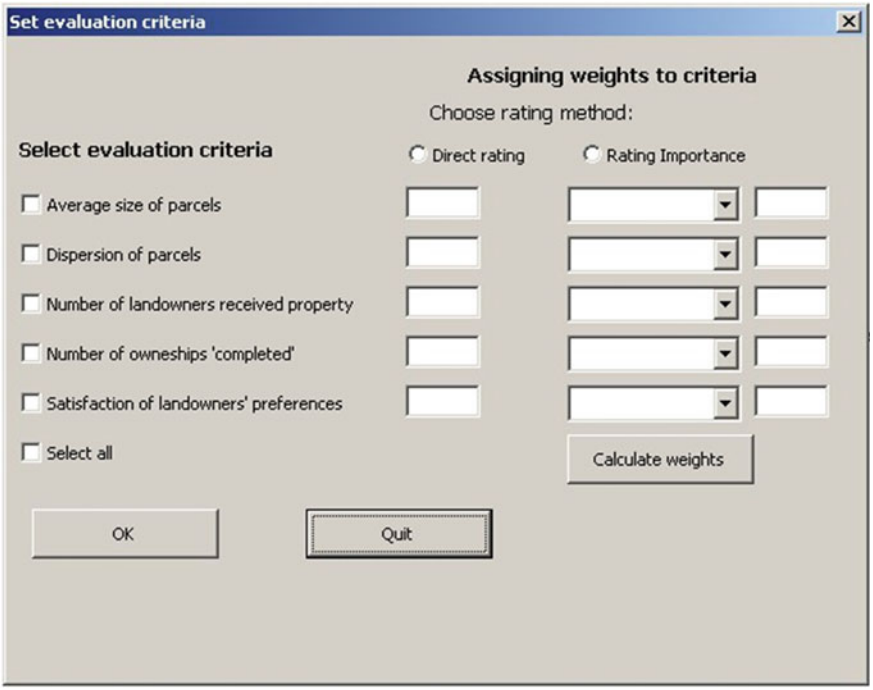


Fig. 9.6 The ‘set evaluation criteria’ window

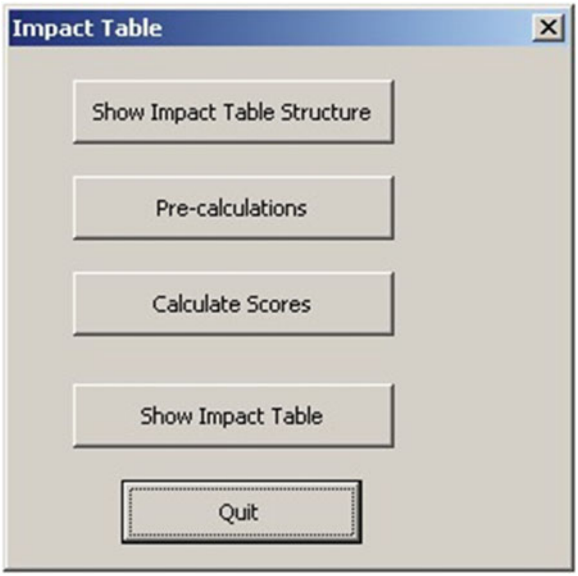
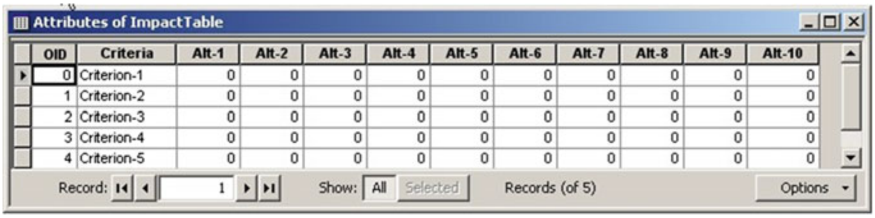


Fig. 9.7 The ‘impact table’ window



Attributes of ImpactTable

OID	Criteria	Alt-1	Alt-2	Alt-3	Alt-4	Alt-5	Alt-6	Alt-7	Alt-8	Alt-9	Alt-10
0	Criterion-1	0	0	0	0	0	0	0	0	0	0
1	Criterion-2	0	0	0	0	0	0	0	0	0	0
2	Criterion-3	0	0	0	0	0	0	0	0	0	0
3	Criterion-4	0	0	0	0	0	0	0	0	0	0
4	Criterion-5	0	0	0	0	0	0	0	0	0	0

Record: 1 Show: All Selected Records (of 5) Options

Fig. 9.8 An example of the structure of the Impact table

(with corresponding buttons): the appearance of the structure of the Impact Table (Fig. 9.8); 'pre-calculations' regarding the dispersion of parcels and the satisfaction of landowners' preferences, which are not provided by the Design; calculation of the scores α_{ij} of the (via the 'Calculate Scores' button); and the finalwith scores (via the 'Show Impact Table' button).

9.3.4 *Standardisation*

All the five criteria involved in the evaluation model need to be standardised. Standardisation is carried out by employing appropriate values functions which have been constructed based on the process described in Sect. 7.2.4. Figure 9.9a–e shows a value function for each criterion. The maximum values for criteria (C1, C3 and C4) have been defined based on the 40 year statistical records provided by the LCD for 74 land consolidation projects representing the perfect achievement of the relevant objectives noted in Fig. 9.2. The other two attributes (C2 and C5), i.e. the mean *LSR* and the mean *PCC* involve, by definition, a maximum value, i.e. 100 % and 1 respectively. Minimum values are all zero. In all functions, scores lower than x_{min} are standardised at 0, while scores higher than x_{max} are standardised to 1.

Figure 9.9a shows a concave benefit value function represented by:

$$V(x_i) = \frac{x_i}{13.754 + 0.882x_i + 2.290\sqrt{x_i}} \tag{9.10}$$

Figure 9.9b presents another concave benefit value function represented by:

$$V(x_i) = \frac{x_i}{0.181 + 0.975x_i - 0.153x_i^2} \tag{9.11}$$

Figure 9.9c shows a mixed bell-shaped benefit-cost value function represented by:

$$\begin{aligned} V(x_i) = 7.914 \times 10^{-6}x_i^4 - 6.368 \times 10^{-4}x_i^3 + 1.361 \times 10^{-2}x_i^2 \\ - 3.208 \times 10^{-2}x_i + 1.332 \times 10^{-3} \end{aligned} \tag{9.12}$$

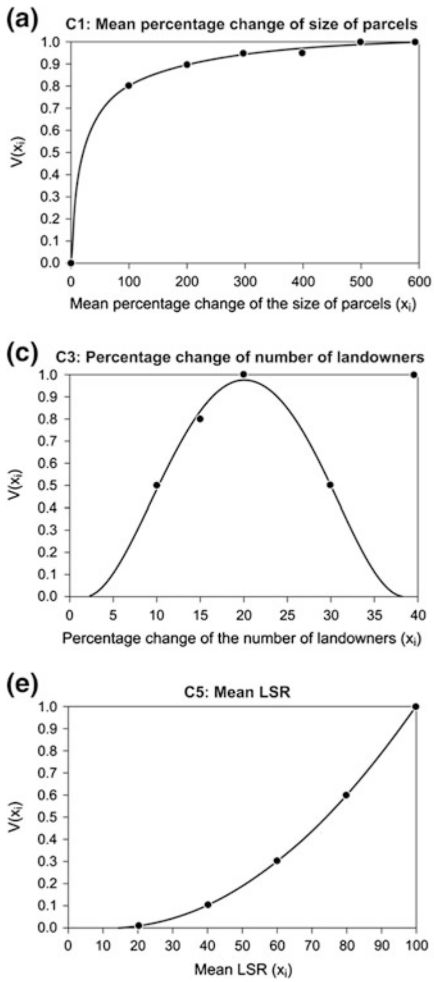


Fig. 9.9 Value functions for the evaluation criteria

Figure 9.9d shows an s-shaped benefit value function represented by:

$$V(x_i) = \frac{x_i}{420.714 + 7.681x_i - 106.064\sqrt{x_i}} \tag{9.13}$$

Figure 9.9e presents a convex benefit value function represented by:

$$\begin{aligned} V(x_i) = & -3.906 \times 10^{-9}x_i^4 + 8.623 \times 10^{-7}x_i^3 + 6.441 \times 10^{-5}x_i^2 \\ & - 1.161 \times 10^{-3}x_i + 1.984 \times 10^{-4} \end{aligned} \tag{9.14}$$

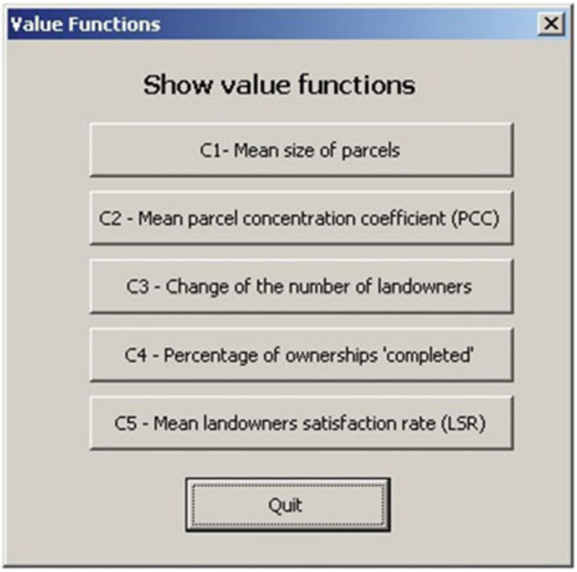


Fig. 9.10 The 'value functions' window

Details about the rationale for defining each value functions are provided in Demetriou et al. [3]. Value functions are not modifiable by the users so they can only be illustrated graphically through the 'Value functions' window (Fig. 9.10).

9.3.5 *Ranking Alternatives*

As shown in Fig. 5.3, the outcome of the MADM is a ranking of alternatives which actually identifies the best alternative for the decision problem concerned. This process involves utilising an appropriate method which is commonly called a 'decision rule'. The most prominent decision rules are classified by Sharifi et al. [2] into three main categories: compensatory methods, outranking methods and non-compensatory approaches. In particular, compensatory methods assume that a weak performance in one criterion may be compensated by a high performance of an alternative in another criterion. Thus, these methods involve aggregation of the performance scores of all criteria concerned. However, this additive representation [4] is appropriate only if the evaluation criteria are independent of each other. The most well-known compensatory approaches are: the simple additive weighting method; the value/utility function approach; the analytic hierarchy process (AHP); and the ideal point method. Interesting findings are that compensatory methods are the most popular for spatial decision-making problems [1] and that the choice between the first three methods noted earlier present little impact on the sensitivity of the results [5]. Outranking methods are partially compensatory since in practice some compensation is acceptable whilst others are not. These methods are based on pairwise comparisons between the alternatives and their outranking relations. The most popular series of such methods is called ELECTRE. On the other hand, non-compensatory methods assume no compensation between the criteria at all, an example being the dominance method. For a comprehensive overview of decision rules, see Keeney and Raiffa [6], Triantaphyllou [7] and Sharifi et al. [2].

Among the above methods, the Evaluation module utilises a value function approach for ordering alternative land redistributions. Both value function and utility function approaches are based on multi-attribute utility theory [8]. The difference between these approaches is that the former is applicable in decision problems where there is certainty (i.e. deterministic problems) whilst the latter is appropriate for decision problems where there is uncertainty (probabilistic problems). The problem concerned in this chapter is clearly deterministic since the scores of the attributes are generated in a certain and straightforward way and not from a probabilistic distribution. Apart from the problem being deterministic, the value function approach is preferred because of the following reasons: (a) it incorporates the decision makers' preferences in the process through the development of the value functions; (b) evaluation criteria are independent and they can be expressed in the same value (via value functions); thus a major requirement of the approach is met, and (c) the simplicity of the method.

Specifically, the value function approach is the weighted average of the single attribute utilities (values) as:

$$V_j = \sum_{i=1}^{N} w_i v_{ij} \tag{9.15}$$

where V_j is the overall value (or performance score) of the *jth* alternative ($j = 1$ to M), v_{ij} is the standardised value of the score α_{ij} in the of the *jth* alternative with respect to the *ith* criterion/attribute ($i = 1$ to N) measured by utilising an appropriate value function, and w_i is the normalised weight for criterion/attribute i so that:

$$\sum_{i=1}^{N} w_i = 1. \tag{9.16}$$

The alternative that results in the highest V_j is characterised as the best alternative compared with the other competitive alternatives solutions.

9.3.6 Sensitivity Analysis

As noted in Sect. 7.3.6 in the case of MADM, two important elements need to be examined in the context of SA: the weights of the evaluation criteria and the criterion scores (or performance measures). Despite this importance, then work by Delgado and Sendra [9] showed that most models involve an SA only on the former element. In addition, it should be noted that SA is a wide issue for which there is a huge literature [10] and specific software packages have been developed such as DEFINITE [11], Expert Choice [12] and Best Choice [13]. Thus, because it is beyond the aim of this research to develop a new method of SA, it adopts the SA methodology used by Triantaphyllou [5, 7] that provides several useful SA parameters and focuses on both the weights of the evaluation criteria and criterion scores.

In particular, the sensitivity of the weights of the criteria is crucial because the process of assigning weights is subjective and hence it may demonstrate significant variation between the decision makers' perceptions and preferences. Moreover, the available methods for defining weights may lead to different results. The decision maker can take better decisions if he/she is aware of how critical each criterion is. Thus, Triantaphyllou [5, 7] developed a methodology to determine the most critical criterion in a twofold way: in the first instance, the focus is on identifying the criterion for which the smallest change of a current weight may alter the best alternative; and in the second case, the aim is to find out for which criterion the smallest change in a current weight may change the ranking of any alternative. In this vein, Triantaphyllou introduced the terms 'top critical criterion' and 'any critical criterion', respectively. Each term may be associated with two concepts with respect to changes in the weights: in relative terms and absolute terms. However, the latter may be misleading since, e.g. a change of 0.02 is very different in terms of influence if the original values of the weights are 0.08 and 0.8. Thus, this research adopts the former approach since expressing the change in relative terms, i.e. as a percentage, is more meaningful.

The relevant terms of this approach are called 'percent-top critical criterion' (PTCC) and 'percent-any critical criterion' (PACC), respectively. In addition, Triantaphyllou [5, 7] defines some more terms as follows: the criticality degree $(\text{sens}(C_k))$ of a criterion as the smallest percentage by which the current value of a weight should change such that the existing ranking of alternatives will change; and the sensitivity coefficient of criterion, which is equivalent to the reciprocal of the criticality degree. Calculation formulas for all these terms are analytically presented in Demetriou et al. [3]. The SA measures noted above, i.e. PTCC, PACC and $\text{sens}(C_k)$ can be calculated in the Evaluation module using the window that appears when clicking on the 'Sensitivity Analysis' menu item. The relevant functions are provided in the first part of this window as illustrated in Fig. 9.11.

The most important table calculated for the SA of the weights of the criteria is the so called SAcriteriaTable; an example is illustrated in Fig. 9.12.

In particular, the latter table involves a value representing, for each combination of pair of alternatives and for each criterion, the percentage change in the certain criterion weight that will invert the ranking order of the chosen pair of alternatives. If the value is negative then this means increase change and *vice versa*. The 'string of ones' means that the ranking order of the pair of alternatives concerned cannot be changed by any change of the weights of the criterion concerned. Based on this table, the three SA measures noted earlier are estimated, which are obviously very vital measures for assessing the reliability of defined weights.

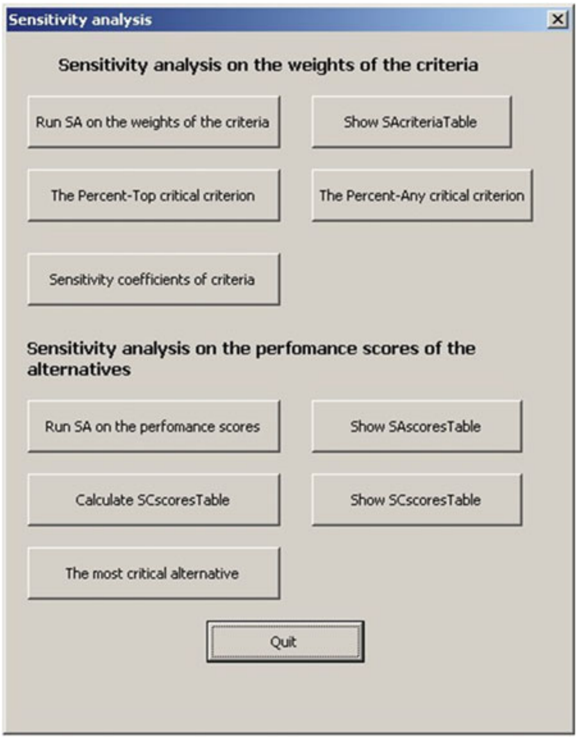


Fig. 9.11 The 'sensitivity analysis' window

In addition to the sensitivity of weights of the criteria, carrying out sensitivity of the performance scores is also important in this model. In particular, although the process of calculating the scores of attributes for each criterion is more certain than assigning weights to criteria, the standardisation process, which utilises value functions, involves a considerable subjectivity after the calculation of the scores, since value functions are defined by experts and hence the process is inherently prone to uncertainties.

Therefore, in the same vein as for the sensitivity of the weights of the criteria, Triantaphyllou [5, 7] defined the following concepts for the sensitivity of the performance scores: the 'most sensitive alternative' is the alternative which is associated with the smallest threshold value representing the minimum change that may occur so as to change the current ranking between a pair of alternatives. The whole set of relevant formulas are presented in Demetriou et al. [3]. Following the same notion as in the SA of criterion weights, Triantaphyllou [5, 7] defined the following terms: the 'criticality degree of alternative', as the minimum threshold value (noted earlier) associated with that alternative and any other alternative. In other words, the smaller the criticality degree is, the easier the ranking of an alternative can change. Based on this, the smallest criticality degree between all alternatives gives the 'most critical alternative'. In addition, a sensitivity coefficient of an alternative in terms of a criterion is the reciprocal of its criticality

Attributes of SAcriteriaTable

OID	Alt(i)	Alt(j)	C1	C2	C3	C4	C5
23	3	10	-89.82	-232.56	11111	81.13	1111111
24	4	5	11111	111111	11111	11111	1111111
25	4	6	11111	111111	11111	11111	-1132.44
26	4	7	11111	111111	11111	11111	-1006.44
27	4	8	11111	111111	11111	11111	-5990.06
28	4	9	35.791	111111	11111	11111	-55.7429
29	4	10	-47.27	-132.46	11111	43.91	94.94031
30	5	6	11111	111111	11111	11111	-260.983
31	5	7	11111	111111	11111	11111	-246.618
32	5	8	11111	111111	11111	11111	-963.893
33	5	9	11111	111111	11111	11111	1111111
34	5	10	18.514	33.5271	-78.93	-18.71	-129.338
35	6	7	-32.19	39.1945	-10.10	9.363	1111111
36	6	8	11111	111111	11111	11111	1111111
37	6	9	11111	111111	11111	11111	-1286.72
38	6	10	77.228	111111	-612.7	-321.3	-230.733
39	7	8	11111	111111	-1067.	11111	1111111
40	7	9	11111	111111	11111	11111	-1127.33
41	7	10	73.065	111111	11111	-201.8	-220.439
42	8	9	11111	111111	11111	11111	-8357.47
43	8	10	11111	111111	-1669.	11111	-738.621
44	9	10	-44.45	-128.94	11111	42.75	88.41496

Record: 28 Show: All Selected

Fig. 9.12 Example output: part of the SAcriteriaTable

degree. It can be concluded that the most sensitive alternative is the one with the highest sensitivity coefficient. These SA concepts regarding the performance scores are calculated by utilising the functions provided in the second part of the window as shown in Fig. 9.11.

In particular, the SAscoresTable, which an example output illustrated in Fig. 9.13, involves in each of its elements a value for each combination of pair of alternatives and criteria involved in the process. Namely, each value means that the certain performance score should be changed by this percentage from its current value so as the certain pair of alternatives will inverse ranking order. The smallest values for each alternative and each criterion called criticality degrees as mentioned earlier are picked up in a table called SC scores Table as exemplified in Fig. 9.14. Criticality degrees define the most competitive alternative of each alternative for each criterion that may reverse ranking. This is also a very critical measure for our case since a potential slight change of the definition of a value function and in general of the standardisation method may considerably alter ranking order of alternatives.

Attributes of SAscoresTable

OID	Alt(i)	Alt(j)	C1	C2	C3	C4	C5
0	1	2	-10.718635	-8.881943	-6.54342	-4.858953	-5.446717
1	1	3	-12.855529	-10.652669	-7.847933	-5.827646	-6.532589
2	1	4	-1.034141	-0.856936	-0.631314	-0.468795	-0.525503
3	1	5	21.276097	17.63033	12.988449	9.644844	10.811534
4	1	6	66.362081	54.990604	40.512154	30.083145	33.722158
5	1	7	65.508927	54.283643	39.991328	29.696395	33.288625
6	1	8	1111111	1111111	95.013228	70.554055	79.088639
7	1	9	-0.618366	-0.512406	-0.377495	-0.280316	-0.314225
8	1	10	14.610101	12.106587	8.919049	6.623026	7.424181
9	2	1	10.550715	8.881943	6.266317	4.823883	5.43899
10	2	3	-2.103417	-1.770727	-1.249269	-0.961701	-1.084331
11	2	4	9.532775	8.025007	5.661739	4.358471	4.914233
12	2	5	31.493497	26.512273	18.704728	14.399113	16.235187
13	2	6	75.873156	63.872547	45.06285	34.689896	39.113309
14	2	7	75.033369	63.165586	44.56408	34.305937	38.680391
15	2	8	1111111	1111111	97.255897	74.868698	84.415432

Record: 1 Show: All Selected Records (of 90)

Fig. 9.13 Example output: part of SAscoresTable

Attributes of SCscoresTable

OID	Alt(i)	C1	Alt-C1	C2	Alt-C2	C3	Alt-C3	C4	Alt-C4	C5	Alt-C5
0	1	0.618366	9	0.512406	9	0.377495	9	0.280316	9	0.314225	9
1	2	2.103417	3	1.770727	3	1.249269	3	0.961701	3	1.084331	3
2	3	2.06366	2	1.770727	2	1.233412	2	0.976525	2	1.076934	2
3	4	0.41152	9	0.34453	9	0.253819	9	0.188479	9	0.211278	9
4	5	6.793695	10	5.919721	10	4.0694	10	3.021818	10	3.594175	10
5	6	1.2712	7	0.846661	7	0.520826	7	0.424285	7	0.420807	7
6	7	1.323463	6	0.828758	6	0.549137	6	0.405892	6	0.419441	6
7	8	193.497422	6	112.823942	6	54.501075	6	56.59338	6	44.771422	6
8	9	0.416306	4	0.34453	4	0.253819	4	0.188479	4	0.21048	4
9	10	4.969975	5	5.031358	5	4.29061	5	3.603758	5	3.696908	5

Record: 1 Show: All Selected Records (of 10) Options

Fig. 9.14 Example output: SCscoresTable

9.4 Case Study: Changing Weights of Criteria

As presented in Sect. 8.4.3, the system ran for ten different sets of facts generating ten alternative land redistributions. These alternative solutions were input in the Evaluation module for assessment based on two different scenarios I and II. The former, which is presented in this section, involves changing the weights of all criteria involved in the process including four different case scenarios and the latter (which is presented in Sect. 9.5) focuses on different project objectives including two case scenarios.

9.4.1 Ranking Alternatives

Ranking alternatives is carried out using four case scenarios. In scenario 1, all five criteria have the same weight. In scenario 2, weights were assigned to each of the five criteria in the following descending order of importance: extremely high, very high, high, intermediate and moderate. In contrast, the weights in scenario 3 have been assigned in ascending order of importance, whilst in scenario 4, they were assigned based on the judgement of the principal author as: extremely high, high, high, intermediate and very high, respectively. The performance score and the rank order of each alternative for each scenario shown in Table 9.3 and the critical criteria and most critical alternative for each scenario are shown in Table 9.4. A graphical representation of ranking of alternatives per scenario is illustrated in Fig. 9.15.

Some interesting findings are the following: no one alternative is the best in all scenarios. In particular, alternatives 3 and 10 are ranked as best in scenarios 1, 3 and 2, 4 respectively. It is also remarkable that alternative 10 ranks third and seventh in scenarios 1 and 3 respectively and in which alternative 3 is ranked first. In contrast, alternative 3 is ranked second in the case of scenarios in which alternative 10 is ranked first, revealing that alterative 3 is more reliable in terms of performance, presenting stable behaviour in all scenarios and hence classifying this as the best alterative in the eye of the expert. The unreliability of alternative 10 is also revealed by the fact that it is the only alternative that presents so much

Table 9.3 The performance score of each alternative for four weighting scenarios

Ranking	Scenario-1		Scenario-2		Scenario-3		Scenario-4	
	Alternative	Score	Alternative	Score	Alternative	Score	Alternative	Score
1	Alt-3	0.823	Alt-10	0.791	Alt-3	0.875	Alt-10	0.797
2	Alt-2	0.820	Alt-3	0.765	Alt-2	0.873	Alt-3	0.789
3	Alt-4	0.809	Alt-2	0.761	Alt-9	0.863	Alt-2	0.784
4	Alt-9	0.809	Alt-4	0.751	Alt-4	0.863	Alt-4	0.775
5	Alt-1	0.808	Alt-9	0.749	Alt-1	0.862	Alt-9	0.774
6	Alt-10	0.804	Alt-1	0.749	Alt-5	0.839	Alt-1	0.773
7	Alt-5	0.787	Alt-5	0.729	Alt-7	0.818	Alt-5	0.75
8	Alt-6	0.737	Alt-6	0.652	Alt-6	0.816	Alt-6	0.695
9	Alt-7	0.735	Alt-7	0.646	Alt-10	0.815	Alt-7	0.69
10	Alt-8	0.647	Alt-8	0.555	Alt-8	0.734	Alt-8	0.612

Table 9.4 Critical criteria and alternatives for each scenario

	Scenario1	Scenario2	Scenario3	Scenario4
Percent top critical criterion	C1	C1	C4	C1
Percent any critical criterion	C1	C5	C1	C1
Most critical alternative	A9	A9	A4	A1

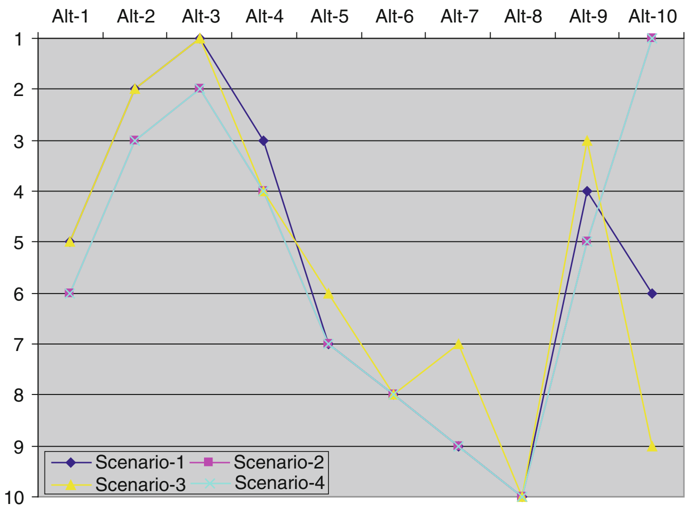


Fig. 9.15 Ranking of alternatives for four different criteria weighting scenarios

difference in ranking positions (i.e. first, sixth and ninth) while all the other alternatives change at worst by two positions in terms of ranking. It is also remarkable that the variability of the performance scores of the best and worst alternatives varies greatly per scenario, i.e. 21.39, 29.84, 16.11 and 23.21 % for the four scenarios respectively, which means that different facts and different weight schemes may produce considerably varying alternatives.

