LACONISS: A LAnd CONsolidation Integrated Support System for Planning and Decision Making

Demetris Demetriou

Summary

This paper presents an Integrated Planning and Decision Support System (IPDSS) for land consolidation called LACONISS that integrates artificial intelligence techniques, namely expert systems and genetic algorithms, with multi-criteria decision making methods and a geographical information system. The system involves four modules: LandFragmentS for measuring land fragmentation in an agricultural context; a LandSpaCES Design module for automating land redistribution; a LandSpaCES Evaluation module for assessing alternative land redistribution plans and; LandParcelS for automating land partitioning. The whole system has been applied to a case study area in Cyprus. The results have shown that LandFragmentS is more reliable than existing methods; the LandSpaCES Design module can successfully emulate planners' reasoning and rapidly produce alternative land redistribution plans; the LandSpaCES Evaluation module is a flexible tool for identifying the most beneficial plan; and LandParcelS produces realistic results. The contribution of LACONISS is relevant to both planners and landowners as it transforms land reallocation into a systematic, automated, transparent and efficient process that may alleviate current problems associated with this process. Eventually, LACONISS may constitute the foundations for developing a generic system that could be applied in any country that implements land consolidation plans.

Zusammenfassung

Der Artikel stellt ein integriertes Planungs- und Entscheidungsunterstützungssystem für die Flurbereinigung vor, genannt LACONISS. Das neue System verbindet künstliche Intelligenztechniken, namentlich Expertensysteme und generische Algorithmen, mit multi-kriteriellen Entscheidungsmethoden sowie einem Geografischen Informationssystem. Das System enthält vier Module: ein LandFragmentS Modul zum Bestimmen der Besitzzersplitterung bei landwirtschaftlichen Grundstücken, ein LandSpaCES Design Modul zur automatischen Neuverteilung der Landabfindungen, ein LandSpaCES Evaluation Modul zur Überprüfung alternativer Neuverteilungspläne sowie ein LandParcelS Modul zur automatischen Aufteilung der Grundstücke. Das neue System wurde in einer Fallstudie auf ein Flurbereinigungsprojekt in Zypern angewendet. Die Ergebnisse haben gezeigt, dass das Modul LandFragmentationS zu verlässlicheren Ergebnissen führt als die bisherigen Methoden. Das LandSpaCES Design Modul kann erfolgreich die planerischen Erwägungen nachvollziehen und rasch alternative Zuteilungspläne erarbeiten. Das LandSpaCES Evaluation Modul ist ein flexibles Werkzeug den vorteilhaftesten Plan auszumachen. Der LandParcelS Modul erzeugt realistische Ergebnisse. Das System LACONISS ist von Bedeutung für Planer und Landeigentümer gleichermaßen, weil es den Neuordnungsvorgang in einem systematischen, automatisierten, transparenten und effizienten Prozess nachbildet, und könnte die gegenwärtig mit der Neuverteilung verbundenen Probleme verringern. LACONISS kann möglicherweise die Grundlage für die Entwicklung eines allgemeinen IT-Systems darstellen, welches auch in anderen Ländern zur Aufstellung von Flurbereinigungsplänen angewendet werden könnte.

Keywords: land consolidation, land reallocation, GIS, expert systems, genetic algorithms, multi-criteria decision methods

1 Introduction

Land fragmentation (e.g. McPherson 1982, Van Dijk 2003) in an agricultural context implies a defective land tenure structure that in many cases may inhibit rational agricultural development and rural sustainable development more generally (Demetriou et al. 2012e). Fragmentation is a frequent occurrence in various parts of the world including European Union (EU27) countries. Decisions for applying certain land management measures to control fragmentation usually involve undertaking a land fragmentation study, an environmental impact assessment study and a feasibility study. The outcome of the former can be represented by an appropriate index. However, at present, there is no standard algorithm or methodology for measuring land fragmentation (Bentley 1987, Van Hung et al. 2007). A variety of indices have been developed in the past (Edwards 1961, Simmons 1964, Dovrin 1965, Januszewski 1968, Igbozurike 1974, Schmook 1976) among which the most popular are those of Simmons and Januszewski but they present significant drawbacks (Demetriou et al. 2012e). As a result, existing indices cannot adequately represent the phenomenon and hence their outcome can be misleading, resulting in suboptimal decisions. Therefore, it is clear that there is a need for a new and more reliable methodology for measuring land fragmentation.