Moreover, ranking of alternative 1 (that represents the solution given by human experts in the case study), i.e. fifth or sixth in the four scenarios, indicates that it underperforms compared to alternatives 2, 3, 4 and 9 with which it is comparable in terms of facts. This proves that the system may produce better solutions than the experts. Moreover, it is clear that alternative 8 ranks last in all scenarios. A general finding is that the ranking of alternatives is very sensitive to the alteration of weights of the criteria. Therefore, planners should be aware both of the weights assigned to each criterion and hence the weighting method utilised.

9.4.2 Performance of Alternatives Per Criterion and Scenario

Figures 9.16, 9.17, 9.18 and 9.19 show the performance of each alternative for each criterion in the four scenarios revealing some more findings associated with the ranking of the alternatives. In particular, while alternative 10 achieves the highest performance (standardised values) for criteria 1 and 2 in all scenarios and is ranked first in scenarios 2 and 4 overall, it significantly underperformed in scenarios 1 and 3 (ranked sixth and ninth, respectively) because criteria 1 and 2 were given lower weights in scenarios 1 and 3 so had significantly less impact on the overall results. More specifically, weights are very high for both criteria in the former scenarios while, in contrast, they are very low in the latter scenarios.

In addition, alternative 10 presents the worst performance values for criteria 3 and 5 in all scenarios. In contrast, alternative 3 is actually the best and more balanced as noted earlier. Regardless of this, it achieves the best performance (among all alternatives) only for criterion 3. In addition, as the aggregated ranking showed earlier, Figs. 9.16, 9.17, 9.18 and 9.19 illustrate more analytically that no alternative is best in all of the criteria in any one scenario. It is also clear that alternative 8, which is ranked last for all scenarios, gives the worst performance in criteria 1, 2 and 4. Another general finding is that criteria 1, 2 and 4 indicate high variability in the values of the alternatives while, in contrast, criteria 3 and 5 present low variability.

If the above findings are associated with the facts of alternatives (Table 8.5), they are absolutely reasonable. In particular, alternative 10, which involves the highest values in facts F1–F8 and F11, was expected to achieve the best performance for the aim 'to minimise land fragmentation' which is linked with criteria: the mean size of parcels (C1) and the dispersion of parcels (C2). In contrast, alternative 10 achieves the worst or poorer performance in terms of the aim 'to minimise social impacts', which is associated with criteria: the land exchange balance (C3), the *LSR* (C5), and the number of ownerships 'completed' (C4), respectively. On the other hand, alternative 3 involves facts that try to balance a trade-off between all the criteria so as to achieve a good performance as much as possible across all criteria. In addition, alternatives 6, 7 and 8, which involve the

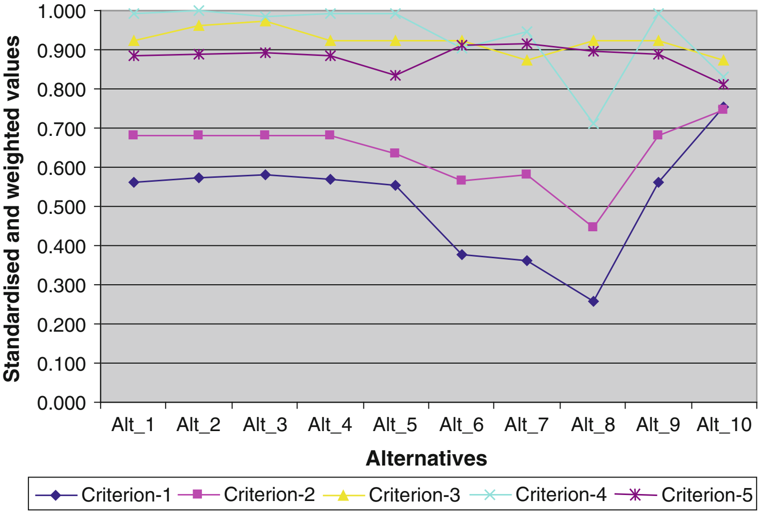


Fig. 9.16 Performance of alternatives for all criteria in scenario 1

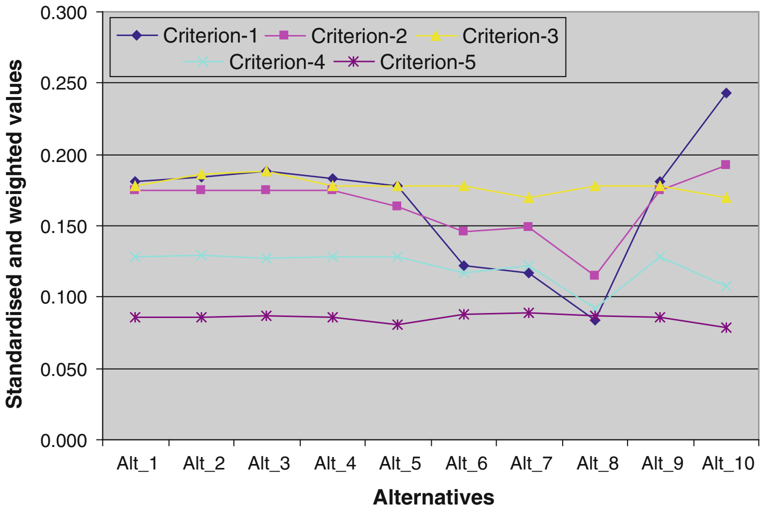


Fig. 9.17 Performance of alternatives for all criteria in scenario 2

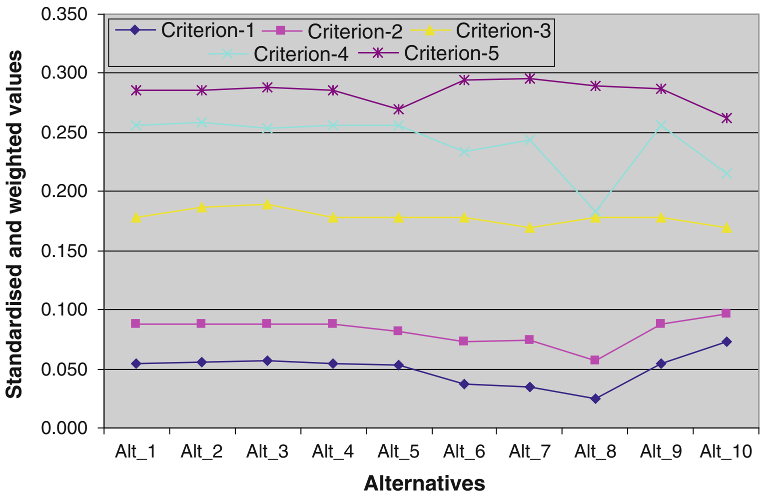


Fig. 9.18 Performance of alternatives for all criteria in scenario 3

lowest value of the fact F1, i.e. the minimum area limit of the new parcels, reasonably achieves the worst outcomes in the criteria that are associated with minimising land fragmentation, i.e. C1, C2 and C4. Hence they rank as the last three alternatives in scenarios 1, 2 and 4 and in the last four in scenario 3.

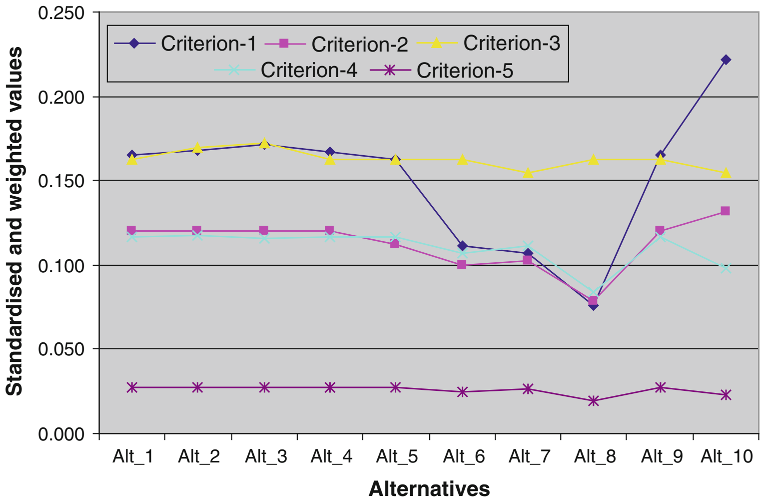


Fig. 9.19 Performance of alternatives for all criteria in scenario 4

9.4.3 Sensitivity Analysis

As mentioned earlier, the module utilises the approach of Triantaphyllou [5, 7] in undertaking a SA of both the weights of the criteria and the performance scores. Therefore, Fig. 9.20 show the sensitivity coefficient variability for all criteria for each scenario; the higher the sensitivity coefficient, the more sensitive is that criterion in terms of changing the rank of the best alternative or any pair of alternatives. It is apparent that all the criteria are very sensitive in scenario 3. The reason is that the weighting scheme in scenario 3 can be considered as paradox in terms of the logical importance of criteria that could be assigned by land consolidation experts. As a result, a slight change of weights towards a more reasonable scheme causes a change in the rank order of the alternatives. In contrast, the criteria are much less sensitive for the other three scenarios because they involve a 'sensible' weighting pattern in terms of practice.

In addition, Table 9.5 shows the most critical criteria and alternatives. The 'percent top critical criterion' (PTCC) is C1 for scenarios 1, 2 and 4. That is, if the weight for C1 changes by 55.8, 46.2 and 14.7 %, the ranking of best alternatives will alter, i.e. alternatives 3, 10 and 4 for the relevant scenarios will change. It is noted that the 'qualitative rating' method involves a change of 90 % from best (i.e. extremely high importance) to worst (i.e. very low importance) (Table 7.1, and hence it is not impossible to have the percentage changes mentioned earlier. Criterion C1 is the most critical for three out of four scenarios since it presents the highest range of values for the former and a low range of values for the latter scenario. Similarly, the 'percent any critical criterion' (PACT) is C1 for scenarios

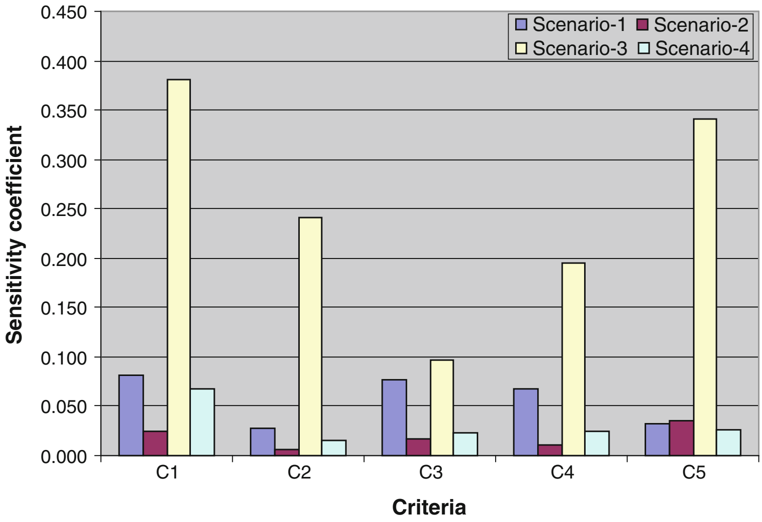


Fig. 9.20 Variability of the sensitivity coefficient for each criterion

Table 9.5 Critical criteria and alternatives for each scenario

	Scenario1	Scenario2	Scenario3	Scenario4
Percent top critical criterion	C1	C1	C4	C1
Percent any critical criterion	C1	C5	C1	C1
Most critical alternative	A9	A9	A4	A1

1, 3 and 4 if the weights of C1 change by 12.3, 2.6 and 14.7 % respectively, i.e. any ranking may change.

In addition, the most sensitive alternative in terms of changing ranking is alternative 9 (because of C4 and C1, respectively) for scenario 1 and 2, alternative 4 (because of C5) for scenario 3, and alternative 1 (because of C5) for scenario 4. This finding is illustrated in Table 9.3 where each alternative pair, i.e. 9-1, 9-1, 9-4 and 9-1 which correspond to the four scenarios respectively, has almost the same performance scores. Thus, even a slight change in weighting will change ranking. Another interesting finding is that there is no association between the sensitivity coefficient and the weights for each criterion for the three first scenarios since the correlation coefficient (R) was calculated as 0, −0.24 and −0.09 respectively, while there is a significant relationship (R = 0.79) in the case of scenario 4 perhaps because this scenario involves weights assigned by the expert and they have not been randomly defined as in the first three scenarios. In addition, the most critical criterion is that with the highest weight, a result that confirms the finding of Triantaphyllou [5].

9.5 Case Study: Changing Project Objectives

In this case, the ranking of alternatives is carried out using case scenarios 1 and 2. In scenario 1, the objective of the project focuses only on minimising land fragmentation, i.e. they are involved in the evaluation of only two criteria, i.e. mean size of new parcels (C1) and mean *PCC* (C2), and they ignore the other three criteria that refer to the objective 'minimising social impacts', i.e. change in the number of landowners (C3); percentage of ownerships 'completed' (C4); and mean *LSR* (C5). In contrast, in scenario 2, the objective of the project focuses only on minimising the social impacts and ignores the objective 'minimising land fragmentation'; thus, only criteria C3, C4, and C5 are involved in the evaluation process. The ranking of alternatives for each scenario is shown in Fig. 9.21.

In particular, alternative 10 is ranked first in scenario 1 while alternative 3 is ranked best in scenario 2. In other words, alternative 10 is best to minimise land fragmentation and in contrast it is the worst in minimising social impacts. On the other hand, alternative 3 is best at minimising social impact but is also ranked second in scenario 1, i.e. minimising land fragmentation, revealing again stability in performance. Specifically, Figs. 9.22 and 9.23 indicate that alternative 10 is best in both land fragmentation criteria, i.e. C1 and C2, and worst in C3 and C5. This clearly illustrates that the objectives of a project and hence the criteria involved in the process play a crucial role in the ranking order in addition to the weight of the criteria. It is also remarkable that the variability of performance scores of alternatives ranked best and worst for scenario 1 is extremely high (53.1 %) whilst it is low for scenario 2 (11.8 %). This indicates that the input facts in the Design module strongly influence the outcome solutions regarding minimising land

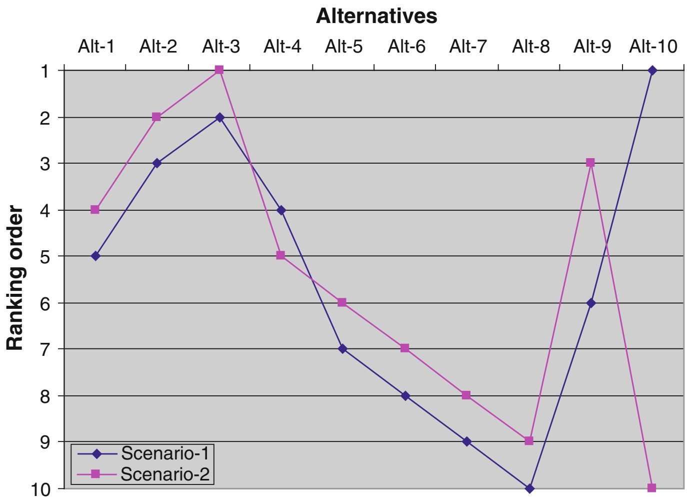


Fig. 9.21 Ranking of alternatives for the two scenarios

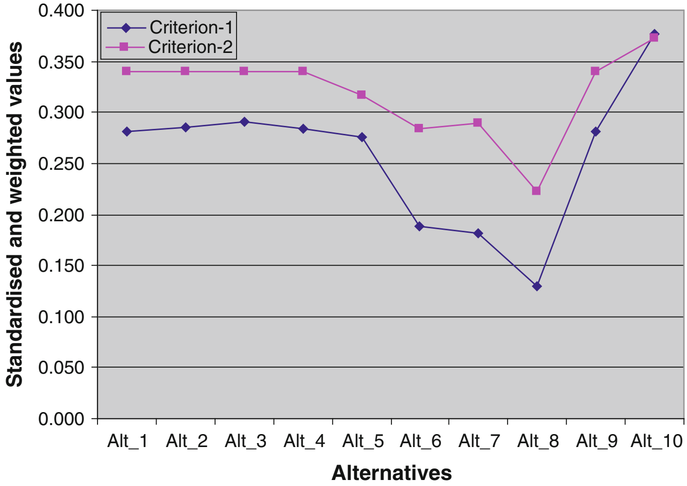


Fig. 9.22 Performance of alternatives for criteria 1 and 2

fragmentation and, in contrast, slightly influence the outcomes regarding minimising social impacts. As a result, this finding suggests flexibility for the planner in the former case and limitations for the planner in the latter case because of legislation's strict provisions.

Figure 9.24 shows that the most sensitive criteria are those associated with scenario 2. In particular, the criteria for scenario 2 are more sensitive than those of scenario 1 regardless of the higher variability in the values of the former case.

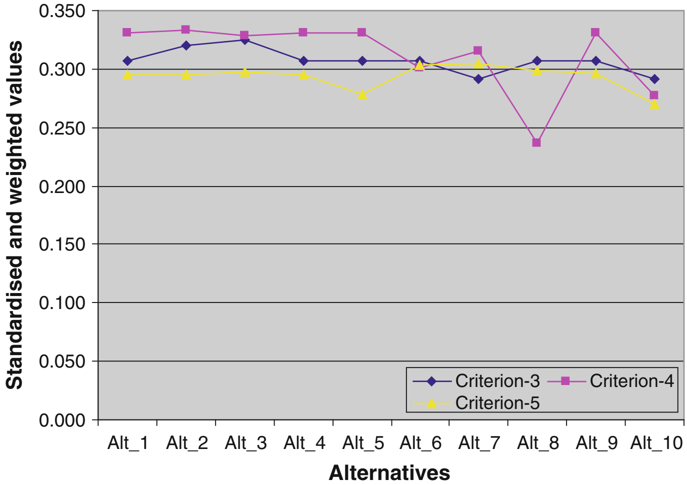


Fig. 9.23 Performance of alternatives for criterion 3, 4 and 5

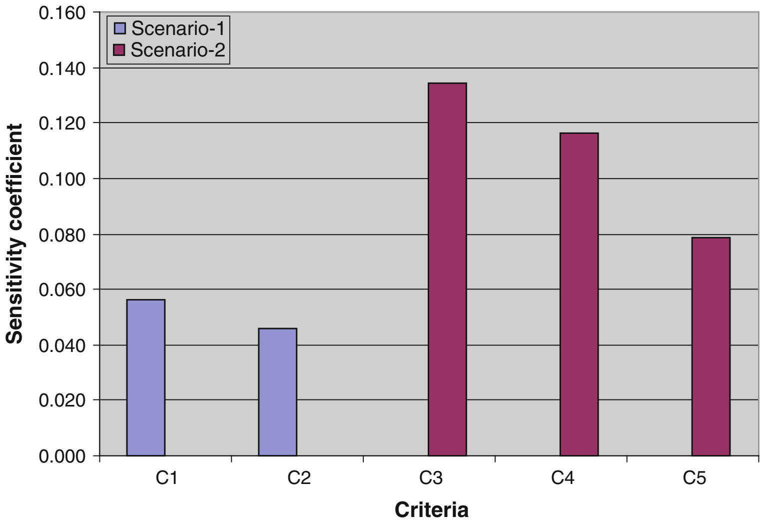


Fig. 9.24 Variability of the sensitivity coefficient for each criterion

This is a controversial finding compared with that for scenario I. This finding reveals again that the selection of the criteria involved in the evaluation process, and hence the objective of a project, play a crucial role in the ranking in addition to the weight of the criteria.

9.6 Conclusions

MADM is nowadays a widely used approach for assessing a discrete number of alternative solutions for a decision problem including those with a spatial context. Although the process is straightforward, it involves several crucial tasks that should be carefully customised for the problem concerned in order to obtain robust outcomes. This chapter has dealt with these issues in the context of the land redistribution problem, and as a result, two research innovations have been generated. In particular, the introduction of a new index called the parcel concentration coefficient (*PCC*) for measuring the dispersion of parcels and a measure called landowner satisfaction rate (*LSR*) for predicting the acceptance of the land redistribution plan by the landowners in terms of the location of their new parcels. Furthermore, it has been shown through a case study that the Evaluation module of LandSpaCES is a powerful and flexible tool for a comprehensive evaluation of alternative land redistributions. The outcome of alternatives, i.e. the best solution, is then passed to the land partitioning module (LandParcelS) for automatically generating the new parcels, which is presented in the Chap. 10.

References

1. Malczewski, J. (1999). *GIS and multi-criteria decision analysis*. New York: Wiley.
2. Sharifi, A., Herwijnen, M., & Toorn, W. (2004). Spatial decision support systems. Lecture Notes. ITC, international institute for geo-information science and earth observation, The Netherlands.
3. Demetriou, D., Stillwell, J., & See, L. (2011). *A multi-attribute decision-making module for the evaluation of alternative land consolidation plans*. Working Paper 11/02. School of Geography, University of Leeds, p. 56. Available from URL: http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/11-02.pdf.
4. Costa, C., & Vansnick, J. (1997). Applications of the MACBETH approach in the framework of an additive aggregation model. *Journal of Multi-Criteria Decision Analysis, 6*, 107–114.
5. Triantaphyllou, E. (1997). A sensitivity analysis approach for some deterministic multi-criteria decision making methods. *Decision Sciences, 28*(1), 151–194.
6. Keeney, R., & Raiffa, H. (1993). *Decision with multiple objectives: Preferences and value trade-offs*. Cambridge: Cambridge University Press.
7. Triantaphyllou, E. (2000). *Multi-criteria decision making methods: A comparative study* (*Applied optimisation, Volume 44*). The Netherlands: Kluwer Academic Publishers.
8. Collins, P., & Glysson, A. (1980). Multi-attribute utility theory and environmental decisions. *Journal of the Environmental Engineering Division*, *106*(EE4), 815–830.
9. Delgado, M. G., & Sendra, J. B. (2004). Sensitivity analysis in multi-criteria spatial decision 984 making: A review. *Human and Ecological Risk Assessment: An international Journal*, 10(6), 985 1173–1187.
10. Pannell, D. (1997). Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. *Agricultural Economics, 16*, 139–152.
11. Janssen, R., Van Herwijnen, M., & Beinat, E. (2001). *DEFINITE for Windows*. Institute for Environmental Studies (IVM), Amsterdam: Vrije Universiteit.
12. Malczewski, J., Moreno-Sanchez, R., & Bojorquez-Tapia, L. A. (1997). Environmental conflict analysis in the Cape Region, Mexico. *Journal of Environmental Planning and Management, 40*, 349–374.
13. Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision making methods. *International Journal of Geographical Information Systems, 9*, 251–273.

Chapter 10
LandParcelS Model

10.1 Introduction

This chapter deals with the development of the land partitioning module called LandParcelS (Land Parcelling System), the fourth and final sub-system of LACONISS. This module aims to generate the new parcels automatically based on the final outcome (best land redistribution solution) produced by LandSpaCES (the Design and the Evaluation modules). The structure of the chapter is as follows. Section 10.2 sets out the land partitioning in modelling terms as both a single-objective and a multi-objective problem. Section 10.3 deals with the design and the operation of the genetic algorithm in terms of representation and the definition of genetic operators and Sect. 10.4 presents the module toolbar that operationalises the model in a GIS environment. Afterwards, Sects. 10.5 and 10.6 report an application of the model using two blocks of land in the case study area, that treats land partitioning as either a single-objective problem involving shape optimisation or a multi-objective problem including a combination between three optimisation parameters, i.e. shape, size and land value, respectively.

10.2 Single and Multi-objective Land Partitioning

The conventional process of land partitioning has already been described in Sect. 4.2.2. An example of such a subdivision that has been carried out by land consolidation experts for land blocks with IDs B25 and B14 for the case study area is illustrated in Fig. 10.1. Both land blocks will be utilised later for applying LandParcelS. The number within each parcel represents the parcel ID. In addition, as explained in Sect. 4.2.3, the land reallocation modelling approach followed in this research splits land reallocation to land redistribution and land partitioning. Land redistribution has been already automated through the Design and Evaluation modules of LandSpaCES as elaborated in Chaps. 8 and 9, respectively. Then, land partitioning receives the outputs of the land redistribution (Sect. 8.3.3) exercise as inputs and involves the design of the subdivision of land into land parcels. An

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_10, © Springer International Publishing Switzerland 2014

Fig. 10.1 The subdivision of land blocks B25 and B14 as carried out by land consolidation experts

example of the output from this best alternative for the above two land blocks is shown in Fig. 10.2 where both land blocks are enclosed by roads. In one case in each block, a centroid has two parcel IDs, namely, 45/15 and 160/189 in blocks B25 and B14, respectively. This means that two co-landowners have been granted a separate parcel in approximately the same location. In practice, these parcels need to be adjacent to one another. It is also noted that parcel IDs are shown within blocks are not comparable to those illustrated in Fig. 10.1.

As noted in Sect. 4.2.3, land partitioning is a multiple objective optimisation problem subject to a set of constraints that searches to find optimum solution(s)

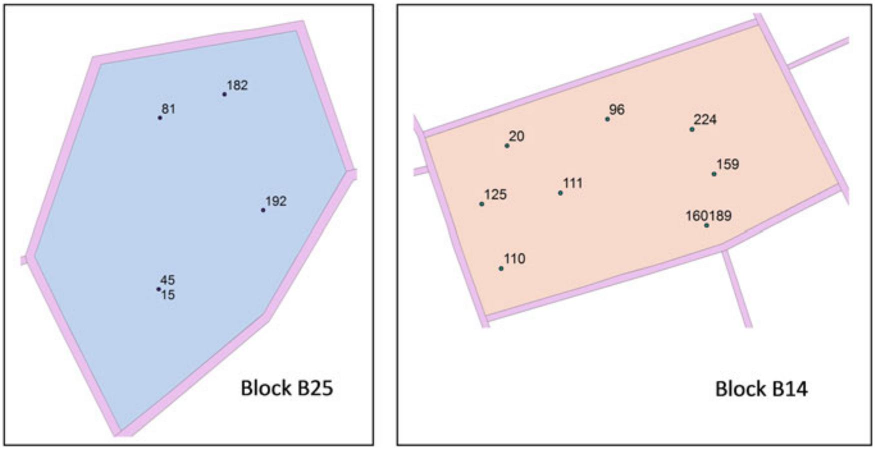


Fig. 10.2 The centroids of new parcels in land blocks B25 and B24 resulting from LandSpaCES

through an infinite number of potential solutions. In particular, optimisation in this research focuses on four primary aspects of a parcel: shape, size, land value and road access. Specifically, the main objective of the problem is to generate parcels with regular shapes subject to three main constraints: parcels should have access to a road and be of a predefined size and land value. Deb [1] distinguishes hard and soft constraints. Whilst a hard constraint cannot be violated without making the solution infeasible, a soft constraint permits a range of variation within which a solution is feasible or alternatively, a maximum variation can be specified. Thus, road accessibility is a hard constraint whereas the size and land value of each parcel are soft constraints with an acceptable maximum variation employed in practice of around ± 10 %. Further to these constraints, there are additional practical constraints such as existing boundaries (e.g. a stone wall or an ecological line), buildings (a house, a farmstead) and other constructions (e.g. a fence, a well); and design constraints such as the final location of each parcel and the minimum limit of its size. However, this latter set of further constraints is not involved in this version of the model because it is sensible to firstly check the performance of the algorithm against those noted as primary constraints and then include the additional constraints.

10.2.1 Single-objective Land Partitioning

Based on the previous considerations, land partitioning can be modelled as a single objective minimisation problem aimed at minimising Eq. 10.1 subject to a set of constraints (Demetriou et al. 2012).

$$min \sum_{i=1}^{N} \left| \frac{1}{16} - \frac{areaP_i}{perimeter^2(P_i)} \right| \tag{10.1}$$

where N is the total number of parcels per land block and i represents one parcel.

Equation 10.1, which has been employed by Tourino et al. [3], is an area-perimeter ratio, which results in a value for rectangular shapes with a length-breadth ratio of 4:1. However, as discussed in Sect. 7.4.2, this formula, which in essence represents the compactness of shape, presents significant weaknesses for evaluating the shape of land parcels. Thus, the new index called the parcel shape index (PSI) was developed in this research (Sect. 7.4) which outperforms other indices and takes values of between 0 and 1 representing the worst and optimum parcel shape, respectively. Therefore, the above objective can be restated using the *PSI* as follows:

$$min \sum_{i=1}^{N} 1 - PSI_i \tag{10.2}$$

Ideally, the above function equals zero if all parcels of a block have the optimum shape, which is a rectangle with a breadth: length ratio of 2:1.

If the aim is to generate parcels with regular shapes independently of their size and land value, then the above objective function can be used and the task could be completed in order to reach a single optimum solution. The definitions of an optimum or regular shape for a land consolidation plan and specification of the relevant *PSI* values have been discussed in Sect. 7.4.3. Based on that analysis, a shape is regular or near regular if it has a *PSI* of 0.7–0.9 and optimum or near optimum if the *PSI* is more than 0.9 (Fig. 7.26). Therefore, for optimisation purposes, any parcel with a *PSI* of more than 0.7 will be considered as acceptable with a gradual increase in terms of quality from near regular to optimum, meaning a *PSI* from 0.7 to 1.0. Thus, a kind of scaling is applied to *PSI* values that fall within this range. Namely, the term (1-*PSI*) is divided by 10, thereby favouring parcel shapes with *PSI* values between 0.7 and 1.0 and penalising parcel shapes with a *PSI* less than 0.7.

As noted earlier, further to the shape of parcels, three constraints must be taken into account in the land partitioning optimisation process: size, land value and the accessibility of a parcel from a road. However, these constraints are easily manageable in the context of optimisation only if a mechanism for generating feasible solutions is available, that is, solutions which do not violate any constraint. In such cases, the optimisation process only needs to find the optimum or near optimum solution in terms of parcel shape. However, this is not the case and the problem is more complicated since the generation of parcels with a predefined size and/or land value is part of the problem. As a result, both parameters must be incorporated into the optimisation process. In other words, the two soft constraints (size and land value) can be treated as objective functions [1]; hence land partitioning is converted from a single to a multi-objective optimisation problem as outlined in the next section. It should be also pointed out that the above constraints refer specifically to a vector-based representation and not to a raster-based representation, which involves more constraints as noted in Demetriou et al. [2].

10.2.2 Multi-objective Land Partitioning

Land partitioning can be formulated as a multi-objective problem with three objective functions representing shape, size and land value as follows:

$$minimise\left(\sum_{i=1}^{N}(1-PSI_i)*w_1+\sum_{i=1}^{N}|dArea|_i*w_2+\sum_{i=1}^{N}|dValue|_i*w_3\right) \quad (10.3)$$

subject to the constraint:

$$\sum_{i}^{N}R_i=0 \quad (10.4)$$

where *dArea* and *dValue* are the percentage differences between the desired and designed size and land value of a parcel respectively, and w_1, w_2, w_3 are the weights for each objective function that sum up to 1. The function R equals 0 or 1 when a parcel has access to a road or not, respectively. This is an equality constraint, that is, a hard constraint which, if not fulfilled, renders the solution infeasible. This constraint can be used as a penalty function that equals the number of parcels without accessibility in a land block and it can be added to the overall fitness function. The use of a penalty function in order to penalise solutions that violate one or more objectives is a popular constraint handling strategy although it may distort the objective function and hence lead to a sub-optimal solution [1].

Based on the above, an overall fitness function can be generated by combining the above two equations that compose four functions: F1, F2, F3 and R. In particular, ideally the sum of the fitness will equal zero if all the parcels included in a land block have an optimum shape (F1) with the desired size (F2), land value (F3) and access from a road (R).

$$Fitness = \left(\sum_{i=1}^{N}(1 - PSI_i) * w_1 + \sum_{i=1}^{N}|dArea|_i * w_2 + \sum_{i=1}^{N}|dValue|_i * w_3\right) + \sum_{i}^{N} R_i \tag{10.5}$$

In contrast to single-objective optimisation that involves a unique optimum solution, multi-objective problems with conflicting objectives involve a different optimum solution for each objective. In addition, there is not a single optimum solution which simultaneously optimises all objectives except if objectives are not conflicting. As a result, the outcome is a set of solutions that are all optimal in varying degrees of trade-off between the objectives. Graphically, these optimal solutions lie on a curve called the Pareto-optimal front. In particular, if all objective functions are to be minimised, this front lies close to the bottom-left corner of the search space. In principle, in multi-objective problems, there exists at least one solution in the Pareto-optimal set which will be better than any other non-Pareto optimum solution [1].

Therefore, the task in multi-objective optimisation is to find the Pareto-optimal solutions, which are also called non-dominated solutions because none of these solutions is the best with respect to all objectives unless the importance of each objective can be defined. Thus, in the case where there is a confidence regarding the weights of objective functions, there is no reason to find other trade-off solutions [1] and the multi-objective problem can then be converted into a single-objective solution by utilising an appropriate vector of weights for objective functions. This requirement of multi-objective optimisation, which focuses on finding multiple optimal solutions in one single simulation run, is what makes genetic algorithms a unique method for this purpose.

10.3 The Land Partitioning GA

10.3.1 Representation

The land partitioning problem can be represented using both available GIS data structures; namely, raster and vector, although the latter is the normal structure used to represent the problem in CAD systems. Thus, a critical question regarding representation of the problem is whether to employ a raster or a vector data structure. Although in Demetriou et al. [2] a raster-based representation was set out, which was aimed at adaptation for a GA, the effort was abandoned early on because the process of crossover (which is the fundamental GA operator) between two raster solutions presented significant weaknesses when executed on a pixel by pixel basis as explained below.

First, it was inherently very time consuming and, in addition, extra time was needed for the calculation of the various parameters involved in the fitness function (the six factors of the *PSI* and the land value of a parcel) which required the conversion from raster to vector because of the limitation of the former structure. Secondly, the crossover operator was tested, and resulted in completely infeasible solutions at times in terms of the number of parcels generated. This is because parcels with the same ID in the crossed solutions may not have any pixels in common so these parcel(s) were not included in the child solution. Thirdly, crossover resulted in parcels with non-linear boundary sides and thus an additional constraint would have been a necessary addition to the process resulting in much more time for optimisation. Fourthly, the accuracy of a vector representation is much higher than the raster (centimetres versus metres). Finally, the vector format is fundamentally the representation utilised in CAD systems where the actual task of land partitioning is normally carried out in practice.

On the other hand, the only advantage of using a raster representation for the particular problem is that it would be easier to reach the desired size and land value of a parcel because it provides a detailed cell based representation of space in contrast to a vector structure that does not divide space into cells. Thus, taking into account the above considerations, it was decided that a vector based structure would be utilised for representing the land partitioning problem. Based on this decision the structure of the GA should fit to this approach. In particular, the conventional process of land partitioning is carried out on a block by block basis until the whole plan is completed. As a result, the optimisation process follows the same rationale, suggesting that optimisation is carried out separately on a block by block basis, because no redistribution changes between blocks are permitted, since the relevant decisions have been already taken in LandSpaCES. In addition, the complexity of the problem is significantly reduced. Thus, the land block is the basic unit on which evolution is undertaken. Specifically, in evolutionary terms, a land block represents an *individual* (or organism) which is evolved during the optimisation process. A land block is divided into parcels representing *chromosomes*. A *chromosome* encodes the characteristics that define an individual such as:

shape, size, land value, accessibility to a road. Moreover, shape is further represented through the *PSI* by the six aforementioned features. Each chromosome has a core *gene*, namely, a centroid which defined by its X, Y coordinates. A set of individuals compose a *population*. Summarising the above, the genetic algorithm has the following hierarchical vector-based structure: population-individuals-chromosomes-genes; representing respectively: a set of subdivision solutions for a land block; one subdivision solution for a land block; land parcels; and centroids of parcels. A graphical representation of this structure is illustrated in Fig. 10.3. The attribute table of an individual including all the relevant parameters is illustrated in Fig. 10.4.

Based on the above structure the genetic process is illustrated by the following sequence:

Create initial population
Evaluate initial population.

Do

- select individuals for mating
- create offspring by crossover with a probability P_c
- mutate selected individuals with a probability P_m
- evaluate new individuals

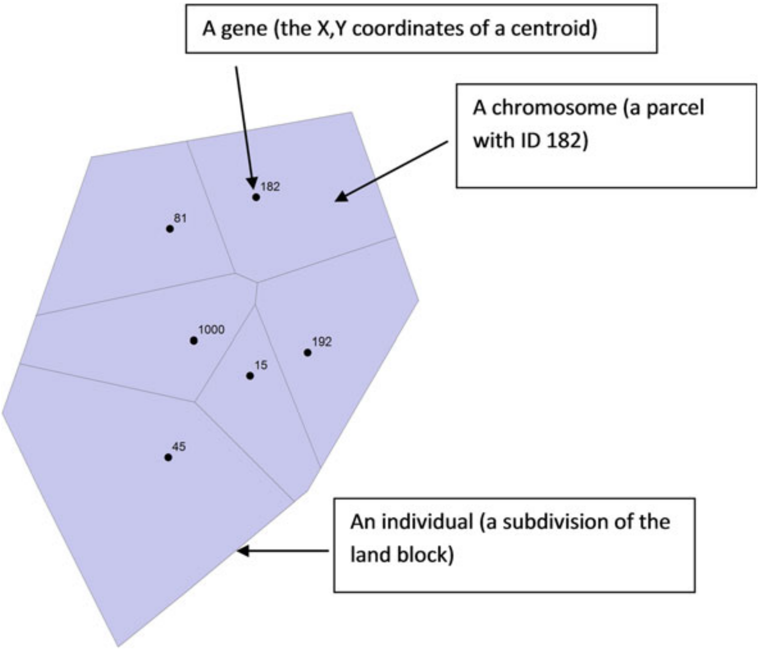
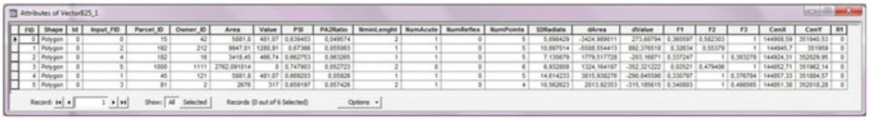


Fig. 10.3 A graphical representation of the GA structure


Attributes of Vector825_1

FID	Shape	Id	Input_FID	Parcel_ID	Owner_ID	Area	Value	PSI	PA2Ratio	NminLenght	NumAcute	NumReflex	NumPoints	SDRadials	dArea	dValue	F1	F2	F3	CenX	CenY	R1
0	Polygon	0	0	15	42	5881.8	481.07	0.639403	0.049574	2	1	0	5	5.698429	-3424.989011	273.68794	0.360597	0.582303	1	144908.59	351940.53	0
1	Polygon	0	2	182	212	9947.01	1280.91	0.67366	0.055063	1	1	0	5	10.697014	-5508.554413	892.376518	0.32634	0.55379	1	144945.7	351959	0
2	Polygon	0	4	182	16	3418.45	466.74	0.662753	0.063265	1	1	0	5	7.135679	1779.517728	-203.16871	0.337247	1	0.363278	144924.31	352029.95	0
3	Polygon	0	5	1000	1111	2762.091014	8	0.747983	0.052723	2	0	0	6	6.932808	1324.164197	-352.321222	0.82521	0.479406	1	144852.71	351962.14	0
4	Polygon	0	1	45	121	5881.8	481.07	0.669203	0.05926	1	1	0	5	14.614233	3815.938276	-290.845598	0.330797	1	0.376784	144857.33	351884.57	0
5	Polygon	0	3	81	2	2676	317	0.659197	0.057426	2	1	0	4	10.562623	2613.92353	-315.185815	0.340803	1	0.498585	144851.38	352018.28	0

Record: 1 Show: All Selected Records (0 out of 6 Selected) Options

Fig. 10.4 The attribute table of an individual

- terminate process if a certain criterion is satisfied
- keep a percentage e of individuals from previous population for mating.

Loop

End of the process.

In particular, a random population of individuals is created and evaluated using all the terms or a combination of terms in Eq. (10.5). Then an iterative process begins whereby an iteration is called a generation. In particular, a selection method is employed to fill the mating pool with the same number of individuals as found in the initial population based on their fitness value. Afterwards, new individuals (offspring) are created by applying the genetic operators to parent individuals. In particular, crossover combines the genetic code of two randomly selected parent individuals from the mating pool. Then, changes are introduced into the genetic code of an individual by mutation. Eventually, new offspring are evaluated using the fitness measure, and if the termination criterion is met, then the iterative process ends (exits loop) and hopefully the best solution is returned. Otherwise, a new population is created by keeping a percentage (e%) of best individuals from the previous population to be put directly into the new mating pool and selecting from the rest of the individuals (using the employed selection method) to complete the mating pool with the equal number of individuals as the initial population. The basic steps of the process are discussed further below.

10.3.2 Generation of a Random Population

This initialisation operation is used to generate a random population consisting of a defined number of individuals. As noted by Deb [1], the size of the population is a critical point in GAs in terms of the success of the algorithm for finding the global optimum and not a sub-optimal solution. The size of the population depends on the complexity of the problem concerned. This initialisation operator is based on a well-known GIS mechanism for space partitioning called Thiessen polygons or Voronoi diagrams/network. This thesis uses the former term. The use of the Thiessen polygon method is based on the fact that the input in land partitioning is the output of LandSpaCES which, as shown in Fig. 10.2, is a set of points for each block representing the approximate centroid of each new parcel accompanied by a set of attributes.

Creating Thiessen polygons is a method for dividing the 2-D Euclidean space into a number of regions equal to the number of points provided (Fig. 10.3). Thiessen polygons have the unique property that each polygon contains only one input point, and any location within a polygon is closer to its associated point than to the point of any other polygon [4]. The concept of Thiessen polygons has been widely applied for space partitioning problems in a variety of disciplines [5, 6]. Dong [5] and Gong et al. [6] have constructed algorithms for the generation of weighted Thiessen polygons based on an attribute of the points using a raster and a vector based structure, respectively. Although both methods have drawbacks, a wider range of spatial situations can be modelled compared to those using ordinary Thiessen polygons. However, both methods are not appropriate for land partitioning, e.g. by employing parcel size or the land value as weights, because the constructed shapes tend to be cyclical and not regular. As a result, ordinary Thiessen polygons are utilised for randomly generating alternative sub-divisions of a land block. The aim to steer Thiessen polygons towards the creation of parcels with regular shapes and a predefined size and/or land value with access to roads, is left to the GA.

The random generation of different subdivisions is based on the simple logic that: if the initial layout of centroids within a land block provided by LandSpaCES is randomly moved to new locations, then a new solution can be created and so on. This random movement (R_m) of centroids can be any distance in a 0.5 m step, in any direction and may reach a $maxR_m$, which is calculated as the square root of the desired size (A_i) of the associated parcel with the centroid concerned, multiplied by a constant (c), which is capable of varying (increasing or decreasing) the searching distance of the algorithm as shown in:

$$maxR_m = c\sqrt{A_i} \tag{10.6}$$

This figure is based on the assumption that, in the case of a square shaped parcel which is very close to the optimum parcel shape, the maximum movement equals the length of the side of the square. As a result, the movement is limited to a circle with diameter $2maxR_m$ so as to be close to the original centroid while on the other hand not limiting the diversity of the population because this prevents the convergence of the algorithm to a global optimum solution. Thus, the constant c largely determines the diversity of the initial population and the search performance during the evolution of the algorithm. Another critical issue related to the $maxR_m$ is to check if a new location of a centroid falls outside the land block concerned; in such a case a new random location is provided until the new point is located within the block. A part of the code for checking if a centroid is within a block is provided in Appendix B.4.1. Another issue is that some centroids provided by LandSpaCES are in a common location because the original parcels in that location are owned by two or more co-landowners (Fig. 10.2). In practice, these owners are usually allocated new parcels in the neighbourhood. Thus, before beginning the creation of the polygons, these common centroids should be separated. A chunk of the code for checking for common centroids and moving them to a new location is provided in Appendix B.4.2. This task is done randomly using the $maxR_m$ distance with a small constant c.

Another problem tackled was how to represent the residual area of a block that has not been allocated to any landowner. This 'unallocated area', which is allocated later before completing the final plan or may be allocated by the LCD, should be represented as a parcel; hence the creation of an extra centroid for each block was needed. Common sense says that this unallocated parcel area should be located in the least dense part of the block. In other words, the new centroid should be the point that has the longest distance from all existing centroids. For this purpose the Euclidean distance tool of Spatial Analyst was employed, which provides an output raster that contains the measured distance from every cell to the nearest source, that is, the existing centroids. Then the cell with the largest value (having the furthest distance) is the one that will be searched for and its coordinates are used to create the new centroid. An example for land block B14 is illustrated in Fig. 10.5 in which the centroid with ID 1000 is the new point having the farthest distance from all of the other points. Cells with the longest distances are represented by a deep brown colour. The algorithm reads this maximum distance and identifies the X, Y coordinates of the relevant cell in order to create a new centroid in this location. A block of the relevant code is shown in section B.4.3.

Once the common centroids are separated, the new centroid representing the unallocated part of the block is created and the initialisation algorithm moves randomly the initial location of the centroids, for a number of times defined by the user, to create a random population, including different subdivisions of the block using Thiessen polygons. This is the starting solution of the model from which the GA begins its search. An example showing six different random solutions for land block B25 is illustrated in Fig. 10.6. The first three solutions are feasible whilst the other three are not. The main chunk of the code for generating a random population is presented in Appendix B.4.1. The basic part of the code for generating a random population is illustrated in Appendix B.4.4.

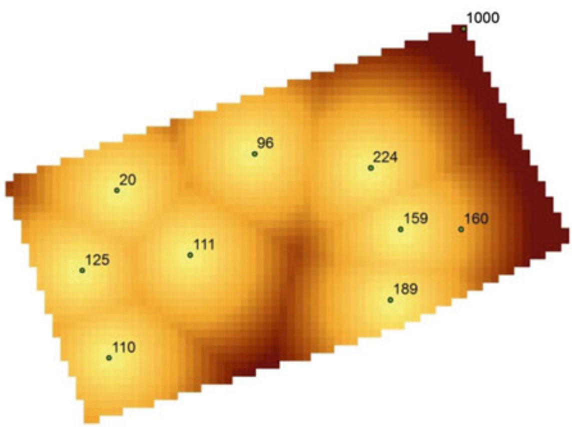


Fig. 10.5 The outcome of the Euclidean distance tool to identify the furthest point from existing centroids for land block B14

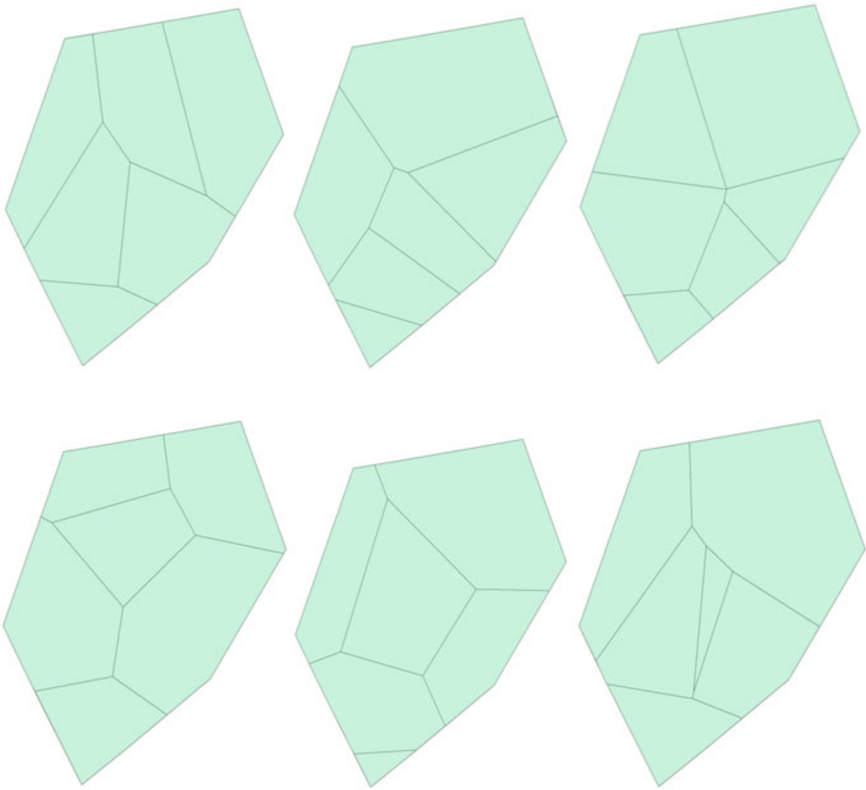


Fig. 10.6 A set of six random individuals for the land block B25 picked up from a population

10.3.3 Genetic Operators

In addition to the initial operator utilised for the generation of a random population, the following five evolutionary operators are involved in the process: the fitness function, selection-mating, crossover, mutation and an elite preserving operator, which is discussed in the next section. The fitness function is applied at two levels: focal and zonal operators referring to the parcel (chromosome) and block (individual) levels, respectively. When the initial population is created, a fitness function is used to measure the quality of each individual with respect to the model objectives. All model objectives are set out in the fitness function shown in Eq. 10.5. However, the fitness function may vary depending on the number of terms (objective functions) included in it, defining land partitioning as a single or multi-objective problem.

A selection operator selects which individuals will be involved in the reproduction process. The main aim of this operator is to make multiple copies of good solutions based on their fitness score and to eliminate bad solutions from a new population, while keeping the population size stable. A number of methods exist for doing this such as tournament selection, proportionate selection, roulette wheel selection and ranking selection [1]. Goldberg and Deb [7] showed that tournament selection outperforms or is at least equivalent both in terms of the convergence and computational time compared to any other selection method that exists in the literature. Therefore, tournament selection was chosen for this evolutionary model as used in other similar spatial problems [8–12]. In tournament selection, two solutions are randomly selected from the current population and the best between the two is placed in the mating pool. Then, two other solutions are selected (excluding those already selected) and the best one fills the mating pool and so on [13].

Crossover is the process of the mating of two individuals (parents) by exchanging or combining genetic material (genes) to create a new individual (an offspring). In particular, this model's crossover involves the combination of genes (X, Y coordinates of a centroid) between two corresponding chromosomes (land parcels) that belong in two parents. Whilst the most popular GA encoding is the binary string system (0 and 1), the genes of this GA are represented by real numbers, i.e. X, Y coordinates, and thus a real parameter crossover encoding is utilised. This is the most common encoding utilised in complex problems [12, 14] when objective functions include real valued parameters because it avoids extra processing associated with decoding the consequents, involving the so called 'Hamming cliff problem' [9].

After examining a plethora of real-parameter operators found in the literature and presented in Gwiazda [15], as well as the relevant suggestions noted by Deb [1], the BLX-a crossover operator introduced by Eshelman and Schaffer [16] was utilised in the model. An advantage of this operator is that it may search outside the line that connects the centroid of the two parent solutions. It also has the property that the location of the offspring depends on the difference between the parent solutions. Thus, this operator follows an adaptive search strategy, which involves searching of the entire spaces early on while and also maintaining a focused search when the population tends to convergence in some region of the search space [1]. As a result, this operator enhances the diversity of a population which is reduced by the selection operator to avoid premature convergence. It is called the Blend Crossover operator and the way it works for the X coordinate is shown in Fig. 10.7. Similarly, it can be applied for the Y coordinate.

The offspring values for X_{new} and Y_{new} are calculated based on Eqs. 10.7 and 10.8, respectively.

$$X_{new} = (1 - \gamma_i) \times X_{parent1} + (\gamma_i \times X_{parent2}). \quad (10.7)$$

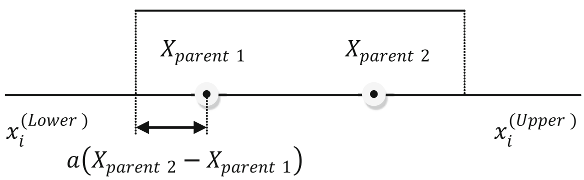


Fig. 10.7 The BLX-a crossover operator for the X coordinate (Adapted from [1])

$$Y_{new} = (1 - \gamma_i) \times Y_{parent1} + (\gamma_i \times Y_{parent2}) \tag{10.8}$$

where

$$\gamma_{i=(1+2a)u_i-a} \tag{10.9}$$

u_i is a random number between 0 and 1
$a = 0.5$

Investigations showed that this operator works best with a equal to 0.5 [1], and hence this value was used. A crossover operator can be applied based on a probability Pc which is usually between 0.7 and 1. Taking into account that the algorithm involves an elitist operator (discussed later), which directly transfers a percentage of best parents into the next generation, there is no reason to adopt a Pc value of less than 1. In addition, this option enhances the searching power of the algorithm and maintains the diversity of the population [10]. The basic part of the code for crossover is provided in Appendix B.4.5.

Mutation which is rare in nature, involves a random change to the genetic material (to the gene) of an individual. Although fitness may be worse than before mutation, the process is necessary to maintain diversity in the population and avoid premature convergence to local optima. In the case of binary coding, it involves the random flipping of a selected gene (e.g. from 1 to 0 or vice versa) in a chromosome. Similarly, in our case, it involves a random change or displacement of a gene (X, Y coordinates) of a chromosome (a parcel) of an individual (land block) in a new location. It can be applied at two levels: parcel based or in just one chromosome of an individual which is randomly selected, or block based where all the chromosomes of an individual (which is randomly selected) subject to the mutation operator. The reason for utilising parcel based and block based mutation is that the former type of mutation only affects the fitness of an individual slightly, especially when an individual consists of many chromosomes. Similarly, Krzanowski and Raper [9] defined a 'small' and a 'big' mutation affecting an individual and the whole population, respectively.

As for crossover operators, after examining a plethora of real-parameter mutation operators found in the literature and presented in Gwiazda [17], a random mutation scheme was used for parcel based and block based levels involving a random displacement in any direction of the current centroid(s) location of a parcel or all parcels, respectively. The maximum displacement bound of the centroids was set at $maxR_m$ (Eq. 10.6). A similar mutation operator has been applied in Delahaye [8] for airspace sectoring. No reference is made for the effects of this operator in the evolution process. A mutation probability P_m or 0.05 is used; hence two individuals from a population of 40 are subject to the mutation operator. A chunk of the mutation operator code is presented in Appendix B.4.6.

A way of speeding up the convergence of a GA is by utilising an elite preserving operator that enhances the possibilities for creating better offspring. Such an operator favours the best or elite members of a population, which are automatically transferred into the next generation. Although it has been proved that an elitist operator is important in the success of a GA [18], it is not clear as to what degree the operator should be used. In its simple form application is determined by a percentage (e) of members of the current population. However, attention should be paid to defining e because if it is too small, then the influence of elite members will not have a positive effect on the next population. If it is too large, the population may lose its diversity and premature convergence is then possible. Deb [1] suggests trial and error to define e for a given problem although a commonly used value is 10 %. Thus, some initial runs to monitor the improvement in the mean fitness may assist in determining an appropriate e.

A termination criterion was not used when applying the GA as the goal was to find the best performance balanced by allowing the GA to run for a reasonable amount of computational time.

The basic code for creating a new generation is shown in Appendix B.4.7.

10.4 Module Interface

The LandParcelS module is operationalised as a toolbar (Fig. 10.8) consisting of four icons: 'Optimisation parameters'; 'Generate Population'; 'GA Run'; and 'Outputs'. Each icon launches a separate window with one or more functionalities. Icons appear on the toolbar in the order in which they must be executed. The functionality of each icon is described below.

The first icon launches the window shown in Fig. 10.9. If only one input parameter is to be optimised, then the weights are not required. If more than one parameter is selected, then weights need to be entered that sum to 1. The penalty function is an added term in the fitness function that penalizes infeasible solutions.

Once the optimisation parameters have been defined, the initial step in the evolutionary process is the generation of a random population of solutions by defining which land block will be partitioned and the size of the population, using the relevant icon that launches the window as shown in Fig. 10.10.

The GA is then run by defining the number of generations and the elitist factor as explained earlier in the window illustrated in Fig. 10.11, which is launched by the 'GA Run' icon.

Fig. 10.8 The toolbar of LandParcelS

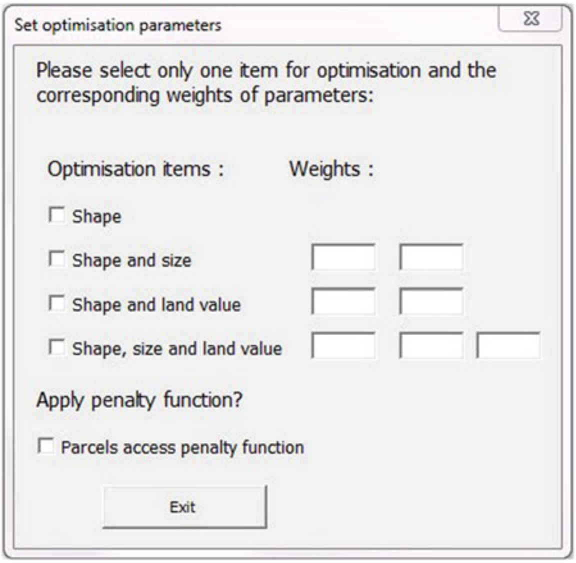


Fig. 10.9 The 'optimisation parameters' window

The Outputs icon launches the window illustrated in Fig. 10.12, which displays two database tables: the 'OFitness' table (Fig. 10.13) and the 'GFitness' table (Fig. 10.14). Both tables contain useful information regarding the evolution of the process for each generation. In particular, the 'OFitness' table presents evolutionary statistics for each generation including minimum, maximum and mean values for each objective function (F1, F2 and F3) and the minimum and mean overall fitness. The 'GFitness' table lists the mean value of the objectives functions F1, F2 and F3 and the overall fitness for each solution for the current generation.

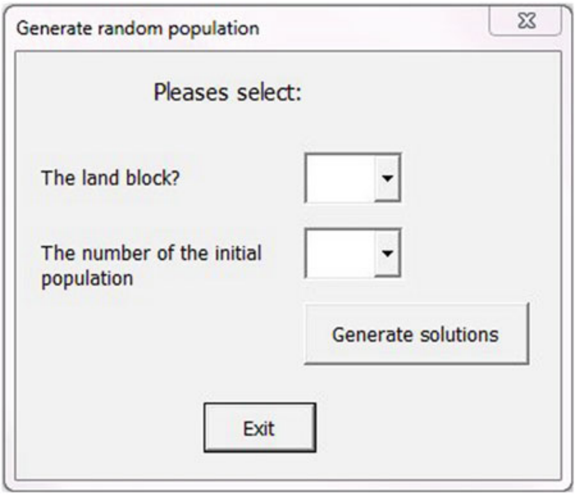


Fig. 10.10 The 'generate random population' window

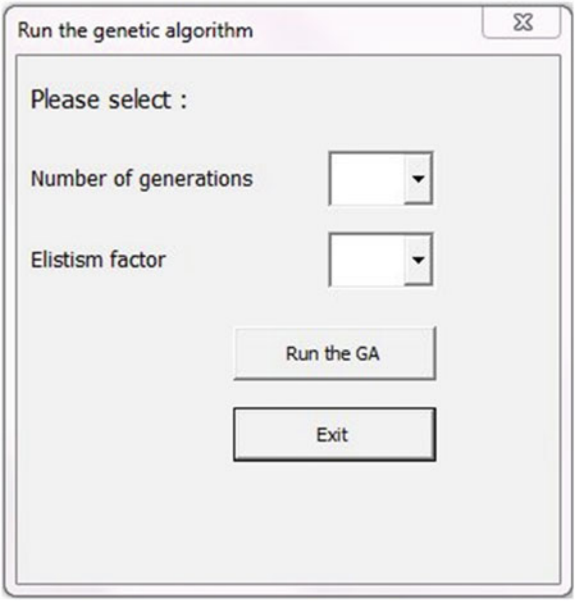


Fig. 10.11 The 'run the GA' window

The graphical outputs consisting of the block subdivision design can be seen by utilising simple functions within the GIS environment. Eventually, the user may store all outputs in a separate folder using, e.g. ArcCatalog, and delete the solutions by selecting the relevant buttons in the 'Outputs' window.

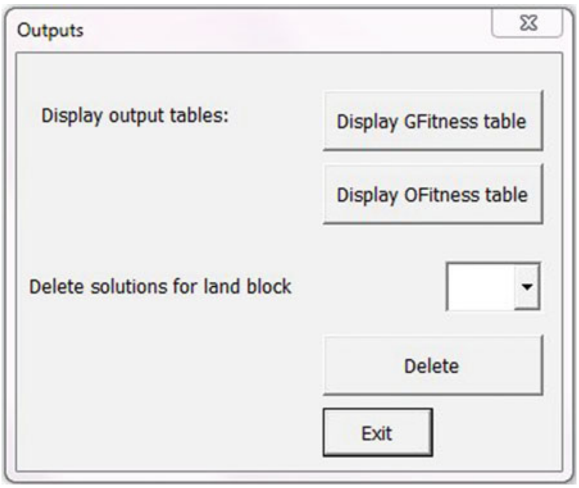
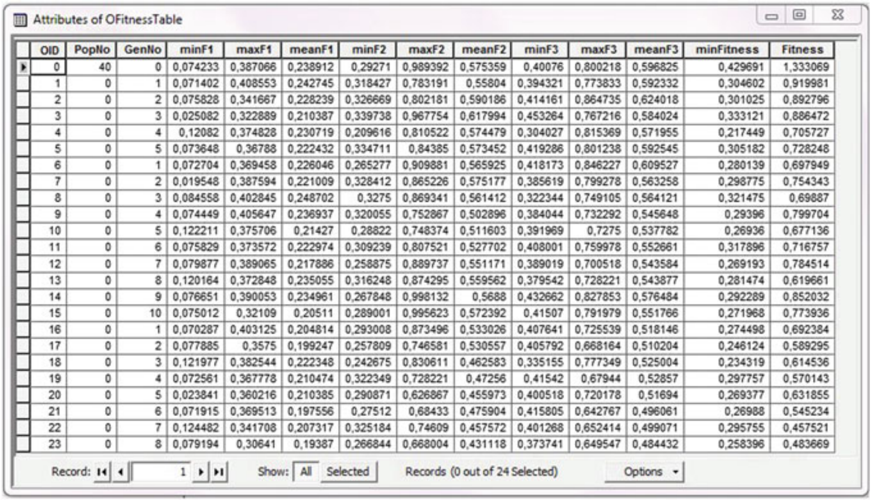


Fig. 10.12 The 'outputs' window


Attributes of OFitnessTable

OID	PopNo	GenNo	minF1	maxF1	meanF1	minF2	maxF2	meanF2	minF3	maxF3	meanF3	minFitness	Fitness
0	40	0	0,074233	0,387066	0,238912	0,29271	0,989392	0,575359	0,40076	0,800218	0,596825	0,429691	1,333069
1	0	1	0,071402	0,408553	0,242745	0,318427	0,783191	0,55804	0,394321	0,773833	0,592332	0,304602	0,919981
2	0	2	0,075828	0,341667	0,228239	0,326669	0,802181	0,590186	0,414161	0,864735	0,624018	0,301025	0,892796
3	0	3	0,025082	0,322889	0,210387	0,339738	0,967754	0,617994	0,453264	0,767216	0,584024	0,333121	0,886472
4	0	4	0,12082	0,374828	0,230719	0,209616	0,810522	0,574479	0,304027	0,815369	0,571955	0,217449	0,705727
5	0	5	0,073648	0,36788	0,222432	0,334711	0,84385	0,573452	0,419286	0,801238	0,592545	0,305182	0,728248
6	0	1	0,072704	0,369458	0,226046	0,265277	0,909881	0,565925	0,418173	0,846227	0,609527	0,280139	0,697949
7	0	2	0,019548	0,387594	0,221009	0,328412	0,865226	0,575177	0,385619	0,799278	0,563258	0,298775	0,754343
8	0	3	0,084558	0,402845	0,248702	0,3275	0,869341	0,561412	0,322344	0,749105	0,564121	0,321475	0,69887
9	0	4	0,074449	0,405647	0,236937	0,320055	0,752867	0,502896	0,384044	0,732292	0,545648	0,29396	0,799704
10	0	5	0,122211	0,375706	0,21427	0,28822	0,748374	0,511603	0,391969	0,7275	0,537782	0,26936	0,677136
11	0	6	0,075829	0,373572	0,222974	0,309239	0,807521	0,527702	0,408001	0,759978	0,552661	0,317896	0,716757
12	0	7	0,079877	0,389065	0,217886	0,258875	0,889737	0,551171	0,389019	0,700518	0,543584	0,269193	0,784514
13	0	8	0,120164	0,372848	0,235055	0,316248	0,874295	0,559562	0,379542	0,728221	0,543877	0,281474	0,619661
14	0	9	0,076651	0,390053	0,234961	0,267848	0,998132	0,5688	0,432662	0,827853	0,576484	0,292289	0,852032
15	0	10	0,075012	0,32109	0,20511	0,289001	0,995623	0,572392	0,41507	0,791979	0,551766	0,271968	0,773936
16	0	1	0,070287	0,403125	0,204814	0,293008	0,873496	0,533026	0,407641	0,725539	0,518146	0,274498	0,692384
17	0	2	0,077885	0,3575	0,199247	0,257809	0,746581	0,530557	0,405792	0,668164	0,510204	0,246124	0,589295
18	0	3	0,121977	0,382544	0,222348	0,242675	0,830611	0,462583	0,335155	0,777349	0,525004	0,234319	0,614536
19	0	4	0,072561	0,367778	0,210474	0,322349	0,728221	0,47256	0,41542	0,67944	0,52857	0,297757	0,570143
20	0	5	0,023841	0,360216	0,210385	0,290871	0,626867	0,455973	0,400518	0,720178	0,51694	0,269377	0,631855
21	0	6	0,071915	0,369513	0,197556	0,27512	0,68433	0,475904	0,415805	0,642767	0,496061	0,26988	0,545234
22	0	7	0,124482	0,341708	0,207317	0,325184	0,74609	0,457572	0,401268	0,652414	0,499071	0,295755	0,457521
23	0	8	0,079194	0,30641	0,19387	0,266844	0,668004	0,431118	0,373741	0,649547	0,484432	0,258396	0,483669

Record: 1 Show: All Selected Records (0 out of 24 Selected) Options

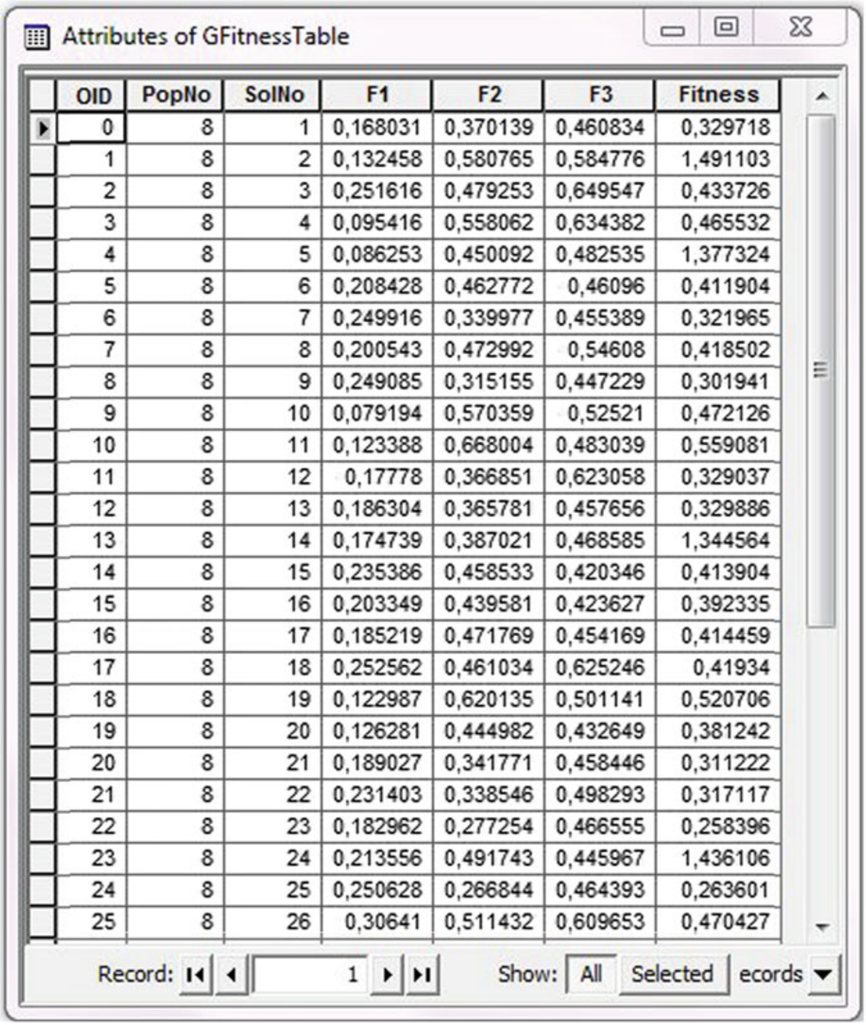
Fig. 10.13 The 'OFitness' table

10.5 Application of Single-objective Land Partitioning

For the application of the model, we selected two typical land blocks (they are surrounded by roads and they have quite regular shapes) of the case study land consolidation area presented in Chap. 6, reflecting a different complexity of land partitioning. Problem complexity is defined by three main factors: the number of parcels that need to be created, the size of the search space and the shape of the block. In particular, block B25 was selected, which involves six parcels and its size equals about 3 ha, and block B14, which involves 10 parcels with a size of around 5 ha. The tests that follow reveal the behaviour of the algorithm for solving these problems for different optimisation cases in the context of both single (in this section) and multi-objective approaches (Sect. 10.6).

10.5.1 Shape Optimisation for Land Block B25

When partitioning is carried out by utilising the Thiessen polygons tool without any optimisation process, the result is shown in Fig. 10.15a. This solution and similarly for land block B14 is referred to as the initial subdivision where the parcel shapes are defined according to the principles of Thiessen polygons. As a result, parcel shape depends entirely upon the layout of the centroids and therefore they are neither necessarily regular nor optimum. The relevant metrics for the three objective functions are the following: F1 (0.264), F2 (0.634), F3 (0.621) and R (0).



Attributes of GFitnessTable

OID	PopNo	SolNo	F1	F2	F3	Fitness
0	8	1	0,168031	0,370139	0,460834	0,329718
1	8	2	0,132458	0,580765	0,584776	1,491103
2	8	3	0,251616	0,479253	0,649547	0,433726
3	8	4	0,095416	0,558062	0,634382	0,465532
4	8	5	0,086253	0,450092	0,482535	1,377324
5	8	6	0,208428	0,462772	0,46096	0,411904
6	8	7	0,249916	0,339977	0,455389	0,321965
7	8	8	0,200543	0,472992	0,54608	0,418502
8	8	9	0,249085	0,315155	0,447229	0,301941
9	8	10	0,079194	0,570359	0,52521	0,472126
10	8	11	0,123388	0,668004	0,483039	0,559081
11	8	12	0,17778	0,366851	0,623058	0,329037
12	8	13	0,186304	0,365781	0,457656	0,329886
13	8	14	0,174739	0,387021	0,468585	1,344564
14	8	15	0,235386	0,458533	0,420346	0,413904
15	8	16	0,203349	0,439581	0,423627	0,392335
16	8	17	0,185219	0,471769	0,454169	0,414459
17	8	18	0,252562	0,461034	0,625246	0,41934
18	8	19	0,122987	0,620135	0,501141	0,520706
19	8	20	0,126281	0,444982	0,432649	0,381242
20	8	21	0,189027	0,341771	0,458446	0,311222
21	8	22	0,231403	0,338546	0,498293	0,317117
22	8	23	0,182962	0,277254	0,466555	0,258396
23	8	24	0,213556	0,491743	0,445967	1,436106
24	8	25	0,250628	0,266844	0,464393	0,263601
25	8	26	0,30641	0,511432	0,609653	0,470427

Record: 1 Show: All Selected ecords

Fig. 10.14 The ‘GFitness’ table

On the other hand, if land partitioning is treated as a single optimisation problem aimed at generating parcels with regular shapes, then the best subdivision is illustrated in Fig. 10.15b. Further to the considerable visual improvement of parcel shape, the overall fitness outcome is very close to zero (0.073), which represents an improvement of 72.4 % compared to that of the initial subdivision. In particular, all parcels have a *PSI* greater than 0.7 with the exception of parcel with ID 15 which has a slightly lower *PSI*, namely, 0.673. As the external shape of the land block is not involved in the optimisation process, it cannot change, and therefore the parcel shapes limit the amount of regularity achievable.

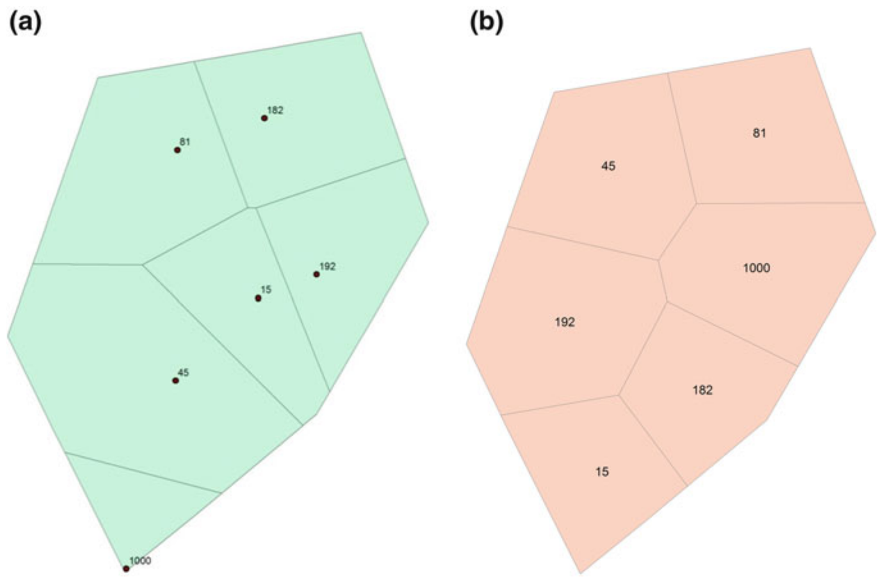


Fig. 10.15 Subdivision of land block B25 by utilising: regular Thiessen polygons (**a**) and the GA (**b**)

In addition, the way in which Thiessen polygons work may prevent the absolute optimality of shapes. For example, an expert would draw a straight line (Fig. 10.15b) from the internal point of the parcel with ID 15 to the internal point of the parcel with ID 1000, to separate parcels with IDs 45, 81 and 192, 182. This is compared to a polyline with three segments and four points as the optimisation outcome. This limitation suggests that the process utilised for generating Thiessen polygons needs additional guidance as explained further later in the multi-objective optimisation section. However, despite these limitations, the results showed that the current algorithm can successfully steer Thiessen polygons to create polygons with regular shapes.

Furthermore, in order to undertake a more in-depth investigation of the behaviour of the algorithm and the effects of its main operators in the evolutionary process, the program ran for six different sets of parameters as follows: Case I: no elitist, block based mutation, no penalty function; Case II: e = 10 %, no mutation, no penalty function; Case III: e = 10 %, block based mutation, no penalty function; Case IV: e = 10 %, parcel based mutation, no penalty function; Case V: e = 10–40 %, block based mutation, with penalty function; Case VI: e = 40 %, parcel based mutation, no penalty function.

For all cases, the population size is set to 40. The population takes 10 min to be created and consists of 1/3 feasible and 2/3 infeasible solutions. It should be noted that before defining the size of the initial population to 40, some trials with a smaller population size, e.g. 20, and larger size, e.g. 60 and 80, were carried out. The former is too small and hence the algorithm cannot converge whilst the latter

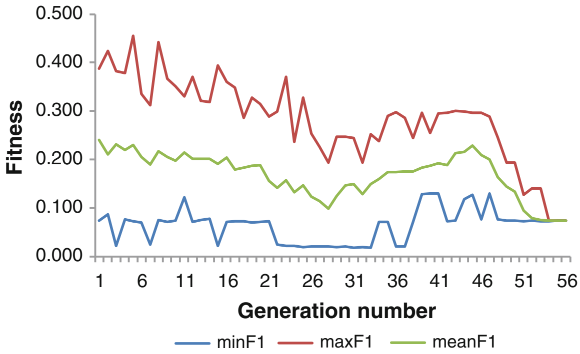


Fig. 10.16 The evolutionary statistics for case I

increased the computational time too much. Therefore, the population size was set to 40 for all optimisation cases presented here. It is worthwhile mentioning that a similar population (with 50 members) has been used by Datta et al. [12] for a similar spatial problem (land use management). In addition, Krzanowski and Raper [9] suggest a population size of 40–80 for spatial problems.

A detailed representation of the behaviour of the GA for the cases I to V is illustrated in Figs. 10.16, 10.17, 10.18, 10.19 and 10.20, respectively, showing four evolutionary statistics, namely, minimum, maximum, mean values of F1 and the overall fitness for each generation. The latter is involved only when the penalty function is added to the fitness measure. Otherwise the overall fitness equals the mean F1.

Some interesting findings can be extracted from these tests. In particular, the fastest convergence of the algorithm was achieved in case III (Fig. 10.18), in the 18th generation in 4.8 h that uses a 10 % application rate for the elitist block based mutation and no penalty function. Initially the mean fitness score is 0.24 but gradually falls to an optimum of 0.07. It is the only mean F1 line (among the above figures) that presents an almost continuous improvement until the optimum solution is found. This improvement is combined with the largest fluctuations of maxF1 that have been caused by the block based mutation, and which may create considerably worse solutions than the existing ones compared to what parcel based mutation may cause (Fig. 10.19). In parallel, the smallest minF1 value has risen very fast (in

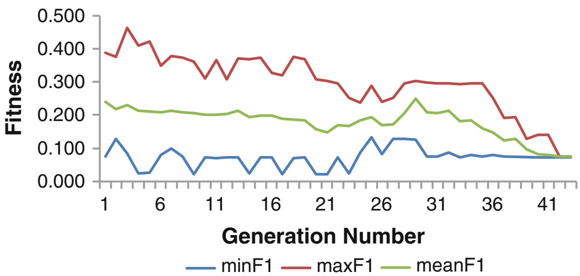


Fig. 10.17 The evolutionary statistics for case II

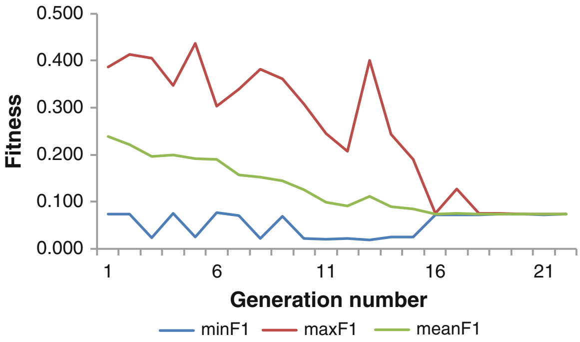


Fig. 10.18 The evolutionary statistics for case III

generation 10) which is a local optimum non-feasible solution (as we saw in the subdivision design of that solution) and remains stable for several generations. Then the search moves out of this local optimum through the crossover operator and quickly reaches the optimum feasible solution. In the other three cases (I, IV and V) the smallest minF1 value rises later, (in the 21st, 20th and 86th generations respectively) while this is not observed in case II where no mutation is applied.

As expected, in such a single-objective problem, all members of the population convergence to one optimum solution and the minF1, meanF1 and fitness level off (Fig. 10.18) after 18 generations. In addition, it is notable that case I, which involves the same parameters as those of case III except for the use of the elitist operator, took a longer time to converge than the latter (in the 55th generation which lasted 14.67 h). This finding highlights the importance of the elitist operator for speeding up the process, in this example by 9.87 h. However, the elitist operator should be introduced very carefully because if it is high (e.g. in case IV), it may lead to premature convergence in a non-optimum solution since the diversity of the population is lost.

Furthermore, it is worthwhile mentioning that case II, which involves a block based mutation, converged faster by nine generations compared with case III, which involved a parcel based mutation. However, it was ranked as having the second fastest convergence (in 27 generations lasting 7.2 h). Despite this, it seems that the block based mutation converges faster; however, this finding is not repeated in the second example involving block B14. Moreover, it is notable that

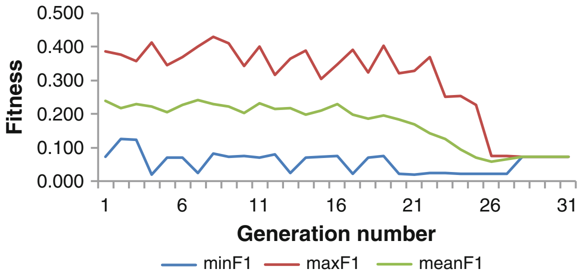


Fig. 10.19 The evolutionary statistics for case IV

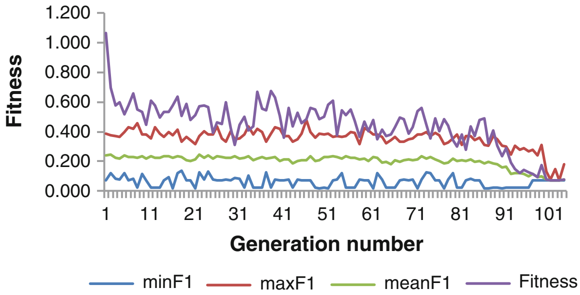


Fig. 10.20 The evolutionary statistics for case V

convergence can be also achieved even without mutation but in a much longer time as shown in case II (in 42 generations that took 11.20 h). This happens, because the BLX-a crossover operator is powerful in maintaining the diversity of the population without the involvement of a mutation operator, although the time is significantly increased.

Another noticeable outcome is that when the penalty function was included in the fitness, the convergence of the algorithm was considerably extended, (in 102 generations that lasted 27.2 h), achieving the maximum computational time (hence the worst case) for this test. This is due to the fact that a penalty function distorts the fitness measure through penalising non-feasible solutions by adding a number to the overall fitness. As a result, the overall fitness and the other metrics as well present continuous fluctuations of varying degrees (Fig. 10.20) until all solutions become feasible and eventually converge to the optimum. Therefore, penalty functions need to be treated carefully in terms of the value(s) of the constraint violation(s) so as to steer the search towards the feasible region [1] and need to be used only if it is really necessary. For example, in this situation the penalty function was not necessary because the algorithm was able to lead the search into the feasible region without it.

10.5.2 Shape Optimisation for Land Block B14

The initial subdivision for land block B14 without optimisation is shown in Fig. 10.21a. The relevant metrics for the three objective functions are the following: F1 (0.221), F2 (0.957) and F3 (0.610) and R = 1 meaning that the solution is not feasible since the parcel with ID 159 has no access from a road.

On the other hand, the best subdivision generated by optimisation is illustrated in Fig. 10.21b for which F1 equals 0.019, which represents an improvement by 91.35 % compared to the initial subdivision, further to the considerable visual improvement. In particular, all parcels have a *PSI* greater than 0.7. This subdivision is exactly what a human expert would do for designing parcels with regular shapes, i.e. symmetrically divide the block with a line in the middle and then design the parcels vertically to each road side. However, as in the previous

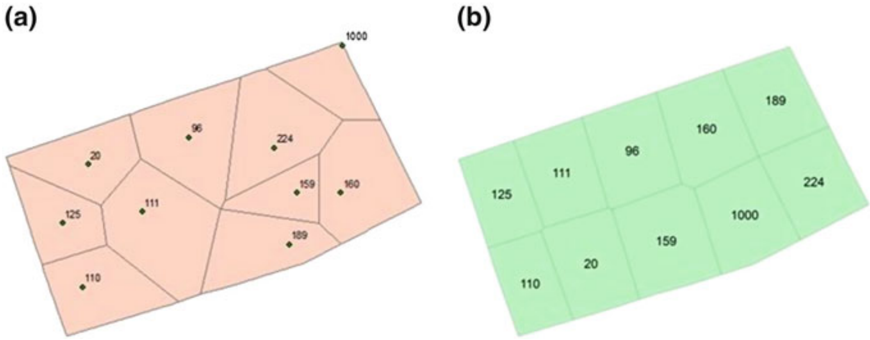


Fig. 10.21 Subdivision of land block B14 by utilising: regular Thiessen polygons (**a**) and the GA (**b**)

example with block B25, the algorithm fails to draw a perfect straight line in the middle of the block. In particular, the algorithm presents a weakness to do that so the joins of parcels are not identical. This limitation suggests again that the algorithm needs additional guidance. Despite this limitation, it is clear again that the algorithm is able to reach a near optimum solution for even a more complex land partitioning problem. In this case, the convergence achieved is better than that for block B25 and reached very close to the absolute optimum, because in contrast to block B25, the boundary of block B14 is almost rectangular.

For a more in-depth investigation of the performance of the algorithm, the model ran for the following five cases representing different sets of parameters: Case I: e = 10–40 %; block based mutation, no penalty function; Case II: e = 10–40 %; no mutation, with penalty function; Case III: e = 10–40 %; parcel based mutation, with penalty function; Case IV: e = 10–40 %; block based mutation, with penalty function; Case V: no elitist, block based mutation, with penalty function. Initially, the algorithm ran (case I) without the penalty function as we did with block B25 but a feasible solution could not be created even after 50 generations. Thus, the penalty function was introduced in the fitness measure with F1 for the next three cases. In addition, taking into account the previous experience gained from the behaviour of the algorithm for case V that includes a penalty function, a varying elitist factor from 10 to 40 % was included, to speed up the process as much as possible whilst avoiding premature convergence. Therefore, in cases I to IV, the elitist factor begins with a value of 10 % and gradually increases to 20, 30 and 40 % when the number of feasible solutions exceeds a certain percentage. For instance, when the number of feasible solutions in a population of 40 members exceeds 20 %, e.g. 8 out of 40 solutions are feasible, then the elitist factor is set to 20 % and so on. This trick was also necessary because the initial random population had only a few feasible solutions, and hence a strategy to preserve feasible solutions in the next set of generations was necessary.

A detailed representation of the behaviour of the GA for cases II, III, IV and V is illustrated in Figs. 10.22, 10.23, 10.24 and 10.25 respectively. The initial

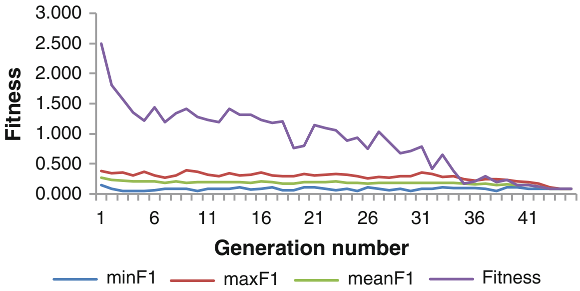


Fig. 10.22 The evolutionary statistics for case II

population (40 random solutions),which took 23 min to be created, consisted of only a few feasible solutions (3–6) out of 40 and as a result, the initial mean fitness score is very high for all cases (around 2.5). The best outcome obtained in case III occurred after 42 generations (12.0 h) although the other two cases (case II and case IV), converged shortly afterwards with 43 (12.3 h) and 46 (13.2 h) generations, respectively. This finding is sharply in contrast to the previous example for block B25, which showed that block based mutation considerably speeded up the process compared with that involving parcel based mutation or even more with no mutation at all. Thus, this case agrees with the statement of Krzanowski and Raper [9] that the mutation operator has no effect on the evolutionary search in spatial problems. However, it is not possible to apply this statement to all spatial problems and there may be situations where the mutation operator has a considerable influence on the evolutionary process depending on the particular features of the problem and the other optimisation parameters set out. In addition, the mutation operator is always useful for maintaining the diversity of a population from generation to generation, especially if the crossover used does not have this ability.

In terms of the evolutionary statistics, all of the cases shown in Figs. 10.22, 10.23, 10.24 and 10.25 present a very similar picture regarding the minimum, maximum and mean values of F1. In particular, they remain stable across the whole evolution with very small fluctuations until the last few generations before their convergence to the optimum solution. This is in contrast with what happened in cases with similar parameters for land block B25, where in many cases they present significant fluctuations. It seems that this phenomenon is due to the shape of the land block B14, which is almost rectangular, and hence does not favour considerably worse or better solutions.

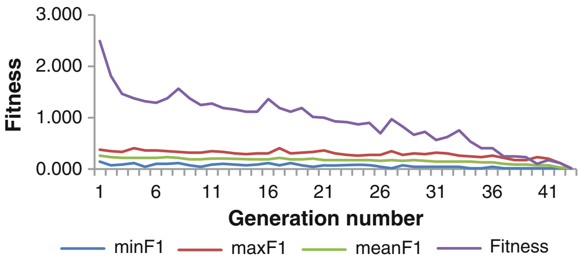


Fig. 10.23 The evolutionary statistics for case III

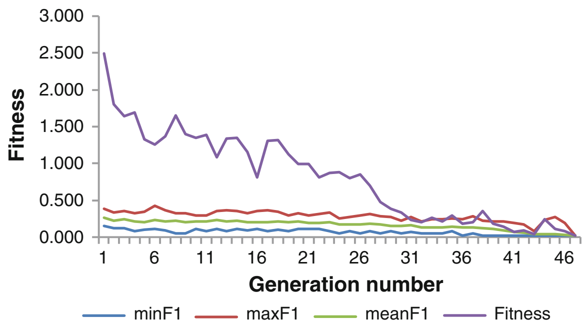


Fig. 10.24 The evolutionary statistics for case IV

Another interesting finding is that without the use of an elitist operator, convergence was achieved after 62 generations (17.77 h), whilst after the introduction of a varying elitist factor, the evolutionary process was speeded up by 32.3 %, again indicating the importance of this operator. The computational time needed to achieve the convergence (12.0 and 4.8 h in the two examples) is very high compared to the time a human expert could design near optimum subdivisions in terms of parcel shape. The reason is that the human brain can easily perceive a rectangular shape from an irregular shape or symmetrical shapes [8] but for a computer, this remains a difficult problem as discussed in Sect. 7.8, which dealt with shape analysis. This happens for many complex problems related to spatial planning or engineering design because the evaluation of the fitness function is time consuming [14, 19]. For example, in a land use management multi-objective problem [12], the algorithm needed 5,000 generations and took 3.82 days to converge. In addition, the simulated annealing algorithm of Tourino et al. [3] needed 10,000 stages (time is not noted) for solving a land partitioning problem with a block involving five parcels. The computational time could be considerably reduced by employing parallel computing that permits the parallel evaluation of individuals and the other computations so as to solve large and difficult problems in a reasonable time [14].

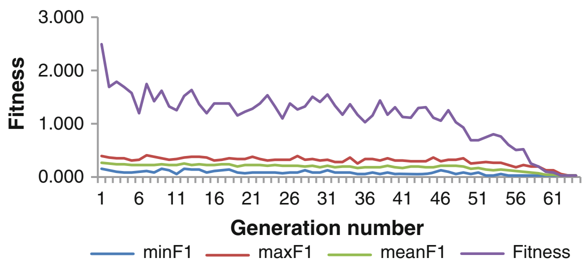


Fig. 10.25 The evolutionary statics for case V

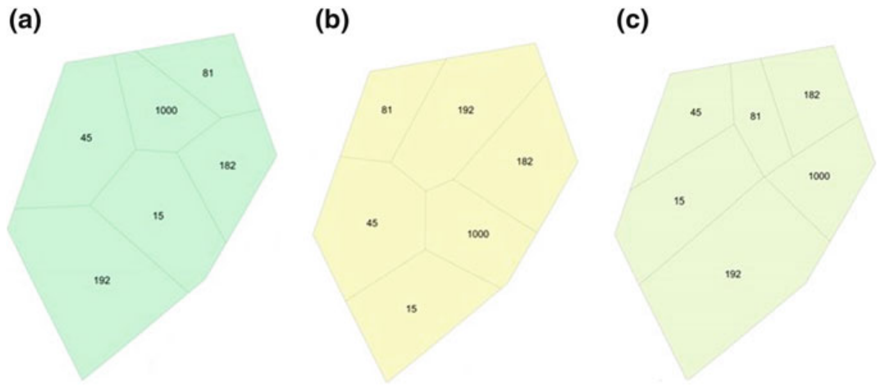


Fig. 10.26 Multi-objective optimisation outcomes for land block B25: shape and size (**a**); shape and land value (**b**); shape, size and land value (**c**)

10.6 Application of Multi-objective Land Partitioning

Land partitioning was handled based on three optimisation cases: shape and size (F1 and F2); shape and land value (F1 and F3) and shape, size and land value (F1, F2 and F3). These cases have been applied to blocks B25 (the best outcomes shown in Fig. 10.26) and B14 (the best outcomes shown in Fig. 10.27). The Pareto-optimal front for each case is presented in Figs. 10.28, 10.29, 10.30, 10.31 and 10.32. These include the solution with the minimum overall fitness (final population) and a few other selected populations having a fitness value close to the minimum.

10.6.1 Shape and Size Optimisation

This case involves two conflicting objectives, namely, minimise F1 and F2. Figures 10.28 and 10.29 shows a set of trade off solutions between the two objectives for land block B25 and B14 and the Pareto-optimal front, respectively. The proof that the two objectives are conflicting is the existence of Pareto-optimal solutions. Solutions that lie on the Pareto-optimal front are all feasible whilst solutions that fall within the non-Pareto optimum front region can be either feasible or infeasible. Taking into account that the earlier results showed that the algorithm can satisfactorily produce regular shapes, we wish to test the performance of the algorithm in minimising objective F2 and therefore assign (in Eq. 10.5) a high weight value of 0.8 in F2 and a low weight of 0.2 in F1 whilst ignoring F3. The penalty function for infeasible solutions is also involved.

In the case of block B25 the best solution (Fig. 10.26a), which is the solution that dominates all the others based on a certain weighting scheme, is that with the

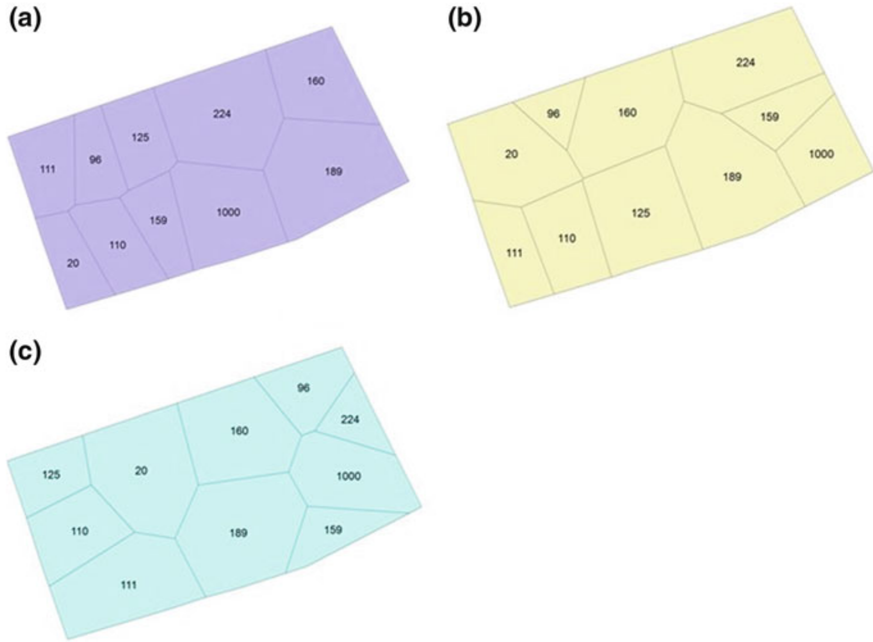


Fig. 10.27 Multi-objective optimisation outcomes for land block B14: shape and size (**a**); shape and land value (**b**); shape, size and land value (**c**)

lowest F2 value; this is marked with a triangle and falls on the Pareto-optimal front, which is marked as a dashed line (Fig. 10.28). All the other solutions belong in the non-Pareto-optimal set. The best solution resulted in F1 of 0.181, F2 of 0.094 and overall fitness of 0.112 meaning that: F1 has been improved by 31.44 % and F2 by 85.17 % compared to the initial subdivision. Furthermore, the parcel shape (F1) and size (F2) are on average only 18.1 and 9.4 % from the optimum, respectively. These are very encouraging results because the *PSI* is on average 0.819 and the variation of parcel size is within the acceptable range in practice (±10 %) suggesting that if a guidance operator was utilised to create the parcels, then the Pareto-optimal front will be shifted even closer to the origin point of the two axes, hence to the optimum solution.

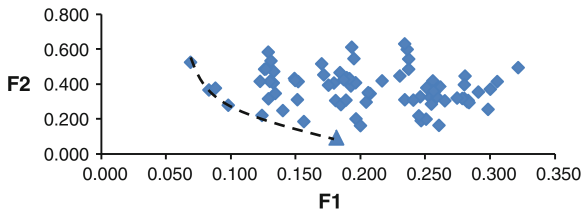


Fig. 10.28 A set of solutions and the Pareto-optimal front for land block B25

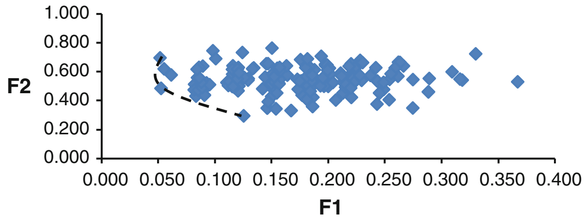


Fig. 10.29 A set of solutions and the Pareto-optimal front for land block B14

In the case of block B14, the results are slightly worse compared to those of block B25 because of the higher complexity of the former block. In particular, the best solution (Fig. 10.27a) is shown again with a triangle (Fig. 10.29) that falls at the bottom of the Pareto-optimal front and has an overall fitness of 0.298, F1 of 0.089 and F2 of 0.35. This represents an improvement of 59.73 and 63.43 % in F1 and F2 respectively, compared with the initial subdivision. It can be also said that parcel shape (F1) and size (F2) are on average far from the optimum by 8.9 and 35.0 %, respectively. The latter outcome regarding the size of the parcels exceeds the desirable variation noted above emphasising the need for improving the performance of the algorithm for more complex land partitioning problems.

10.6.2 Shape and Land Value Optimisation

Similar to the outcome for minimising the shape and the size of the parcels, the results for minimising the shape and the land value for land block B25 are encouraging. In particular, the best solution (Fig. 10.26b) marked in the Pareto-optimal front (Fig. 10.30) has a fitness of 0.130, F1 of 0.079 and a F3 of 0.142 meaning that F1 has been improved by 70.07 % and F3 by 77.13 % compared to the initial subdivision. The parcel shape (F1) and land value (F3) are on average far from the optimum by 7.9 and 14.2 %, respectively.

As expected, the outcome for land block B14 is not as good as that for land block B25. In particular, the best solution (Fig. 10.27b) marked in the Pareto-optimal front (Fig. 10.31) has an overall fitness of 0.281, F1 of 0.128 and F3 of 0.319. This indicates that F1 has been improved by 42.1 % and F3 by 47.7 % compared to the initial subdivision. Moreover, the parcel shape (F1) and land value (F3) are on average far from the optimum by 12.8 and 31.9 %, respectively.

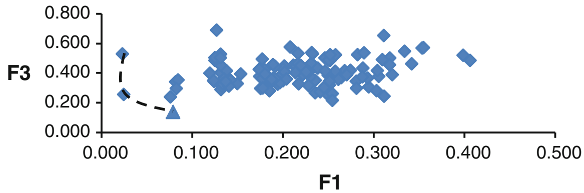
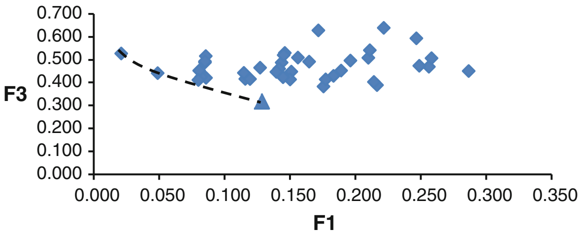


Fig. 10.30 A set of solutions and the Pareto-optimal front for land block B25

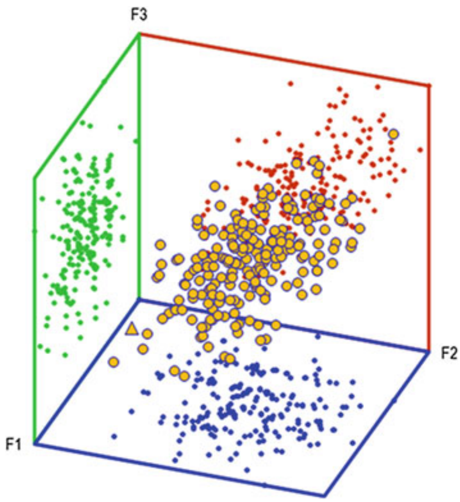
Fig. 10.31 A set of solutions and the Pareto-optimal front for land block B14



10.6.3 Shape, Size and Land Value Optimisation

The best solutions for simultaneously optimising shape, size and land value of parcels for block B25 and B14 are shown in Figs. 10.26c and 10.27c, respectively. In addition, Figs. 10.32 and 10.33 show, in a 3D plane, the projection of a set of solutions with respect to the three objective functions, F1, F2 and F3 for both blocks B25 and B14, respectively. The best solution for land block B25 (marked with a triangle in Fig. 10.32) resulted in the following metrics: Fitness (0.143), F1 (0.138), F2 (0.176) and F3 (0.113) involving an average improvement of F1, F2 and F3 by 47.7, 72.2 and 81.8 %, respectively. In other words, F1, F2 and F3 are on average far from the absolute optimum by 13.8, 17.6 and 11.3 %, respectively. Despite the complexity of simultaneously optimising three objectives, the results are very encouraging. It is obvious from Fig. 10.32 that several trade-off solutions from the cloud of points representing the overall fitness (large points) are close to the origin of the three axes that reflect the optimum solution. It should also be noted that in this case, the size (F2) and the land value (F3) are not conflicting but correlated as shown below.

Fig. 10.32 A set of solutions for simultaneous optimisation of parcels shape, size and land value for land block B25



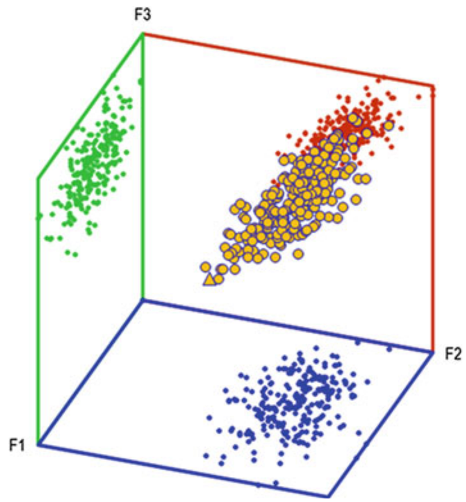


Fig. 10.33 A set of solutions for simultaneous optimisation of parcels shape, size and land value for land block B14

In the case of block B14, the outcome is worse than expected although it is in general moderate. In particular, the best solution gave the following results: overall Fitness (0.332), F1 (0.193), F2 (0.355) and F3 (0.378). This represents an improvement in each optimisation parameter compared with the initial subdivision of 12.7, 62.9 and 38.0 %, respectively. In other words, F1, F2 and F3 are on average far from the absolute optimum by 19.3, 35.5 and 37.8 %, respectively. This result is reflected graphically in Fig. 10.33 where the cloud of points representing the overall fitness is quite far from the origin of the three axes that reflect the optimum solution.

Although the above outcomes are encouraging, undoubtedly there is a need for improving the performance of the algorithm for reaching optimum solution(s) for both single and multi-objective land partitioning, especially for the latter case. This is due to the fact that the genotype of the algorithm involves two input variables, i.e. X and Y of the centroid of each polygon, that indirectly define optimisation parameters, i.e. shape, size and land value. As a result, the latter are not involved directly in the optimisation process. Therefore, the improvement of the performance of the algorithm can be achieved either by developing a new generic space partitioning algorithm or by introducing a so called guidance (or learning or local optimiser) within the current optimisation process. In the former case, the algorithm should take as input parameters the geometric features of shapes through the *PSI* and the size/land value of parcels that will then be optimised through LandParcelS. In the latter case, size and land value will be considered as constraints and the guidance operator will try to satisfy them during both the initialisation and optimisation process through a kind of hill climbing process.

10.7 Conclusions

The integration of GIS with GAs and MODM for solving the land partitioning process produced encouraging results indicating a step forward for solving this complex spatial problem. In particular, the model was applied to two land blocks of different complexity. In the case of single optimisation, involving optimising the shape of the parcels, the results are near optimum for both land blocks, illustrating that the *PSI* is an efficient and reliable index for evaluating parcel shapes. Therefore, the algorithm may successfully steer the Thiessen polygon process to generate polygons with regular shapes. This may have relevance to other spatial problems that deal with space partitioning combined with certain types of polygon shapes.

On the other hand, in the case of multi-objective optimisation with two objectives, namely, the shape and size or shape and land value, the results present a different picture depending on the complexity of the block. In particular, for the block with the lower complexity, the outcome is fairly close to the optimum whilst for the block with the higher complexity, the outcomes are further from the optimum in the case of size and land value. A similar picture is presented in the case of multi-objective optimisation with three objectives (shape, size and land value). Multi-objective space partitioning with constraints may also present wider interest for various spatial disciplines.

These findings suggest that, although the results are promising, further research is needed to improve the algorithm either by developing a specific space partitioning algorithm that will involve *PSI* parameters in the polygon design process or by introduction a guidance operator in the current algorithm that will be capable of correcting separately each polygon during the initialisation and evolutionary process. Another limitation of the algorithm is that the computational time is quite long for both single and multi-objective land partitioning compared to what a planner would expect from a sophisticated planning system. Two potential solutions to decrease computation times are: firstly, parallel computing that permits the simultaneous processing of various functionalities of the algorithm, and secondly, the use of a more powerful programming language.

Further to the evaluation of the results, several interesting findings are useful for other spatial evolutionary optimisation models due to the behaviour of the algorithm when various parameters are changed. Namely, an elitist operator is necessary to significantly speed up the process whilst a mutation operator may not always be necessary for all spatial problems, although its use may benefit performance. Similarly, the mutation of the whole individual (block based) may benefit the performance of the algorithm compared with the mutation of a chromosome (parcel based) or they may both have no significant influence on the process. In addition, the introduction of a penalty function definitely extends computational time but, on the other hand, it is necessary sometimes to steer solutions towards the feasible region. Moreover, it seems that a population size of around 40 individuals fits for several spatial problems including land partitioning.

This chapter completes the presentation of all the modules of LACONISS and the next chapter draws conclusions and suggests further research for improving the system.

References

1. Deb, K. (2001). *Multi-objective optimization using evolutionary algorithms*. West Sussex: Wiley.
2. Demetriou, D., Stillwell, J., & See, L. (2012). An integrated planning and decision support system (IPDSS) for land consolidation: Theoretical framework and application of the land redistribution modules. *Environment and Planning B: Planning and Design, 39*(4), 609–628.
3. Tourino, J., Boullon, M., & Gonzalez, X. (2003). A GIS-embedded system to support land consolidation plans in Galicia. *International Journal of Geographical Information Science, 17*(4), 377–396.
4. Chrisman, N. (2002). *Exploring geographic information systems*. New York: Wiley.
5. Dong, P. (2008). Generating and updating multiplicatively weighted Voronoi diagrams for point, line and polygon features in GIS. *Computers & Geosciences, 34*(4), 411–421.
6. Gong, Y., Li, G., Tian, Y., Lin, Y., & Liou, Y. (2011). A vector-based algorithm to generate and update multiplicatively weighted Voronoi diagrams for points, polyline and polygons. *Computers & Geosciences, 42*, 118–125.
7. Goldberg, D., & Deb, D.: (1991). A comparison of selection schemes used in genetic algorithms. In: G. Rawlins (Ed.), *Foundations of genetic algorithms I*, (pp. 69–93). San Mateo, CA, USA: Morgan Kaufmann.
8. Delahaye, D.: (2001). Airspace sectoring by evolutionary computation. In: R. Krzanowski & J. Raper (Eds.), *Spatial evolutionary modelling*, (pp. 203–233). New York: Oxford University Press.
9. Krzanowski, R., & Raper, J. (2001). *Spatial evolutionary modelling*. New York: Oxford University Press.
10. Van Dijk, S., Thierens, D., & Berg, M. (2002). Using genetic algorithms for solving hard problems in GIS. *Geoinfomatica, 6*(4), 381–413.
11. Bacao, F., Lobo, V., & Painho, M. (2005). Applying genetic algorithms to zone design. *Soft Computing, 9*, 341–348.
12. Datta, D., Deb, K., Fonseca, C., Lobo, F., & Condado, P.: (2006). *Multi-objective evolutionary algorithm for land use management problem*. Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Report Number 2006005. Available from URL:http://repository.ias.ac.in/82720/1/1-a.pdf.
13. Demetriou, D., Stillwell, J. & See, L.: (2012). *LandParcelS: A module for automated land partitioning*. Working Paper 12/02. School of Geography, University of Leeds, pp 59. Available from URL:http://www.geog.leeds.ac.uk/fileadmin/documents/research/csap/12-02.pdf.
14. Renner, G., & Ekart, A. (2003). Genetic algorithms in computer-aided design. *Computer Aided Design, 35*(8), 709–726.
15. Gwiazda, T.: (2006). *Genetic algorithms reference*. Volume I: Crossover for single objective numerical optimisation problems. Tomaszgiazda, Poland.
16. Eshelman, L., & Schaffer, D.: (1993). Real coded genetic algorithms and interval schemata. In: D. Whitley (Ed.), *Foundations of genetic algorithms II*, (pp. 187–202). San Mateo, CA, USA: Morgan Kaufmann.

17. Gwiazda, T.: (2007). *Genetic algorithms reference*. Volume II: Mutation operator for numerical optimisation problems. Tomaszgiazda, Poland.
18. Rudolph, G.: (1996). Convergence of evolutionary algorithms in general search spaces. *In*: *Proceedings of the third IEEE conference on evolutionary computation*, 50–54 May, pp. 20–22.
19. Stewart, T., Janssen, R., & Herwijnen, M. (2004). A genetic algorithm approach to multi-objective land use planning. *Computers & Operations Research, 31*, 2293–2313.

Chapter 11
Conclusions and Further Research

11.1 Introduction

This final chapter of the thesis is divided into three sections. The first section highlights the research innovations and the main findings whilst the second deals with the research and system limitations. The third section suggests further research focusing on improving different parts of LACONISS.

11.2 Research Outcomes

A summary of research findings relating to each of the six objectives of the thesis is provided below.

Objective 1: To critically evaluate the literature on land fragmentation, land consolidation and land reallocation.

The literature demonstrates that land fragmentation is a fundamental spatial problem in rural areas that prevents rational agricultural development and sustainable rural development in many parts of the world. Planners and decision makers need a reliable metric for quantifying land fragmentation on which to base their decisions. However, existing land fragmentation indices presented in the literature suffer from significant weaknesses that may be misleading and support wrong decisions regarding adopting appropriate methods of land management. Land consolidation is the most effective measure for eliminating land fragmentation, which is a popular land management approach that is currently applied in many countries. However, the literature suggests that there are major problems associated with land reallocation.

The core process of land consolidation is split into two sub-processes: land redistribution and land partitioning. The review of existing studies and current systems showed that land reallocation is not adequately supported by GIS and the efforts made in this direction since the 1960s have failed to provide an integrated planning and decision support system for land consolidation that is truly automated

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2_11, © Springer International Publishing Switzerland 2014

and which supports the process in a systematic and efficient manner. In contrast, most existing research focuses on isolated algorithms for land redistribution, land partitioning and evaluation of land consolidation plans that present certain limitations. In particular, land redistribution automation provides solutions that are sometimes optimal in terms of efficiency but are not necessarily realistic or operationally applicable. Similarly, land partitioning automation may produce operationally encouraging results but solutions are different from what experts would have produced. Furthermore, land consolidation evaluation studies have also suffered from the lack of a tool capable of providing detailed land reallocation inputs for ex-ante land consolidation project evaluation.

The above findings provide clear evidence of the need for an integrated planning and decision support system (IPDSS) that is able to reliably represent the land fragmentation problem and to automate and support both sub-processes of land reallocation in a systematic and efficient manner through new sophisticated algorithms and methods applied in the context of a common GIS platform that will be capable of overcoming limitations of existing studies. This demand is addressed in this research through the development of a new system called LACONISS that contributes to alleviating current problems of land consolidation associated with land reallocation.

Objective 2: To critically evaluate the literature on the tools, methods and techniques for supporting spatial planning processes and to develop a conceptual framework for an integrated planning and decision support system for land consolidation.

The literature review has shown that multi-criteria decision methods (MCDM), both multi-attribute (MADM) and multi-objective (MODM), artificial intelligence (AI) techniques, namely expert systems (ES) and genetic algorithms (GAs), fully integrated in ArcGIS through VBA and ArcObjects programming tools are able to provide the methodological framework for developing the four modules of LACONISS. These four modules are linked via the well-known three-stage model of Simon [1] utilised for planning and decision making. More specifically, MADM is considered as appropriate for constructing a new model called LandFragmentS for measuring the land fragmentation problem involving the evaluation of the performance of an existing system (land tenure) against an ideal system status (Intelligence phase).

In addition, investigation showed that ES are appropriate for solving the land redistribution problem (operationalized as the LandSpaCES Design model) because it is a decision-making problem based on human reasoning and not an optimisation problem as most studies consider it (Design phase). Furthermore, MADM can be classically employed for building a model (called LandSpaCES evaluation) for evaluating alternative land redistribution plans (Choice phase I) as used for many spatial problems. Moreover, evidence is provided that GAs with MODM are well suited for solving the land partitioning problem (LandParcelS model), which is a complex, non-linear design-optimisation process (Design and Choice phase II). LACONISS has attempted to overcome a common problem of many existing planning support systems, namely, the fact that there exists a gap between the planning needs and system capabilities resulting in limited success and use due to the involvement of a group of experts (including end users) in the development process.

Objective 3: To develop and test a new model for measuring the land fragmentation problem by integrating the multi-attribute decision making method with GIS.

The new land fragmentation model (LandFragmentS) overcomes the weaknesses of existing indices. More specifically, the new model is: comprehensive, since it integrates six core (spatial and non-spatial) land fragmentation factors giving a better representation of all the dimensions of the problem concerned; flexible because the user may select which factors should be taken into account for a particular project; and problem-specific since the planner may decide on the weighting given to each factor for a specific project. As a result, the new global land fragmentation index (*GLFI*) is more reliable and accurate than existing indices as shown by the application to the case study area where the existing indices underestimate the problem of land fragmentation since they ignore several important variables, and hence may be misleading if used in subsequent decision making.

Furthermore, other innovations should be highlighted. A new measure called the parcel shape index (*PSI*) has been developed for evaluating the shape of parcels. The case study showed that the *PSI* is more accurate and reliable than existing shape indices because it avoids the deficiencies associated with interpretation of the similarities and differences in their values in relation to parcel shape. In particular, the index increases gradually as the shape becomes better and moves towards the optimum; dissimilar shapes have different values especially compared to rectangular ones; and similar rectangular shapes have the same index. Furthermore, a new transformation process called the 'mean standardisation method' (mSM) has been introduced, which is appropriate in cases when a sample includes extreme minimum and/or maximum values. Specifically, the new method overcomes the potential favouring of large scores against small scores and vice versa by balancing the standardised values through taking into account the mean score of a sample.

Moreover, the development of LandFragmentS has also shown that MADM can be used not only for assessing a discrete number of alternative solutions as applied more conventionally, but also for spatial systems analysis, i.e. exploring and measuring the performance of an existing system (i.e. the land tenure system in this case) compared to an ideal system or evaluating the shape of an object (i.e. parcel shape in this case) compared to an optimum standard, which can be applicable in other disciplines that focus on system or object evaluation.

Objective 4: To develop and test a new land redistribution model that is capable of automatically generating alternative land redistribution plans by integrating expert systems with GIS.

Evaluation that is based on a real case study proved that the Design module of LandSpaCES is a robust and reliable system that has fulfilled its aims. In particular, it can efficiently solve the problem of land redistribution by producing results that are very close to human expert decisions and hence the outcome is realistic and applicable in contrast to existing studies. In addition, it can easily generate a set of alternative land redistributions for various sets of facts. Furthermore, the time performance is impressive, showing that it has tremendously diminished the time needed by a human expert to carry out the land redistribution process involving a contribution to alleviating two of the significant problems of the land consolidation process, i.e. the long duration of projects and the high operational costs. LandSpaCES transforms the land redistribution process, which is semi-structured, complex and time consuming, into an efficient, systematic, standardised and transparent methodology. In addition to this internal evaluation, the system seems to outperform, in several ways, the well-known Dutch program for land reallocation (TRANSFER), which has been developed over many years and is currently implemented in practice by the Dutch Cadastre.

The above encouraging results are accompanied by the fact that the integration of GIS with ES is not an easy task, since there is a lack of specialised external or embedded tools in proprietary GIS for this purpose, which can be a significant disadvantage. The decision to employ a conventional programming platform provided by VBA and ArcObjects, rather than an ES development tool (e.g. an ES shell) involves disadvantages noted later in the limitations section but which are compensated, however, by the capability of developing a fully integrated system within a GIS by utilising the 'No-Inference Engine Theory'. The latter offers an alternative for integrating GIS with ES using a conventional language that can be adopted by other spatial disciplines. Another innovation in the new land redistribution process is the introduction of the parcel priority index (*PPI*), which is a powerful measure representing both the preferences of landowners regarding the location they wish to receive their new parcels and the priority of the dual entity landowner-parcel in the land redistribution process in terms of allocating a parcel to a certain location or not. As a result, the *PPI* ensures equity, transparency and standardisation of the process, which contributes towards alleviating the problem of conflicts between the stakeholders involved.

Objective 5: To develop and test a new evaluation model that is capable of evaluating alternative land redistribution plans by integrating a multi-attribute decision-making method with GIS.

The application of the Evaluation module of LandSpaCES using a real case study showed that it is a flexible tool for evaluating alternative land redistributions. Some interesting findings are revealed from running the model for different weighting schemes and project objectives. More specifically, it proved that the system may produce better solutions than those of the experts. In addition, the ranking of alternatives is very sensitive to the alteration of weights of the criteria and the criteria themselves, which may vary depending on the project objectives. Therefore, planners should be aware of the criteria involved in the process, the weights assigned to each criterion and hence the weighting method utilised.

In addition to the above findings, three research innovations have been generated in the context of the development of the Evaluation module. In particular, the introduction of a new index called the parcel concentration coefficient (*PCC*) for measuring the dispersion of parcels in an explicit manner since it may take values from −1 to 1. This new formula, which is based on the standard distance, may have broader applicability in other spatial problems for measuring the potential change of spatial units represented by points before and after a policy that involves unification, separation and no change of the units concerned. Furthermore, a measure called the landowner satisfaction rate (*LSR*) was introduced for predicting the acceptance of the land redistribution plan by the landowners in terms of the location of their new parcels. In addition, an approach called the 'qualitative rating method' has been introduced as a modified version of the ratio estimation procedure for assigning weights in the evaluation criteria. The latter method can also have wider usefulness in evaluation problems.

Objective 6: To develop and test a new land partitioning model that is capable of automatically generating the new parcels in terms of shape, size and land value by integrating genetic algorithms and multi-objective decision making methods with GIS.

The integration of GIS with GAs and MODM for solving the land partitioning process produces encouraging results indicating a step forward for solving this complex and still unsolved spatial problem. In particular, the model was applied to two land blocks of different complexity. These examples were chosen from a real land consolidation case study area and the land partitioning was treated as both a single and a multi-objective problem. In the case of single optimisation involving optimising the shape of parcels, the results are near optimum for both land blocks, illustrating that the *PSI* is an efficient and reliable index for evaluating parcel shapes. Therefore, the algorithm may successfully steer the Thiessen polygon process in generating polygons with regular shapes. This may have relevance to other spatial problems that deal with space partitioning combined with certain types of polygon shapes.

In the case of multi-objective optimisation with two objectives, namely, the shape and size or shape and land value, the results present a different picture depending on the complexity of the block. In particular, for the block with the lower complexity, the outcome is fairly close to the optimum whilst for the block with the higher complexity, the outcomes are further from the optimum in the case of size and land value. A similar picture is presented in the case of multi-objective optimisation with three objectives (shape, size and land value). These findings suggest that, although the results are promising, further research is needed to improve the algorithm as noted later. Multi-objective space partitioning with constraints may also present wider interest for various spatial disciplines.

Further to the evaluation of the results, several interesting findings are useful for other spatial evolutionary optimisation models due to the behaviour of the algorithm when various parameters are changed. In particular, an elitist operator is necessary to significantly speed up the process whilst a mutation operator may not be always necessary for all spatial problems, although its use may benefit performance. Similarly, the mutation of the whole individual (block based) may benefit the performance of the algorithm compared with the mutation of a chromosome (parcel based) or they may both have no significant influence on the process. In addition, the introduction of a penalty function definitely extends computational time but, on the other hand, it is necessary sometimes to steer solutions towards the feasible region. Moreover, it seems that a population size of around 40 individuals fits for several spatial problems including land partitioning.

11.3 Research Limitations

Limitations are divided into those that are generic, i.e. that refer to the whole system, and those that are specific, i.e. those that are focused on one particular module of the system. Although the whole system philosophy is driven by the general concepts and application of land consolidation, LACONISS specifically reflects land consolidation legislation and practice in Cyprus. Therefore, some parts and elements of the system, e.g. the knowledge base, some of the evaluation criteria, some of the factors involved in the land redistribution and land fragmentation models respectively, the constraint(s) involved in the land partitioning model and the various value functions utilised for standardising criteria and factors, are specific to land consolidation conditions in Cyprus.

In addition, LACONISS is a prototype system and not a commercial system. The system consists of around 500 procedures and functions involving thousands of lines of code. It has a user friendly interface and it is fully operational. However, the aim was not to produce a commercial system. For example, functions regarding the administration of files or error trapping and programming efficiency have not been added to the system. Priority has been given to producing a fully operational prototype involving the four modules outlined in Fig. 1.1 that demonstrate the applicability, reliability and superiority (where possible) of the methodologies and concepts introduced in this research. Furthermore, LACONISS has been developed by utilising VBA and ArcObjects within ArcGIS 9.2 and 9.3, although ESRI has since replaced VBA with VB.NET with the launch of ArcGIS 10 (September 2010). The reason for staying with VBA is that when this project began in January 2009, ArcGIS 10.0 was not yet available and it was not yet clear what ESRI would do regarding VBA in the future. No efforts were made to migrate to VB.NET since more than half of the programming had been already done in VBA. Regardless, VBA and the ArcObjects code works in ArcGIS 10.0 but it is not possible to edit the code in this latest environment.

Moreover, the evaluation of the results of LACONISS is based on one case study area. In particular, the core module of the system, which is the LandSpaCES Design module, has been validated by comparing the decisions of the system with those of a number of experts. Good practice would be to test the module with a case study area having different cadastral, morphological and land use characteristics. However, the Land Consolidation Department (LCD) in Cyprus does not have their data available in a GIS format and it took a considerable time to develop the database for the case study area as discussed in Chap. 6. As a result, it was decided to have only one case study because of the time constraints. Similarly, LACONISS has not undergone a comprehensive evaluation by any end users (e.g. land consolidation technicians), other experts (e.g. land consolidation experts) or the main stakeholders involved (i.e. landowners) because of time constraints and the different research priorities as noted earlier. Nevertheless, the author (who has been a land consolidation expert for 15 years) did undertake a systematic discussion during the development of the system with a group of five land consolidation experts (including end users). In addition, much feedback was received via valuable presentations given in international and national organisations such as FAO and the Dutch Cadastre; and four international meetings of FIG (International Federation of Surveyors) Commissions specialised in fields such as cadastre, land management, land consolidation, land administration and spatial information management.

Further to the above generic system limitations, specific limitations can be identified for each module of the system. In particular, some minor operational limitations of LandFragmentS is the fact that value functions and the optimum shape for calculating the *GLFI* and *PSI* respectively are predefined programmatically and cannot be defined interactively by the user. In addition, adding a new land fragmentation factor is not operationally flexible. Similarly, value functions are predefined and adding an evaluation criterion is not operationally flexible in the Evaluation module of LandSpaCES. Furthermore, the Design module of LandSpaCES has three limitations. First, as was expected, it is very difficult to model all of the land redistribution reasoning of a human expert. Investigation into the differences between the system results and human expert results have shown that some more rules need to be added into the model to improve its performance. However, some of these rules involved the combination of complex operations that required further programming tasks and extra time, which was not available in the context of this research. Second, the system does not provide two facilities offered in a typical ES. In particular, since the knowledge base is not separated by the inference engine, it cannot be edited (e.g. new rules cannot be added easily or existing rules cannot be edited) by a user. Instead, programming skills are necessary to carry out this task. Also, the system does not offer an explanation facility, which is a very important part of a decision-making system in order to explain its decisions step by step. Third, although the system predicts the landowners' preferences regarding the location of their new parcels, it is not capable of directly accommodating the landowners' preferences regarding the reallocation of their properties that include issues additional to the location of new parcels.

Although the fourth module, LandParcelS, produced encouraging outcomes, particularly when the complexity of the problem is taken into account, there is undoubtedly a need to improve the performance of the algorithm for reaching optimum solution(s) for both single and multi-objective land partitioning, especially the latter. The weaknesses of the algorithm stem from the fact that optimisation treats the problem through a generic mechanism for space partitioning (i.e. Thiessen polygons). Hence the genotype of the algorithm involves only the two input parameters (X and Y coordinates of the centroid of each parcel) in the optimisation process, based on which the other parameters of the problem are defined, i.e. shape, size and land value. Suggestions for tackling these problems are discussed in the subsequent section. Another limitation of the algorithm is that computational time is quite long for both single and multi-objective land partitioning compared to what a planner expects from a sophisticated planning system. Two potential solutions to decrease computation times are: first, to use parallel computing that permits the simultaneous processing of various functionalities of the algorithm and second, the use of a more powerful programming language.

11.4 Further Research

The limitations noted above suggest further research and development for improving LACONISS as an entire system and each module separately. In particular, further research should be focussed on how LACONISS can be converted from a prototype single country system into generic commercialised or open source software that could be adjusted by a user to fit with the land consolidation legislation and practices of the country concerned. Of course this is not an easy task. The most difficult part of this process will be the capability of incorporating the land redistribution rules derived from legislation, expert knowledge and current practices of a country into the system. Such a system will provide all the common user friendly operations that are available in other commercial systems and the generic system should be tested with more case studies representing different forms of the problem with different levels of complexity. In addition, the system should be evaluated by the stakeholders involved in the land consolidation process such as end users, landowners and members of the committees.

Suggestions for future research can also be made that focus on each module of LACONISS. Three improvements to LandFragmentS are as follows. First, the value functions utilised for standardising scores for each factor and ownership should be easily and interactively defined by the user and not be predefined. Similarly, this suggestion applies to the calculation of the *PSI*. Second, the system should be able to incorporate more land fragmentation factors that could capture the prevailing conditions in another country. Third, the *PSI* needs more investigation so as to improve its accuracy and flexibility. In particular, the noted limitation of *PSI* regarding favouring or disfavouring certain shapes of parcels (parcels with symmetrical shapes and parcel shapes whose outlines looks rectangular except for one side, respectively) should be faced by introducing additional shape geometrical parameters and by improving the existing value functions of the associated parameters. In terms of flexibility, ideally the user should be able to define the optimum parcel shape or at least select one from a list rather than utilise a predefined one, which is currently a rectangle with a length: breadth ratio of 2:1.

Furthermore, the extension of the *PSI* (which currently evaluates 2D shapes) to the evaluation of 3D shapes by analysing their digital terrain would be an interesting area of research because the morphology of the terrain of a parcel strongly influences its agricultural exploitation. Moreover, the investigation of applying other methods and techniques currently utilised by other disciplines such as computer science and mathematics, which may seem appropriate for parcel shape analysis, would be a challenge for further research. The fields of differential geometry, deformable shape modelling and graph based shape analysis all involve interesting research areas of exploration for developing new parcel shape analysis methods.

In addition, the enhancement of the second module of LACONISS, the Design module of LandSpaCES, involves aspects focusing on the ES part. Namely, the knowledge base should be developed so as to be editable. Thus, a user may add or remove rules at any time. Furthermore, an explanation facility that will be able to justify system decisions to planners and landowners is another prominent research issue. Moreover, new rules should be involved in the model such as the definition by the user of parcels that will not change after the reallocation process. Both requirements suggest a broader need for proprietary GIS that would be able to easily incorporate knowledge for a spatial problem domain without considerable programming and customisation. The development of a specific ES shell for proprietary GIS would be a solution that needs considerably wider research. In addition, the system should be able to incorporate the actual landowners' preferences at the planning stage when these are available and when they can be linked to the rules.

Further to the above suggestions, future research could redevelop this module by employing more modern technologies such as ontologies that are able to build knowledge based models. Ontologies in GI science have arisen during the last decade ([2–5]) and seem to be promising tools for software interoperability [6] and representing knowledge regarding a problem domain. Another older technique for developing knowledge based systems is case based reasoning (CBR), which relies on the general principle that new problems can be solved based on the solutions given by similar problems in the past [7]. CBR can be used as complementary to the current ES rather than to replicate it. CBR works with concrete examples of previous solutions, a principle which is also adopted in practice by land consolidation planners for land reallocation issues. CBR has been also utilised for spatial planning disciplines [8–10]. Exploration of these two methods could prove a very interesting research challenge as well.

The Evaluation module of LandSpaCES would benefit from the first two recommendations made for improving LandFragmentS. In addition, although it was beyond the aims of this research, this model can be extended to become a comprehensive ex-ante evaluation tool for land consolidation. In particular, this model is currently capable of the ex-ante evaluation of different land consolidation plans, investigating at the micro level the land redistribution 'outputs' involving rearrangement of the existing land tenure structure. Therefore, further research could aim at building a comprehensive land consolidation evaluation module including models for all the ex-ante evaluation outcomes associated with the land consolidation intervention logic flowchart illustrated in Chap. 4. This includes, further to 'outputs', the 'results' and 'impacts' representing the medium-term and macro-term effects, respectively, of land consolidation. More specifically, based on the outputs of land reallocation and the infrastructure involved (i.e. the road network), the subsequent 'results' of the most immediate effects of the programme could be modelled, such as the increase of production and productivity, the reduction of agricultural costs and the improvement of accessibility to land and water. Thereafter, the subsequent 'impacts' could be modelled, which are linked to the strategic objectives of land consolidation, such as rural sustainable development, which is split into three main dimensions: economic, social, and environmental sustainability.

Finally, improving the fourth and last module of LACONISS, i.e. LandParcelS can be achieved in three ways. First, the performance of the algorithm in terms of optimisation results for both single and multi-objective optimisation can be achieved if a new method for space partitioning is developed from scratch that will involve, as design parameters, those *PSI* which will also be involved in the current optimisation process using a parametric GA. Of course this suggestion involves considerable effort. Second, another way of improving the current algorithm could be the introduction of a guidance operator (learning operator or local optimiser operator are alternative terms) that will be capable of correcting separately each parcel in terms of shape, size and land value between the evolutionary cycles including initialisation. Such an operator is implemented as a local, deterministic, hill-climbing search algorithm [11, 12]. Third, once the performance of the algorithm is ensured for all cases, then more constraints should be introduced so that the results will represent more practical cases that might occur in reality. In particular such constraints are: the existence of a boundary line (ecological lines, stone walls and fences); the existence of a construction(s) within a parcel (farmsteads, buildings and wells); and the final location of parcels represented by their centroids, which should be within a defined distance close to the initial seed points provided by the Design module of LandSpaCES.

In addition to the improvement of the current algorithm, future research may include the exploration of applying other optimisation methods such as greedy growing, tabu search and simulated annealing for solving land partitioning. All three might be applicable in land partitioning (in a raster based GIS) because they are proven to be robust, fast and capable of solving large combinatorial design problems. Simulated annealing has already been tested by Tourino et al. [13]. The other two methods have also been utilised for solving spatial problems within GIS: greedy growing by Cova and Church [14] and Jellemaa et al. [15] and tabu search by Ware et al. [16] and Martinez et al. [17].

11.5 Final Remark

Research regarding land consolidation planning support and automation began in the 1960s and has failed to achieve its ambitious aim of developing a generic integrated land consolidation system that could be adjusted to fit the needs of any country that implements such schemes. This thesis has provided a new scientific framework for land consolidation planning, which involves a prototype support system that could become the foundation stone for the future construction of such a generic system.

References

1. Simon, A. (1960). *The new science of management decision*. New York: Harper & Row.
2. Fonseca, F., Egenhofer, M., Davis, C., & Borges, K. (2000). Ontologies and knowledge sharing in urban GIS. *Computer, Environment and Urban Systems 24*(3), 232–251.
3. Moore, T. (2000). *Geospatial Expert Systems*. In: Openshaw and Aprahart (eds.), 2000. GeoComputation, Taylor & Francis, London and New York, 127–159.
4. Schuurman, N., & Leszczynski, A. (2006). Ontology based metadata. *Transactions in GIS, 10*(5), 709–726.
5. Couclelis, H. (2010). Ontologies of geographic information. *International Journal of Geographical Information Science, 24*(12), 1785–1809.
6. Eldrandaly, K. (2007). Expert systems, GIS, and spatial decision making: current practices and new trends. In A. Tyler (Ed.), *Expert systems: research trends* (pp. 207–228). New York: Nova.
7. Watson, L. (1997). *Applying case-based reasoning*. San Francisco: Morgan Kaufmann Publishers.
8. Holt, A., & Benwell, G. L. (1999). Applying case-based reasoning techniques to GIS. *International Journal of Geographic Information Science, 13*(1), 9–25.
9. Yeh, A. G. O. (2005). The integration of case-based reasoning and GIS in a planning support system. In D. J. Maguire, M. F. Goodchild, & M. Batty (Eds.), *GIS, spatial analysis, and modelling* (pp. 289–314). Redlands: ESRI Press.
10. Chen, J., He, B., Cui, Y., & He, Z. (2010). Case-based reasoning and GIS approach to regional metallogenic prediction. In: *Proceedings of 18th International Conference on Geoinformatics*, June 18–20, 2010, Beijing, China.
11. Krzanowski, R., & Raper, J. (2001). *Spatial evolutionary modelling*. New York: Oxford University Press.
12. Datta, D., Deb, K., Fonseca, C., & Lobo, F., Condado, P. (2006). *Multi-objective evolutionary algorithm for land use management problem*. Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Report Number 2006005. Available from URL: http://repository.ias.ac.in/82720/1/1-a.pdf.
13. Tourino, J., Boullon, M., & Gonzalez, X. (2003). A GIS-embedded system to support land consolidation plans in Galicia. *International Journal of Geographical Information Science, 17*(4), 377–396.
14. Cova, T. J., & Church, R. L. (1997). Modelling community evacuation vulnerability using GIS. *International Journal of Geographical Information Science, 11*(8), 763–784.
15. Jellemaa, A., Stobbelaara, D., Groota, J., & Rossinga, W. (2009). Landscape character assessment using region growing techniques in geographical information systems. *Journal of Environmental Management, 90*(2), 161–174.
16. Ware, J. M., Wilson, I. D., Ware, J. A., & Jones, C. B. (2002). A tabu search approach to automated map generalisation. In: McLean, V. A., (ed.), *Proceedings of 10th ACM International Symposium on Advances in Geographical Information Systems,* pp. 101–111.
17. Martinez, S., Merwade, V., & Maidment, D. (2010). Linking GIS, hydraulic modeling and Tabu search for optimizing a water level-monitoring network in South Florida. *Journal of Water Resources Planning and Management, 136*(2), 167–176.

Appendix A
Land Fragmentation Statistics

Global Statistics

Table A.1

Table A.1 Average holding size and number of parcels per holding, 1986–2004

Countries by continents	Census year	Average holding size (ha)	Average number of parcels per holding
Africa (20 countries)			
Algeria	01	8.26	–
Botswana	93	3.20	–
Burkina Faso	93	3.90	9.60
Cape Verde	04	1.00	1.92
Comoros	04	0.60	1.82
Democratic Republic of the Congo	90	0.50	2.00
Egypt	00	0.82	1.70
Ethiopia	02	1.03	3.28
Guinea	01	1.63	2.70
Guinea Bissau	88	1.10	2.80
Lesotho	90	1.40	–
Libya	01	10.24	1.46
Malawi	93	0.70	1.80
Marocco	96	5.83	6.37
Mozambique	00	1.28	–
Namibia	97	2.89	1.05
Reunion	89	4.40	–
Sao Tome and Principe	90	5.50	1.00
Tanzania	03	2.44	–
Uganda	91	2.20	1.60
North and Central America (18 countries)			
Bahamas	94	11.60	–
Barbados	89	1.30	–
Canada	01	273.38	–
Dominica	95	2.30	–

(continued)

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2, © Springer International Publishing Switzerland 2014

Table A.1 (continued)

Countries by continents	Census year	Average holding size (ha)	Average number of parcels per holding
Grenada	95	0.80	–
Guadeloupe	89	3.20	–
Honduras	93	11.20	–
Martinique	89	3.10	–
Mexico	91	41.40	–
Nicaragua	01	31.34	–
Panama	01	11.69	1.30
Puerto Rico	02	15.37	–
Saint Lucia	86	2.00	1.20
St. Kitts and Nevis	00	2.07	–
St. Vincent and Grenadines	00	0.97	1.11
Trinidad and Tobago	04	4.45	1.37
U.S.A.	02	178.35	–
Virgin Islands (US)	87	27.00	–
South America (*10 countries*)			
Argentina	96	72.76	–
Brazil	02	582.45	–
Chile	97	83.74	1.59
Colombia	01	25.08	–
Ecuador	00	14.66	–
French Guiana	00	6.52	–
Paraguay	91	77.50	–
Peru	94	20.10	3.30
Uruguay	00	287.4	–
Venezuela	97	60.02	1.18
Asia (*24 countries*)			
Bangladesh	05	0.35	–
China	97	0.67	–
Cyprus	03	3.50	5.00
Georgia	04	1.21	2.32
India	96	1.41	–
Indonesia	93	0.90	–
Iran	03	4.07	–
Israel	95	14.20	–
Japan	00	1.20	–
Jordan	97	3.31	1.57
Republic of Korea	90	1.10	–
Kyrgyzstan	02	1.15	–
Laos	99	1.57	2.10
Lybanon	91	1.27	2.52
Myanmar	03	2.52	–
Nepal	02	0.79	3.27
Pakistan	00	3.09	1.90
Philippines	02	1.98	–

(continued)

Table A.1 (continued)

Countries by continents	Census year	Average holding size (ha)	Average number of parcels per holding
Qatar	01	11.91	–
Saudi Arabia	99	16.70	2.31
Sri Lanka	02	0.50	–
Thailand	03	3.16	–
Turkey	01	6.00	4.08
Viet Nam	02	0.71	–
Europe (*28 countries*)			
Albania	98	4.05	–
Austria	00	34.11	–
Belgium	00	23.32	–
Croatia	02	3.09	–
Czech Republic	00	99.28	–
Denmark	00	49.78	–
Esthonia	01	20.34	–
Finland	00	72.24	–
France	00	45.04	–
Germany	00	40.46	–
Greece	00	4.74	–
Hyngary	00	6.67	–
Ireland	00	33.31	–
Italy	00	7.57	3.61
Latvia	01	19.89	–
Lithuania	03	4.96	–
Luxembourg	00	48.98	–
Netherlands	00	22.05	–
Norway	99	89.84	–
Poland	02	6.59	–
Portugal	99	12.47	–
Romania	02	2.93	–
Slovakia	01	48.74	–
Slovenia	00	10.99	–
Spain	99	23.90	10.21
Sweden	00	93.87	–
Switzerland	90	11.80	7.00
United Kingdom	00	70.86	–
Oceania (*13 countries*)			
American Samoa	90	6.10	–
Australia	01	3,243.21	–
Cook Islands	00	0.60	2.01
Fiji	91	6.20	–
French Polynesia	95	4.90	–
Guam	87	15.10	–
New Caledonia	02	51.94	–
New Zealand	02	223.43	–

(continued)

Table A.1 (continued)

Countries by continents	Census year	Average holding size (ha)	Average number of parcels per holding
Niue	89	6.10	8.60
Northern Mariana Islands	02	4.45	–
Palau	89	0.50	2.70
Samoa	99	3.62	2.40
Tonga	01	2.62	1.46

Source FAO, The Statistics Division

EU Statistics

Table A.2

Table A.2 Distribution of agricultural holdings by size in EU, 1995–2005

Countries	Size class (ha)	1995	1997	2000	2003	2005
EU-27	Under 5	–	–	–	72.9	75.7
	From 5 to 10	–	–	–	10.2	10.5
	From 10 to 20	–	–	–	6.8	7
	From 20 to 50	–	–	–	5.6	5.8
	Over than 50	–		–	4.6	4.7
EU-25	Under 5	–	–	–	61.9	63.1
	From 5 to 10	–	–	–	13.1	13.4
	From 10 to 20	–	–	–	9.9	10.1
	From 20 to 50	–	–	–	8.3	8.5
	Over than 50	–	–	–	6.8	6.9
EU-15	Under 5	56.4	55.3	57.6	56.6	60.4
	From 5 to 10	13.0	13.3	12.3	12.3	13.1
	From 10 to 20	10.6	10.8	10.2	10.2	10.9
	From 20 to 50	11.5	11.5	10.9	11.0	11.7
	Over than 50	7.9	8.6	8.9	9.9	10.6
Belgium	Under 5	31.1	30.1	30.8	28	29.8
	From 5 to 10	14.5	14.2	13.5	13.2	14.1
	From 10 to 20	17.9	17.1	16.5	16.1	17.2
	From 20 to 50	25.8	26.5	27.1	27.8	29.6
	Over than 50	8.5	10.0	12.2	14.9	15.9
Bulgaria	Under 5	–	–	–	96.8	95.62
	From 5 to 10	–	–	–	1.5	1.95
	From 10 to 20	–	–	–	0.6	0.90
	From 20 to 50	–	–	–	0.4	0.54
	Over than 50	–	–	–	0.8	0.99

(continued)

Table A.2 (continued)

Countries	Size class (ha)	1995	1997	2000	2003	2005
Czech Republic	Under 5	–	–	–	58.1	62.9
	From 5 to 10	–	–	–	10.5	11.4
	From 10 to 20	–	–	–	9.3	10.1
	From 20 to 50	–	–	–	8.5	9.2
	Over than 50	–	–	–	13.5	14.7
Denmark	Under 5	2.6	3.1	3	3.7	3.7
	From 5 to 10	16.6	16.3	16.4	16.5	16.6
	From 10 to 20	21.7	21.3	20	18.2	18.3
	From 20 to 50	33.9	31	29.7	26.3	26.4
	Over than 50	24.9	27.8	30.6	35.3	35.6
Germany	Under 5	31.2	31	24.9	23.6	25
	From 5 to 10	14.8	14.6	15.7	14.6	15.4
	From 10 to 20	17.6	16.9	18.5	18.7	19.8
	From 20 to 50	23.3	22.9	24.2	22.8	24.1
	Over than 50	12.6	14.2	16.7	20.3	21.4
Estonia	Under 5	–	–	–	50.8	67.5
	From 5 to 10	–	–	–	19.7	26.2
	From 10 to 20	–	–	–	14.5	19.3
	From 20 to 50	–	–	–	9.1	12.1
	Over than 50				5.8	7.7
Greece	Under 5	74.8	75.8	76.8	76.1	75.3
	From 5 to 10	15.0	14.1	13.3	13.3	13.2
	From 10 to 20	6.7	6.6	6.4	6.5	6.4
	From 20 to 50	2.7	2.6	2.9	3.3	3.3
	Over than 50	0.4	0.4	0.5	0.8	0.8
Spain	Under 5	54.3	52.7	57.5	55	58.1
	From 5 to 10	16.6	16.4	14.9	14.8	15.7
	From 10 to 20	11.5	12.4	11.0	11.5	12.2
	From 20 to 50	9.0	9.5	8.9	10.0	10.5
	Over than 50	7.6	8.2	7.8	8.7	9.2
France	Under 5	26.7	26.2	29.1	27.6	29.9
	From 5 to 10	9.5	9.1	9.1	9.3	10.1
	From 10 to 20	12.1	11.0	10.7	10.4	11.2
	From 20 to 50	24.1	23.4	20.8	19.8	21.4
	Over than 50	27.0	29.7	30.3	32.9	35.7
Ireland	Under 5	9.3	7.3	8.3	6.3	6.5
	From 5 to 10	13.4	12.4	11.8	14.7	15
	From 10 to 20	26.5	27.1	24.2	23.7	24.2
	From 20 to 50	37.3	38.8	38.7	38.3	39.2
	Over than 50	13.2	14.1	17.1	17.0	17.3
Italy	Under 5	77.9	75.6	78.3	76.8	87.3
	From 5 to 10	10.4	11.8	10.1	10.5	11.9
	From 10 to 20	5.6	6.5	6.0	6.2	7.1
	From 20 to 50	4.2	4.1	3.8	4.4	5
	Over than 50	1.6	1.8	1.7	2.1	2.3

(continued)

Table A.2 (continued)

Countries	Size class (ha)	1995	1997	2000	2003	2005
Cyprus	Under 5	–	–	–	87.5	87.6
	From 5 to 10	–	–	–	6.3	6.3
	From 10 to 20	–	–	–	3.4	3.4
	From 20 to 50	–	–	–	1.9	1.9
	Over than 50	–	–	–	0.9	0.9
Latvia	Under 5	–	–	–	50.6	49.8
	From 5 to 10	–	–	–	23.2	22.9
	From 10 to 20	–	–	–	15.8	15.6
	From 20 to 50	–	–	–	7.3	7.2
	Over than 50	–	–	–	3.0	2.9
Lithuania	Under 5	–	–	–	62.1	66.8
	From 5 to 10	–	–	–	21	22.6
	From 10 to 20	–	–	–	10.5	11.3
	From 20 to 50	–	–	–	4.6	4.9
	Over than 50	–	–	–	1.9	2.0
Luxembourg	Under 5	25.0	23.8	22.1	19.6	19.6
	From 5 to 10	9.4	8.7	9.6	8.9	8.9
	From 10 to 20	9.4	7.7	7.5	7.8	7.8
	From 20 to 50	21.9	19.5	18.9	17.8	17.8
	Over than 50	37.5	39.6	42.0	45.8	45.9
Hungary	Under 5	–	–	–	89.6	97.0
	From 5 to 10	–	–	–	4.3	4.7
	From 10 to 20	–	–	–	2.8	3.0
	From 20 to 50	–	–	–	1.8	2.0
	Over than 50	–	–	–	1.4	1.5
Malta	Under 5	–	–	–	97.8	97
	From 5 to 10	–	–	–	2.0	2.0
	From 10 to 20	–	–	–	0.2	0.2
	From 20 to 50	–	–	–	0	0
	Over than 50	–	–	–	–	–
Netherlands	Under 5	31.4	30.4	31.2	29.6	30.9
	From 5 to 10	16.0	16.0	15.6	14.2	14.8
	From 10 to 20	18.4	17.9	17.2	15.9	16.6
	From 20 to 50	26.3	27	27.8	28.1	29.4
	Over than 50	6.4	7.1	8.2	12.2	12.7
Austria	Under 5	38.1	37.2	36.4	32.3	32.8
	From 5 to 10	18.8	18.7	19.1	19.0	19.4
	From 10 to 20	22.1	22.3	22.5	23.2	23.7
	From 20 to 50	16.1	17.0	17.6	19.7	20
	Over than 50	3.6	4.1	4.5	5.9	6.0
Poland	Under 5	–	–	–	66.5	58.3
	From 5 to 10	–	–	–	17.1	15
	From 10 to 20	–	–	–	11.4	10
	From 20 to 50	–	–	–	4.2	3.6
	Over than 50	–	–	–	0.8	0.7

(continued)

Table A.2 (continued)

Countries	Size class (ha)	1995	1997	2000	2003	2005
Portugal	Under 5	76.4	75.9	78.8	76.6	85
	From 5 to 10	11.5	11.7	10.1	10.8	12
	From 10 to 20	6.3	6.4	5.6	6.2	6.9
	From 20 to 50	3.4	3.6	3.1	3.6	4
	Over than 50	2.2	2.3	2.4	2.7	3
Romania	Under 5	–	–	–	93.8	98.8
	From 5 to 10	–	–	–	4.9	5.1
	From 10 to 20	–	–	–	0.8	0.9
	From 20 to 50	–	–	–	0.2	0.2
	Over than 50	–	–	–	0.3	0.3
Slovenia	Under 5	–	–	–	57.5	57.5
	From 5 to 10	–	–	–	26.7	26.7
	From 10 to 20	–	–	–	12.6	12.6
	From 20 to 50	–	–	–	2.9	2.9
	Over than 50	–	–	–	0.3	0.3
Slovakia	Under 5	–	–	–	91.9	96.2
	From 5 to 10	–	–	–	2.1	2.2
	From 10 to 20	–	–	–	1.4	1.5
	From 20 to 50	–	–	–	1.3	1.3
	Over than 50	–	–	–	3.3	3.5
Finland	Under 5	10.0	8.3	10.5	9.9	10.5
	From 5 to 10	17.7	15.8	13.7	12.9	13.7
	From 10 to 20	30.0	30.0	24.9	23.5	24.9
	From 20 to 50	34.9	36.8	37.4	37.2	39.5
	Over than 50	6.8	8.8	13.5	16.5	17.5
Sweden	Under 5	11.8	12.1	12.0	10.4	9.3
	From 5 to 10	17.5	17.7	17.2	15.1	13.5
	From 10 to 20	21.4	20.4	20.9	20.1	18.0
	From 20 to 50	27.8	26.4	26.5	26	23.3
	Over than 50	20.9	21.3	23.3	28.4	25.4
UK	Under 5	13.0	14.6	23.1	36.9	36.1
	From 5 to 10	12.6	12.2	11.0	9.6	9.4
	From 10 to 20	15.4	14.9	13.0	10.6	10.3
	From 20 to 50	24.1	23.8	20.5	16.0	15.7
	Over than 50	34.2	33.6	32.4	26.9	26.3

Source European Commission, Eurostat

Appendix B
Blocks of Basic Code

B.1 LandFragmentS module

B.1.1 Calculate the original dispersion of parcels (DoP)

```
Set pOwnersRow = pOwnersCursor.NextRow
Do Until pOwnersRow Is Nothing
        If pOwnersRow.Value(intPosReceiveField) = "YES" Then
        Dim OwnerID As Double
        OwnerID = pOwnersRow.Value(intPosOwnersField)
        Set pDataSetRel = pRelClass1
        Set pRelSet1 = pRelClass1.GetObjectsRelatedToObject(pOwnersRow)
        pRelSet1.Reset

        Set pOwnershipRow = pRelSet1.Next
        Do Until pOwnershipRow Is Nothing
                'Get relation2
                Set pDataSetRel2 = pRelClass2
                Set pRelSet2 = pRelClass2.GetObjectsRelatedToObjectSet(pRelSet1)

                ' Assumes pRelSet2 is an ISet
                Dim pArray As IArray
                Dim pFeature As IFeature
                Dim pFeature2 As IFeature
                Dim lFldIdx As Long
                Dim bInserted As Boolean
                Dim f As Long

                ' The field no. you want to sort the features on
                lFldIdx = intPosPPI

                ' Setup a new array to hold the sorted features
                Set pArray = New esriSystem.Array

                pRelSet2.Reset
                Set pFeature = pRelSet2.Next
                While Not pFeature Is Nothing

                  bInserted = False
```

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2, © Springer International Publishing Switzerland 2014

```
        For f = 0 To pArray.count - 1
                Set pFeature2 = pArray.Element(f)
                If pFeature2.Value(lFldIdx) < pFeature.Value(lFldIdx) Then
                    pArray.Insert f, pFeature
                    bInserted = True
                    Exit For
                  End If
                Next f
          If Not bInserted Then pArray.Add pFeature
          Set pFeature = pRelSet2.Next
        Wend
        Dim DoP As Double
        Dim Dist As Double
        Dim CenX As Double
        Dim CenY As Double
        Dim SumDist As Double
        Dim insidevalue As Double
        Dim Sumwi As Double
        ' Now we can loop through the array and the features will be sorted in descending
        ' order of the specified field no. lFldIdx
        SumDist = 0
        For f = 0 To pArray.count - 1
                Set pFeature = pArray.Element(f)
              CenX = GetParcelCenX(pFeature)  '* pFeature.Value(intPosArea)
              CenY = GetParcelCenY(pFeature)  '* pFeature.Value(intPosArea)
              Dist = (CenX - pOwnersRow.Value(intPosXwmcField)) ^ 2 _
              + (CenY - pOwnersRow.Value(intPosYwmcField)) ^ 2
              SumDist = SumDist + Dist
              Counter = Counter + 1
          Next f
          ' Clean up the array
          pArray.RemoveAll
          Set pArray = Nothing
          Set pOwnershipRow = pRelSet1.Next
  Loop
insidevalue = SumDist
DoP = Sqr(insidevalue / Counter)
pOwnersRow.Value(intPosDOPField) = DoP
pOwnersRow.Store
SumDist = 0
Sumwi = 0
Counter = 0
End If
```

```
            Set pOwnersRow = pOwnersCursor.NextRow
   Loop
```

B.1.2 Check if a parcel has access on a road or not

```
Dim pRRoadsFeature As IFeature
Dim pOriginalParcelsFeature As IFeature
Dim FID As Single
Dim pRRoadsFC  As IFeatureClass
Set pRRoadsFC = pRRoads.FeatureClass
Dim pRRoadsFields  As IFields
Set pRRoadsFields = pRRoadsFC.Fields
Dim pGeom As IGeometry
Dim pSpatialFilter As ISpatialFilter
Set pSpatialFilter = New SpatialFilter

Dim pRRoadsCursor As IFeatureCursor
Set pRRoadsCursor = pRRoadsFC.Search(pSpatialFilter, False)

Set pRRoadsFeature = pRRoadsCursor.NextFeature
Do Until pRRoadsFeature Is Nothing

        Set pGeom = pRRoadsFeature.Shape
        With pSpatialFilter

          Set .Geometry = pGeom
            .GeometryField = "Shape"
            .SpatialRel = esriSpatialRelTouches
        End With

        Dim pRelOp As IRelationalOperator
        Set pRelOp = pGeom
          Set pOriginalParcelsFeature = pOriginalParcelsCursor.NextFeature
          Do Until pOriginalParcelsFeature Is Nothing
                FID = pOriginalParcelsFeature.Value(intposFID)
                If pRelOp.Touches(pOriginalParcelsFeature.Shape) Then
             'Fill the 'Access' field in the Original Parcels layer with 1 if the parcel has access and 0 if not
             Call FillAccessField
                 End If
                Set pOriginalParcelsFeature = pOriginalParcelsCursor.NextFeature
          Loop
         Set pRRoadsFeature = pRRoadsCursor.NextFeature
  Loop
```

B.1.3 Calculate the number of parcel sides having less than the minimum length

```
Dim pFeature As IFeature
Set pFeature = pFCursor.NextFeature
Do Until pFeature Is Nothing
        FID = pFeature.Value(intposFID)
        pFilter.WhereClause = "FID=" & FID
        pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
        Set pSelection = pLayer
        pSelection.SelectFeatures pFilter, esriSelectionResultNew, True
            ' Get all disjoint paths
            Set pGeomColl = pFeature.Shape

            ' Loop thru the paths
            For i = 0 To pGeomColl.GeometryCount - 1
              ' Get all segments that make up this path
              Set pSegColl = pGeomColl.Geometry(i)
              Set pCurve = pSegColl

              ' Loop thru the segments
                      For j = 0 To pSegColl.SegmentCount - 2

                            ' Get the next two lines
                            Set pLine1 = pSegColl.Segment(j)
                            Set pLine2 = pSegColl.Segment(j + 1)

                            dVtxAng = CalcAngleBetweenLines(pLine1, pLine2)
                             angleDeg = dVtxAng * 57.2957795

                            If angleDeg >= 175 And angleDeg <= 185 Then
                            Counter = Counter
                            GoTo Nextsegment
                            End If
                            If (angleDeg < 175 Or angleDeg > 185) And pLine1.Length < 25 Then
                            Counter = Counter + 1
                            End If

                        Nextsegment:Next j

            Next i
        pFeature.Value(intPosminLenght) = Counter
        pFCursor.UpdateFeature pFeature
        Counter = 0
        Set pFeature = pFCursor.NextFeature
Loop
```

B.1.4 Calculate the number of acute angles of a parcel

```
Dim pFeature As IFeature
Set pFeature = pFCursor.NextFeature

Do Until pFeature Is Nothing
        FID = pFeature.Value(intposFID)
        pFilter.WhereClause = "FID=" & FID
        pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
        Set pSelection = pLayer
        pSelection.SelectFeatures pFilter, esriSelectionResultNew, True
        'Code for measuring angles
            ' Get all disjoint paths
            Set pGeomColl = pFeature.Shape
              ' Loop thru the paths
            For i = 0 To pGeomColl.GeometryCount - 1
                      ' Get all segments that make up this path
                      Set pSegColl = pGeomColl.Geometry(i)
                      Set pCurve = pSegColl
                ‘Loop thru the segments
                      For j = 0 To pSegColl.SegmentCount - 2
                              ' Get the next two lines
                              Set pLine1 = pSegColl.Segment(j)
                              Set pLine2 = pSegColl.Segment(j + 1)

                              ' Calculate the left side angle (in degrees)
                              dVtxAng = CalcAngleBetweenLines(pLine1, pLine2)
                               angleDeg = dVtxAng * 57.2957795
If angleDeg <= 80 Then
                                 Counter = Counter + 1
                                 Else
                                 Counter = Counter + 0
                              End If
                Next j

                      If pCurve.IsClosed Then
                        Set pLine1 = pSegColl.Segment(j)
                        Set pLine2 = pSegColl.Segment(0)
                        dVtxAng = CalcAngleBetweenLines(pLine1, pLine2)
                        angleDeg = dVtxAng * 57.2957795
                      End If
                         If angleDeg <= 80 Then
                        Counter = Counter + 1
                      Else
                        Counter = Counter + 0
```

```
                End If
        Next i
        pFeature.Value(intPosminAccute) = Counter
        pFCursor.UpdateFeature pFeature

        Counter = 0
        Set pFeature = pFCursor.NextFeature
Loop
```

B.1.5 Calculate the number of points of a parcel

```
Dim pFeature As IFeature
Set pFeature = pFCursor.NextFeature

Do Until pFeature Is Nothing
        FID = pFeature.Value(intposFID)
        pFilter.WhereClause = "FID=" & FID
        pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
        Set pSelection = pLayer
        pSelection.SelectFeatures pFilter, esriSelectionResultNew, True
            ' Get all disjoint paths
            Set pGeomColl = pFeature.Shape
            ' Loop thru the paths
            For i = 0 To pGeomColl.GeometryCount - 1
                    ' Get all segments that make up this path
                    Set pSegColl = pGeomColl.Geometry(i)
                    Set pCurve = pSegColl

                    ' Loop thru the segments
                    For j = 0 To pSegColl.SegmentCount - 2

                        ' Get the next two lines
                        Set pLine1 = pSegColl.Segment(j)
                        Set pLine2 = pSegColl.Segment(j + 1)


                        ' Calculate the left side angle (in degrees)
                        dVtxAng = CalcAngleBetweenLines(pLine1, pLine2)
                         angleDeg = dVtxAng * 57.2957795


                        If angleDeg >= 175 And angleDeg <= 185 Then
                        Counter = Counter + 0
                        Else
                        Counter = Counter + 1
                        End If
```

```
                    Next j
                    ' Check for a closed polylin
            If pCurve.IsClosed Then
                        Set pLine1 = pSegColl.Segment(j)
                        Set pLine2 = pSegColl.Segment(0)
                        dVtxAng = CalcAngleBetweenLines(pLine1, pLine2)
                        angleDeg = dVtxAng * 57.2957795
                    End If
            If angleDeg >= 175 And angleDeg <= 185 Then
                        Counter = Counter + 0
                        Else
                        Counter = Counter + 1
                    End If
        Next i
    'Store number of points in the field
    pFeature.Value(intPosNumPoints) = Counter
    pFCursor.UpdateFeature pFeature
    Counter = 0
    Set pFeature = pFCursor.NextFeature
Loop
```

B.1.6 Check regularity of parcels

```
Dim pFeature As IFeature
Set pFeature = pFCursor.NextFeature

Do Until pFeature Is Nothing
    FID = pFeature.Value(intposFID)
    CenX = GetParcelCenX(pFeature)
    CenY = GetParcelCenY(pFeature)

    pFilter.WhereClause = "FID=" & FID
    pActiveView.PartialRefresh esriViewGeoSelection, Nothing, Nothing
    Set pPoly = pFeature.Shape
    Set pEnumVertices = pPoly.EnumVertices

    'Calculate the variance and then standard deviation
    For j = 0 To pPoly.PointCount - 1
        pEnumVertices.Next pPoint, outIndex, verIndex
        Pointx = pPoint.x
        PointY = pPoint.Y
        'Find the distanvce beteen the centroid and a point of the parcel
        Dist = Sqr(((Pointx - CenX) ^ 2) + ((PointY - CenY) ^ 2))
```

```
                'Get the mean distance of all distnaces from points to parcel centroid
                MeanDist = GetParcelMeanDist(FID)
                DRadials = DRadials + ((Dist - MeanDist) ^ 2)
                Counter = Counter + 1
                Dist = 0
                Pointx = 0
                PointY = 0
        Next j
        Sdeviation = Sqr(DRadials / (Counter - 1))
        'Store S.D in the field
        'MsgBox Sdeviation
        pFeature.Value(intPosSDRadials) = Sdeviation
        pFCursor.UpdateFeature pFeature
        Counter = 0
        SumDist = 0
        MeanDist = 0
        DRadials = 0
        Sdeviation = 0
        Set pFeature = pFCursor.NextFeature
Loop
```

B.2 LandSpaCES Design module

B.2.1 The Main Flowchart rule cluster procedure

```
'Start the loop through Owners-Ownership-OriginalParcel tables
Call CalculatePPI
Set pOwnersRow = pOwnersCursor.NextRow
Do Until pOwnersRow Is Nothing
'Get relation1
        Set pDataSetRel = pRelClass1
        Set pRelSet1 = pRelClass1.GetObjectsRelatedToObject(pOwnersRow)
        pRelSet1.Reset
Set pOwnershipRow = pRelSet1.Next
Do Until pOwnershipRow Is Nothing
 'Get relation2
        Set pDataSetRel2 = pRelClass2
        Set pRelSet2 = pRelClass2.GetObjectsRelatedToObjectSet(pRelSet1)
        pRelSet2.Reset
Set pFeature = pRelSet2.Next
Do Until pFeature Is Nothing
‘Rule 1
    If _
      pOwnersRow.value(intPosTotalAreaField) < CDbl(InputFacts.txtCommMinArea) _
```

```
        And pOwnersRow.value(intPosTotalValueField) < CDbl(InputFacts.txtCommMinValue) _
        And pFeature.value(intPosException) = "NO" Then
        pOwnersRow.value(intPosReceiveField) = "NO"
        pOwnersRow.Store
      End If
'Rule 2
     If _
        pOwnersRow.value(intPosCompletionField) = "NO" _
        And pFeature.value(intPosException) = "NO" Then
        pOwnersRow.value(intPosReceiveField) = "NO"
        pOwnersRow.Store
      End If
'Rule 3
     If _
        pOwnersRow.value(intPosTotalAreaField) >= CDbl(InputFacts.txtCommMinArea) _
        Or pOwnersRow.value(intPosTotalValueField) >= CDbl(InputFacts.txtCommMinValue) _
        And pOwnersRow.value(intPosTotalAreaField) >= CDbl(InputFacts.txtLawMinArea) Then
        pOwnersRow.value(intPosReceiveField) = "YES"
        pOwnersRow.Store
      End If
'Rule 4
     If _
        pOwnersRow.value(intPosCompletionField) = "YES" _
        And pOwnersRow.value(intPosTotalAreaField) >= CDbl(InputFacts.txtCommMinArea) _
        And pOwnersRow.value(intPosTotalAreaField) <= CDbl(InputFacts.txtLawMinArea) Then
        pOwnersRow.value(intPosReceiveField) = "YES"
        pOwnersRow.Store
      End If
'Rule 5
     If _
        pOwnersRow.value(intPosCompletionField) = "YES" _
        And pOwnersRow.value(intPosTotalValueField) >= CDbl(InputFacts.txtCommMinValue) _
        And pOwnersRow.value(intPosTotalAreaField) <= CDbl(InputFacts.txtLawMinArea) Then
        pOwnersRow.value(intPosReceiveField) = "YES"
        pOwnersRow.Store
      End If
'Rule 6
     If _
        pOwnersRow.value(intPosCompletionField) = "NO" _
        And pOwnersRow.value(intPosTotalAreaField) >= CDbl(InputFacts.txtCommMinArea) _
        And pOwnersRow.value(intPosTotalAreaField) <= CDbl(InputFacts.txtLawMinArea) Then
        pOwnersRow.value(intPosReceiveField) = "NO"
        pOwnersRow.Store
      End If
'Rule 7
     If _
```

```
pOwnersRow.value(intPosCompletionField) = "NO" _
And pOwnersRow.value(intPosTotalValueField) >= CDbl(InputFacts.txtCommMinValue) _
And pOwnersRow.value(intPosTotalAreaField) <= CDbl(InputFacts.txtLawMinArea) Then
pOwnersRow.value(intPosReceiveField) = "NO"
pOwnersRow.Store
End If
'Rule 8
If _
pOwnersRow.value(intPosReceiveField) = "NO" Then
pFeature.value(intPosEliminate) = "YES"
 pFeature.Store
End If
Set pFeature = pRelSet2.Next
Loop
Set pOwnershipRow = pRelSet1.Next
 Loop
Set pOwnersRow = pOwnersCursor.NextRow
Loop
```

B.2.2 The Flowchart B2 rule cluster procedure

```
'Start the loop through Owners-Ownership-OriginalParcel tables
Set pOwnersRow = pOwnersCursor.NextRow

Do Until pOwnersRow Is Nothing
    'Get relation1
    'Update PPI values for the current land owner
    Dim OwnerID As Double
    OwnerID = pOwnersRow.value(intPosOwnersField)
    Call UpdatePPIs(OwnerID)
    Set pDataSetRel = pRelClass1
    Set pRelSet1 = pRelClass1.GetObjectsRelatedToObject(pOwnersRow)
    pRelSet1.Reset
    Set pOwnershipRow = pRelSet1.Next

    Do Until pOwnershipRow Is Nothing
        'Get relation2
         Set pDataSetRel2 = pRelClass2
         Set pRelSet2 = pRelClass2.GetObjectsRelatedToObjectSet(pRelSet1)
        Dim pArray As IArray
        Dim pFeature As IFeature
        Dim pFeature2 As IFeature
        Dim lFldIdx As Long
        Dim bInserted As Boolean
        Dim f As Long
```

```
' The field no to sort the features
lFldIdx = intPosPPI

' Setup a new array to hold the sorted features
Set pArray = New esriSystem.Array

' Loop through the features in the Set and use an Insert Sort
' to add them to the Array
pRelSet2.Reset
Set pFeature = pRelSet2.Next
While Not pFeature Is Nothing
   bInserted = False
For f = 0 To pArray.count - 1
        Set pFeature2 = pArray.Element(f)
         If pFeature2.value(lFldIdx) < pFeature.value(lFldIdx) Then
                pArray.Insert f, pFeature
                bInserted = True
                Exit For
        End If
Next f

If Not bInserted Then pArray.Add pFeature
   Set pFeature = pRelSet2.Next
Wend

' Now we can loop through the array and the features will be sorted in descending
' order of the specified field no. lFldIdx

For f = 0 To pArray.count - 1
   Set pFeature = pArray.Element(f)

'Apply Flowchart B2
   If _
      pOwnersRow.value(intPosNumParcelsField) > 1 _
      And pOwnersRow.value(intPosMaxNumParField) = 1 _
      And pOwnersRow.value(intPosReceiveField) = "YES" Then
      'Get the OwnerID
      Dim o As Double
      o = pOwnersRow.value(intPosOwnersField)

      Dim ParcelID As String
      ParcelID = pFeature.value(intPosParcelID)

      Dim dblShareFactor As Double
      dblShareFactor = GetShareFactor(o, ParcelID)
```

```
        'Get the the OriginalArea owned(A) and calculate the new area (NewA)
        Dim a As Double
        Dim NewA As Double
        a = pOwnersRow.value(intPosTotalAreaField)
        NewA = Round(Calculations.CalculateNewOwnerArea(a), 2)
  ' RULE 1
        If NewA < InputFacts.txtLawMinArea Then
        NewA = InputFacts.txtLawMinArea

        'Get the the OriginalValue owned(V) and calculate the new area (NewV)
        Dim V As Double
        Dim NewV As Double
        V = pOwnersRow.value(intPosTotalValueField)
        NewV = Round(Calculations.CalculateNewOwnerValue(V), 2)

        'Get the max num of parcels may received by a land owner
        intMaxNumPar = pOwnersRow.value(intPosMaxNumParField)

'Call GetCenX and GetCenY functions to get the coordinates of the centroids
Dim CoorX As Double
Dim CoorY As Double
CoorX = CreateParcelsCentroids.GetCenX(pFeature)
CoorY = CreateParcelsCentroids.GetCenY(pFeature)

'Find the BlockID in whcih that Parcel-Centroid belongs to
Dim BlockID As Integer
BlockID = CreateParcelsCentroids.GetBlockIDofParcels(pFeature)

'Sum the Area of all NEWPARCELS belongs to that Block to estimate the current occupied
area
Dim CurrentBlockArea As Double
CurrentBlockArea = SumBlockArea(BlockID)

'Call Function TotalBlockArea to get the total area of a block
Dim AvailableBlockArea As Double
AvailableBlockArea = GetBlockArea(BlockID) - CurrentBlockArea

'Get the PPI of the parcel
Dim PPI As Double
PPI = pFeature.value(intPosPPI)
Dim ParcelArea As Double
ParcelArea = pFeature.value(intPosArea) * dblShareFactor
Dim ParcelValue As Double
ParcelValue = pFeature.value(intPosValue) * dblShareFactor

'Check if there is available area to locate the parcels
```

```
Dim NoParcels As Integer
NoParcels = 0
 'RULE 2
  If NewA <= AvailableBlockArea Then

   'Check if the number of parcels received by an owner reach the maximum accepatble
   'and stop the process

      'Create the new records in the NEWPARCELSLS table
      Call AddRecNewParcelLS(NewA, NewV, CoorX, CoorY, BlockID, PPI)

      'Create the new records in the NEWPARCELSLS table
      Call AddRecNewOwnershipLS(o)

      'Call the CreateLabelPoints procedure to create the centroids on the map
      Call CreateParcelsCentroids.CreateLabelPoints(pFeature, o)

         NoParcels = NoParcels + 1
'RULE 3
         If NoParcels = intMaxNumPar Then

         Exit For 'i.e. Exit Loop of parcels

         End If
  'RULE 4
   ElseIf NewA > AvailableBlockArea Then
  'i.e. if there is not available area in that Block
  'Get the minPPI value for the certain block
         Dim minPPI As Double
         minPPI = GetMinBlockPPI(BlockID)


      If PPI > minPPI Then
      Dim FlagP As Boolean
      FlagP = True
      Call Reallocation(BlockID, PPI, NewA, NewV, CoorX, CoorY, o, pFeature, NoParcels,
FlagP)
    'RULE 5
      If FlagP = False Then
            'Check if there is available land in the next parcels'BlockID
             Call GetNextBlockID(o, BlockID, NewA)
    'RULE 6
             Call AddRecNewParcelLS(NewA, NewV, 0, 0, BlockID, 0)
             Call AddRecNewOwnershipLS(o)  'Get a BlockID which has availabe land for the
NewParcel
      End If
```

```
                    If NoParcels = intMaxNumPar Then
                      Exit For 'i.e. Exit Loop of parcels
                    End If

                     End If
                  End If
                End If
              End If

              NextParcel:
              Next f
                ' Clean up the array
                pArray.RemoveAll
                Set pArray = Nothing

              Set pOwnershipRow = pRelSet1.Next
        Loop
        Set pOwnersRow = pOwnersCursor.NextRow
Loop
```

B.3 LandSpaCES Evaluation module

B.3.1 Calculate the parcel concentration coefficient (*PCC*)

```
Set pOwnersRow = pOwnersCursor.NextRow
Do Until pOwnersRow Is Nothing
        'Get relation1
        If pOwnersRow.Value(intPosReceiveField) = "YES" Then
              DoP = pOwnersRow.Value(intPosDOP)
              NewDop = pOwnersRow.Value(intPosNewDOP)
              OwnerID = pOwnersRow.Value(intPosOwnerID)
              NumParLS = GetNumParLS(Altern, OwnerID)

              If NumParLS = 0 Then
                GoTo NextLandOwner
                End If

                If DoP = NewDop Then
                PCC = 0
                End If

                If DoP > NewDop Then
                PCC = ((DoP - NewDop) / DoP) / NumParLS
                End If

                If DoP < NewDop Then
```

```
                PCC = -((NewDop - DoP) / NewDop) / NumParLS
                End If
        End If
        pOwnersRow.Value(intPosPCC) = PCC
        pOwnersRow.Store
        NextLandOwner: Set pOwnersRow = pOwnersCursor.NextRow
Loop
```

B.3.2 Calculate the landowner satisfaction rate (*LSR*)

```
Set pOwnersRow = pOwnersCursor.NextRow
Do Until pOwnersRow Is Nothing
        check1 = CheckOwnerID(tablename1, OwnerID)
        If check1 = False Then
        Exit Sub
        End If
        Set pDataSetRel = pRelClass1
        Set pRelSet1 = pRelClass1.GetObjectsRelatedToObject(pOwnersRow)
        pRelSet1.Reset
        Set pOwnershipRow = pRelSet1.Next
                Do Until pOwnershipRow Is Nothing
                 'Get relation2
                 Set pDataSetRel2 = pRelClass2
                 Set pRelSet2 = pRelClass2.GetObjectsRelatedToObjectSet(pRelSet1)
                 If OwnerID <> pOwnershipRow.Value(intPosOwnerID) Then
                Exit Sub
                End If

                Dim Counter As Integer
                Counter = 0
                 Set pNewParcelsRow = pRelSet2.Next
                        Do Until pNewParcelsRow Is Nothing
                                Counter = Counter + 1
                                NumPar = pOwnersRow.Value(intPosNumParField)
                                NumParLS = GetNumParLS(Altern, OwnerID)
                                p = GetPvalue(Altern, OwnerID)
                                Ro = pNewParcelsRow.Value(intPosRO)
                                p2 = 100 / p

                                If Ro = 0 Then
                                GoTo NextParcel
                                End If

                                If NumPar > NumParLS And Counter <= NumParLS Then
```

```
                m = p2
                End If

                If NumPar > NumParLS And Counter > NumParLS Then
                m = NumPar - Ro + 1
                End If

                If NumPar <= NumParLS Then
                m = p2
                End If

                Sumofm = Sumofm + m

            NextParcel: Set pNewParcelsRow = pRelSet2.Next
             Loop
          Set pOwnershipRow = pRelSet1.Next
         Loop

    LSR = Round(((Sumofm * p) / NumParLS), 2)
    pOwnersRow.Value(intPosLSRField) = LSR
    pOwnersRow.Store
    Sumofm = 0
    Counter = 0
    Set pOwnersRow = pOwnersCursor.NextRow
Loop
```

B.4 LandParcelS module

B.4.1Check if a centroid is within a land block

```
Dim pGeom As IGeometry
Set pGeom = pFeature.Shape

Dim pSpatialFilter As ISpatialFilter
Set pSpatialFilter = New SpatialFilter

With pSpatialFilter
 Set .Geometry = pGeom
  .GeometryField = "Shape"
  .SpatialRel = esriSpatialRelWithin
End With
Dim pNEWPARCELSFC As IFeatureClass
Set pNEWPARCELSFC = pNEWPARCELS.FeatureClass

Dim pNewParcelsCursor As IFeatureCursor
```

```
Set pNewParcelsCursor = pNEWPARCELSFC.Search(pSpatialFilter, False)

Dim pNewParcelFeature As IFeature
Set pNewParcelFeature = pNewParcelsCursor.NextFeature

Dim pNewParcelsFields As IFields
Set pNewParcelsFields = pNEWPARCELSFC.Fields

Dim pRelOp As IRelationalOperator
Set pRelOp = pGeom

Do Until pNewParcelFeature Is Nothing

    Set pNewParcelFeature = pNewParcelsCursor.NextFeature
 Loop
```

B.4.2 Check if there are common centroids

```
Set pFeature = pFCursor.NextFeature
Do Until pFeature Is Nothing
        Counter = Counter + 1
        Set pPointA = pFeature.Shape
        Xa = pPointA.x
        Ya = pPointA.Y

        Set pFCursor2 = pFeatureClass.Search(Nothing, True)
        Set pFeature2 = pFCursor2.NextFeature

        Do Until pFeature2 Is Nothing

                If pFeature2.Value(intposFID) <= Counter Then
                        GoTo NextItem
                        Else
                        Set pPointB = pFeature2.Shape
                        Xb = pPointB.x
                        Yb = pPointB.Y
                        ParcelID = pFeature2.Value(intPosParcelID)
                        ParcelArea = GetArea(ParcelID)

                        If Xa = Xb And Ya = Yb Then
                        Call MoveCommonPoints(BlockID)
                        End If
                End If
                NextItem: Set pFeature2 = pFCursor2.NextFeature
        Loop
```

```
        Xa = 0
        Ya = 0
        Xb = 0
        Yb = 0
         Set pActiveView = pMap
         pActiveView.Refresh
        Set pFeature = pFCursor.NextFeature
Loop
```

B.4.3 Create an Euclidean distance raster, get the max value and create a new centroid

```
Dim GP As Object
Set GP = CreateObject("esriGeoprocessing.GpDispatch.1")
 'Set the toolbox
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx"

'Create the Euclidean distance raster
GP.EucDistance_sa "C:\LACONISS\LandSpaCES\CentroidsB" & BlockID & ".shp", _
"C:\LACONISS\LandSpaCES\EucDI" & BlockID & ".img"
GP.ExtractByMask_sa "C:\LACONISS\LandSpaCES\EucDI" & BlockID & ".img", _
"C:\LACONISS\LandSpaCES\LandBlock" & BlockID & ".shp", "C:\LACONISS\LandSpaCES\EucDRaster" &
BlockID & ".img"
'Get the max cell value and create a new centroid on that location
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument

Dim pMap As IMap
Set pMap = pMxDoc.FocusMap

Dim pActiveView As IActiveView
Set pActiveView = pMxDoc.FocusMap

Dim strRasterName1 As String
strRasterName1 = "EucDRaster" & BlockID

Dim strRasterName2 As String
strRasterName2 = "EucDI" & BlockID

Dim i As Integer
Dim pRLayer As IRasterLayer
```

```
    For i = 0 To pMxDoc.ActivatedView.FocusMap.LayerCount - 1

    If pMxDoc.FocusMap.Layer(i).Name = strRasterName1 Then
        Set pRLayer = pMxDoc.FocusMap.Layer(i)
    End If
    Next i
Dim pRaster As IRaster2
Set pRaster = pRLayer.raster
Dim pLayers As IEnumLayer
Set pLayers = pMap.Layers

'Get the layer
Dim pLayer As ILayer
Set pLayer = pLayers.Next
Do Until pLayer Is Nothing
    If pLayer.Name = "CentroidsB" & BlockID Then
        Exit Do
    End If
    Set pLayer = pLayers.Next
Loop
'Get the feature class
Dim pFeatureLayer As IFeatureLayer
Set pFeatureLayer = pLayer
Dim pFeatureClass As IFeatureClass
Set pFeatureClass = pFeatureLayer.FeatureClass
Dim pFields As IFields
Set pFields = pFeatureClass.Fields
'Check if there is already a the above field name
Dim intPosAreaField As Integer
intPosAreaField = pFields.FindField("Area")

If intPosAreaField = -1 Then
        ' QI to IFieldEdit to set the field's properties
            Dim pAreaFieldEdit As IFieldEdit
            Set pAreaFieldEdit = New Field
        'Set the properties of the new field
            With pAreaFieldEdit
                .Name = "Area"
                .AliasName = "Area"
```

```
            .Type = esriFieldTypeDouble
            .Length = 8
        End With

        pFeatureClass.AddField pAreaFieldEdit
End If
intPosAreaField = pFields.FindField("Area")

Dim intPosParcelID As Integer
intPosParcelID = pFields.FindField("Parcel_ID")

Dim intposValue As Integer
intposValue = pFields.FindField("Value")


Dim intPosOwnerID As Integer
intPosOwnerID = pFields.FindField("Owner_ID")

'Loop though all pixels in the raster
Dim pInputBandCol As IRasterBandCollection
Set pInputBandCol = pRaster

Dim pInputBand As IRasterBand
Set pInputBand = pInputBandCol.Item(0)

Dim pInputRasProps As IRasterProps
Set pInputRasProps = pInputBand

Dim IWidth As Double
Dim IHeight As Double
IWidth = pInputRasProps.Width
IHeight = pInputRasProps.Height

Dim pInputRawPixel As IRawPixels
Set pInputRawPixel = pInputBand

Dim pPnt As IPnt
Set pPnt = New DblPnt
pPnt.x = IWidth
pPnt.Y = IHeight
pPnt.SetCoords IWidth, IHeight

Dim pInputBlock As IPixelBlock
Set pInputBlock = pInputRawPixel.CreatePixelBlock(pPnt)

Dim pTLC As IPnt
Set pTLC = New DblPnt
```

```
pTLC.x = 0
pTLC.Y = 0
pInputRawPixel.Read pTLC, pInputBlock

Dim col As Long
Dim row As Long
Dim Xout As Double
Dim Yout As Double
Dim MaxValue As Single
MaxValue = Round(FindRasterMaxValue(BlockID), 0)

For col = 0 To pInputRasProps.Width - 1
        For row = 0 To pInputRasProps.Height - 1
                Dim rawVal As Long
                rawVal = pInputBlock.GetVal(0, col, row)
                If rawVal = MaxValue Then

                    Dim pCen As IPoint
                    Set pCen = New Point
                    pRaster.PixelToMap col, row, Xout, Yout
                    pCen.x = Xout
                    pCen.Y = Yout
                    pCen.PutCoords Xout, Yout
                    Exit For
                End If
        Next row
Next col
Dim pFeature As IFeature
Set pFeature = pFeatureClass.CreateFeature

Set pFeature.Shape = pCen
pFeature.Value(intPosAreaField) = GetResBlockArea(BlockID)
pFeature.Value(intPosParcelID) = 1000
pFeature.Value(intPosOwnerID) = 1111
pFeature.Store
```

B.4.4 Generation of a random population

```
Dim GP As Object
Set GP = CreateObject("esriGeoprocessing.GpDispatch.1")

'Set the toolbox
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx"
GP.Extent = "144566.589424817 351191.130242809 145772.160174817 353810.742942809"
```

```
'Select block
GP.Select_analysis "C:\LACONISS\LandSpaCES\LandBlocks.shp", _
"C:\LACONISS\LandSpaCES\LandBlock" & BlockID & ".shp", "Block_ID =" & BlockID
'Clip centroids
GP.Clip_analysis "C:\LACONISS\LandSpaCES\ParcelsCentroids3.shp", _
"C:\LACONISS\LandSpaCES\LandBlock" & BlockID & ".shp", "C:\LACONISS\LandSpaCES\CentroidsB" &
BlockID & ".shp"
'Create a new centroid in the Centroids table representing the unallocated area of a block
Call CreateNewCentroid(BlockID)
Call CheckAndMoveCommonPoints(BlockID)

Dim i As Integer
i = 0
Dim intpopNo As Integer
intpopNo = CInt(PopNo)
Dim strPop As String
strPop = CStr(PopNo)
Dim stri As String
Call CreateGenerationFitnessTable
Dim SolNo As Integer
Dim F1 As Double
Dim F2 As Double
Dim F3 As Double
Dim Fitness As Double
Dim NumCen As Integer

'Loop through many population members
For i = 1 To PopNo
        If i = 1 Then
                'Avoid random movement to get the initial stage of points
                stri = CStr(i)
                GP.CreateThiessenPolygons_analysis "C:\LACONISS\LandSpaCES\CentroidsB" &
                BlockID & ".shp", _
                  "C:\LACONISS\LandSpaCES\Thiessen" & BlockID & "_" & i & ".shp", "ONLY_FID"
                  'Create a sorted Thiessen file
                  UpdateCentroidsB (BlockID)
                  'Clip Thiessen with LandBlock
                   GP.Clip_analysis "C:\LACONISS\LandSpaCES\Thiessen" & BlockID & "_" & i & ".shp",
                _
                  "C:\LACONISS\LandSpaCES\LandBlock" & BlockID & ".shp",
                "C:\LACONISS\LandSpaCES\VectorB" & BlockID & "_" & i & ".shp"
                NumCen = GetNumCentroids(BlockID)
```

```
            If NumCen = 1 Then
            Call UpdateVector2B(BlockID)
            Else
            Call UpdateVector3B(BlockID, stri)
            Call UpdateVector3BValue(BlockID, stri)
            End If

            SolNo = i
            F1 = GetF1(BlockID, stri)
            F2 = GetF2(BlockID, stri)
            F3 = GetF3(BlockID, stri)
            Fitness = GetFitness(BlockID, stri)
            Call UpdateGFitnessTable(PopNo, BlockID, SolNo, F1, F2, F3, Fitness)
            Call DeleteFCclass2("Thiessen", BlockID, stri)
            GoTo Nextpop
        End If

        stri = CStr(i)
        Call RandomMovement(BlockID)
        GP.CreateThiessenPolygons_analysis "C:\LACONISS\LandSpaCES\CentroidsB" & BlockID &
        ".shp", _
        "C:\LACONISS\LandSpaCES\Thiessen" & BlockID & "_" & i & ".shp", "ONLY_FID"
        UpdateCentroidsB (BlockID)

        'Clip Thiessen with LandBlock
        GP.Clip_analysis "C:\LACONISS\LandSpaCES\Thiessen" & BlockID & "_" & i & ".shp", _
        "C:\LACONISS\LandSpaCES\LandBlock" & BlockID & ".shp",
        "C:\LACONISS\LandSpaCES\VectorB" & BlockID & "_" & i & ".shp"
        NumCen = GetNumCentroids(BlockID)

        If NumCen = 1 Then
           Call UpdateVector2B(BlockID)
           Else
           Call UpdateVector3B(BlockID, stri)
           Call UpdateVector3BValue(BlockID, stri)
        End If

        SolNo = i
        F1 = GetF1(BlockID, stri)
        F2 = GetF2(BlockID, stri)
        F3 = GetF3(BlockID, stri)
        Fitness = GetFitness(BlockID, stri)
        Call UpdateGFitnessTable(PopNo, BlockID, SolNo, F1, F2, F3, Fitness)

        Nextpop:
    Next i
```

B.4.5 Apply crossover operator

```
Dim GP As Object
Set GP = CreateObject("esriGeoprocessing.GpDispatch.1")
GP.SetProduct "ArcInfo"

'Set the toolbox
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx"
GP.AddToolbox "C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx"
GP.Workspace = "C:\LACONISS\LandSpaCES"
GP.Extent = "144566.589424817 351191.130242809 145772.160174817 353810.742942809"

Dim Output_Feature_Class As String
Dim Thiessens As String
Dim LandBlock As String
Dim strPopNo As String
strPopNo = CStr(PopNo)

GP.CreateThiessenPolygons_analysis "C:\LACONISS\LandSpaCES\CentroidsB" & BlockID & ".shp", _
"C:\LACONISS\LandSpaCES\Thiessen" & BlockID & "_" & GenNo & PopNo & ".shp", "ONLY_FID"
UpdateCentroidsB (BlockID)
Output_Feature_Class = "C:\LACONISS\LandSpaCES\VectorB" & BlockID & "MM" & "_" & PopNo & ".shp"
Thiessens = "Thiessen" & BlockID & "_" & GenNo & PopNo
LandBlock = "LandBlock" & BlockID

' Process: Clip...
GP.Clip_analysis Thiessens, LandBlock, Output_Feature_Class, ""

Call UpdateVector3BMM(BlockID, strPopNo)
Call UpdateVector3BValueMM(BlockID, strPopNo)
Call RenameMMfile("VectorB", BlockID, strPopNo, strPopNo)
```

B.4.6 Apply mutation operator

```
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument

'Get the active map (data frame)
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap

Dim UpperBound As Integer
Dim LowerBound As Integer
Dim i As Integer
UpperBound = NumLayers
```

```
LowerBound = 1
Dim RndNo As Integer
Dim Check As Boolean
Dim strRndNo As String

If MutationNo = 1 Then
     ReRandom1:
    RndNo = Int((UpperBound - LowerBound + 1) * Rnd + LowerBound)
    'Check mutation table to see if a solutaion has been selected again for mutation
    strRndNo = CStr(RndNo)
    'Select Big or Small mutation
    Call MutationMoveCentroids(BlockID, RndNo)
    Call DeleteFCclass2("VectorB", BlockID, strRndNo)
    Call CreateMutationSolution(BlockID, RndNo, k)
    Call UpdateMutationTable(RndNo)
End If

If MutationNo > 1 Then
     For i = 1 To MutationNo
       ReRandom2:
       RndNo = Int((UpperBound - LowerBound + 1) * Rnd + LowerBound)
       strRndNo = CStr(RndNo)
       Check = CheckMutationTable(RndNo)
       If Check = True Then
       GoTo ReRandom2
       End If

       Call MutationMoveCentroids(BlockID, RndNo)
       Call DeleteFCclass2("VectorB", BlockID, strRndNo)
       Call CreateMutationSolution(BlockID, RndNo, k)
       Call UpdateMutationTable(RndNo)
     Next i
End If
```

B.4.7 Create a new generation

```
For k = 1 To GenNo '(Number of generations)
      Call CreateMPtable1(RestMatingPop)
      Call CreateMPtable2
      Call CreateElistismPool(BlockID, ElitismPop)
      Call DeleteFitnessTable("G")
      Call CreateMatingPool1Elit(BlockID, ElitismPop, RestMatingPop)
      Call CreateMatingPool2Elit(BlockID, ElitismPop, RestMatingPop, NumLayers)
      Call CreateMatingTable
      Call CreateGenerationFitnessTable
      Call CreateMutationTable
```

```
UpperBound = NumLayers
LowerBound = 1
j = NumLayers

For i = 1 To j
        ReRandom:
        Mp1 = Int((UpperBound - LowerBound + 1) * Rnd + LowerBound)
        MP2 = Int((UpperBound - LowerBound + 1) * Rnd + LowerBound)

        If Mp1 = MP2 Then
        GoTo ReRandom
        End If

        Sol1 = GetSol(Mp1)
        Sol2 = GetSol(MP2)

        If Sol1 = Sol2 Then
        GoTo ReRandom
        End If

        Dim strSol1 As String
        Dim strSol2 As String
        Dim strMP1 As String
        Dim strMP2 As String
        Dim stri As String
        Dim strk As String
        strSol1 = CStr(Sol1)
        strSol2 = CStr(Sol2)
        strMP1 = CStr(Mp1)
        strMP2 = CStr(MP2)
        strk = CStr(k)

        If i = 1 Then
                stri = CStr(i)
                Call MoveCentroidsonBLXpoints(BlockID, strSol1, strSol2, strMP1, strMP2)
                Call CreateCrossOverSolution(BlockID, strSol1, strSol2, strMP1, strMP2, k, i)
                Call UpdateMatingTable(Mp1, MP2, Sol1, Sol2)
                Call DeleteFCclass3("Thiessen", BlockID, strk, stri)
                F1 = GetF1(BlockID, stri)
                F2 = GetF2(BlockID, stri)
                F3 = GetF3(BlockID, stri)
                Fitness = GetFitness(BlockID, stri)
                Call UpdateGFitnessTable(k, BlockID, i, F1, F2, F3, Fitness)
        End If

        If i > 1 Then
```

```
                stri = CStr(i)
                check2 = CheckMatingTable(Mp1, MP2, Sol1, Sol2)
                        If check2 = True Then
                        GoTo ReRandom
                         Else
                         'Get sol1 and sol2 for mp1 and mp2 from the MPtable2 respectively
                        Call MoveCentroidsonBLXpoints(BlockID, strSol1, strSol2, strMP1, strMP2)
                        Call CreateCrossOverSolution(BlockID, strSol1, strSol2, strMP1, strMP2, k, i)
                        Call UpdateMatingTable(Mp1, MP2, Sol1, Sol2)
                        Call DeleteFCclass3("Thiessen", BlockID, strk, stri)
                        F1 = GetF1(BlockID, stri)
                        F2 = GetF2(BlockID, stri)
                        F3 = GetF3(BlockID, stri)
                        Fitness = GetFitness(BlockID, stri)
                        Call UpdateGFitnessTable(k, BlockID, i, F1, F2, F3, Fitness)
                        End If
                End If
                  Sol1 = 0
                  Sol2 = 0
         Next i

        minF1 = GetminF1
        maxF1 = GetmaxF1
        meanF1 = GetmeanF1
        minF2 = GetminF2
        maxF2 = GetmaxF2
        meanF2 = GetmeanF2
        minF3 = GetminF3
        maxF3 = GetmaxF3
        meanF3 = GetmeanF3
        minFitness = GetminFitness
        OFitness = GetOFitness
        Call UpdateOFitnessTable(0, k, minF1, maxF1, meanF1, minF2, maxF2, meanF2, _
        minF3, maxF3, meanF3, minFitness, OFitness)

        pFitness = GetLastFitness(k - 1)
        dFitness = Abs(OFitness - pFitness)
        MutationNo = 0.05 * NumLayers

        If MutationNo < 1 Then
        MutationNo = 1
        End If

        If k <> GenNo Then
        Call MutationOperator(BlockID, MutationNo, NumLayers, k)
        End If
```

```
        Call DeleteMPtables("1")
        Call DeleteMPtables("2")
        Call DeleteLayersMP("VectorB", BlockID)
        Call DeleteTable("MatingTable")
        Call DeleteTable("MutationTable")
        dFitness = 0
Next k
```

Biographical Notes

Dr. Demetris Demetriou is a Land Consolidation Officer in the Department of Land Consolidation in Cyprus and a Visiting Research Fellow in the School of Geography, University of Leeds (UK). He holds a Diploma (Eng.) in Rural and Surveying Engineering from the Aristotle University of Thessaloniki (Greece) and three postgraduate qualifications from the University of Leeds: an MSc (Eng.) in Transport Planning and Engineering; an MSc in Geographical Information Systems (GIS) and a PhD in Geographical Information Science. He has authored a series of journal articles, book chapters and conference papers and is a reviewer for several international journals. His main research interests are in land management; land consolidation; land administration systems; GIS; Planning Support Systems (PSS); Spatial Decision Support Systems (SDSS); and artificial intelligence techniques and multi-criteria decision methods (MCDM) and their integration with GIS.

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2, © Springer International Publishing Switzerland 2014

Index

D. Demetriou, *The Development of an Integrated Planning and Decision Support System (IPDSS) for Land Consolidation*, Springer Theses,
DOI: 10.1007/978-3-319-02347-2, © Springer International Publishing Switzerland 2014

W

Z