On the other hand, land consolidation, which began in Europe in the 14th century (Van Dijk 2003, Uimonen 2004), is considered to be the most favoured land management response to the problem of land fragmentation. Thus, it is currently implemented in 25 out of the 27 EU countries and in many other parts of the world. Both the EU and the Food and Agriculture Organization (FAO) regard land consolidation schemes among the most important measures in their integrated rural development programmes (FAO 2003, European Commission 2005, FAO 2008). Land consolidation consists of two main components: land reallocation (or readjustment) and agrarian spatial planning (Thomas 2006a). 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.

In many cases, the process of land consolidation is subject to major problems such as the long duration of projects, the high operational costs involved, the conflicts of interest among landowners and the different perceptions that arise between stakeholders. These latter problems are associated with land reallocation, which is the most critical stage of the land consolidation process (Sonnenberg 2002, Thomas 2006b). Therefore, there is a demand to support and automate land reallocation 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. Land redistribution, which involves the decision-making part of the whole process, comprises the preparation of a preliminary plan to restructure land parcels in terms of their number, ownership, size, value and approximate location. It is based on legislation, the existing land tenure structure, rules of thumb and the experience of the planner. Land partitioning, on the other hand, involves a design process, i.e. the subdivision of land into smaller "subspaces" (land parcels) in terms of parcel shape, size, value, final location and various constraints. In practice, it is conventionally a trial-and-error procedure based on the legislation concerned, the existing land structure, design criteria, constraints and rules of thumb. The outcome of this process is the final land consolidation plan.

It might be expected that land reallocation would be supported by GIS. However, proprietary GIS are not capable of adequately supporting such complex spatial planning and decision-making problems (e.g. Geertman and Stillwell 2009) since they are too generic and lack mechanisms to incorporate expert knowledge, produce alternative solutions or allow evaluation of these solutions without considerable programming or customisation. In addition, although focused research on land reallocation has been ongoing since the 1960s (Rosman and Sonnenberg 1998), an integrated planning and decision support system for land consolidation that truly automates the process in a systematic and efficient manner has not yet been realised. Instead, existing research focuses mainly on isolated algorithms for land redistribution, land partitioning and the evaluation of land consolidation plans.

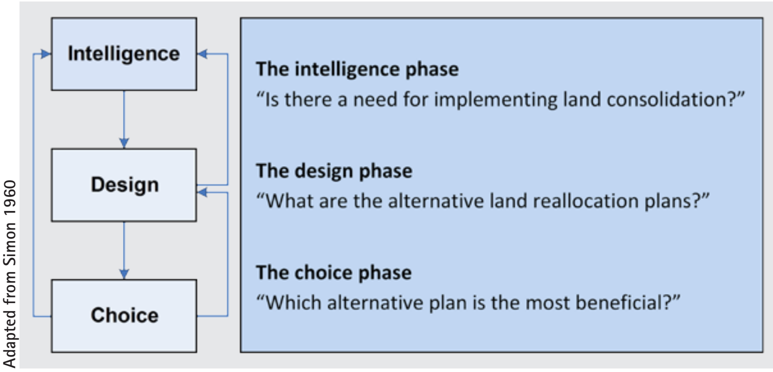
More specifically, some previous studies have attempted to automate the problem of land redistribution by treating it as a mathematical optimisation problem (e.g. Rosman and Sonnenberg 1998, Ayranci 2007). This means that, although the results are sometimes optimal in terms of efficiency, they are not necessarily realistic or operationally applicable. Other studies, focusing on land partitioning (Buis and Vingerhoeds 1996, Tourino et al. 2003), have produced encouraging results but still far from expectations. Furthermore, land consolidation evaluation studies (e.g. Coelho et al. 2001, Sklenicka 2006) have also suffered from the lack of tools capable of providing detailed land reallocation inputs for *ex-ante* project evaluation. In addition, similar efforts to solving the problem concerned which are presented in German literature are remarkable (Pelzer 1972, Klempert 1974, Kropff 1977, De Vos 1983, Hoisl 1984, Wurzl 1984, Lemmen and Sonnenberg 1986, Stutzer 1991, Hoisl and Nadolski 1994). 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.

Therefore, a new system called LACONISS (Land CONsolidation Integrated Support System for planning and decision-making) which is the focus of this paper, aims to fill this gap. LACONISS (Demetriou et al. 2012b) is a hybrid prototype system that integrates GIS, artificial intelligence (AI) techniques (e.g. Openshaw and Openshaw 1997), namely expert systems (ES) (e.g. Giarrantano and Riley 2005), genetic algorithms (GAs) (e.g. Goldberg 1989) and multi-criteria decision methods (MCDM) (Malczewski 1999), both multi-attribute (MADM) (Sharifi et al. 2004) and multi-objective (MODM) (Deb 2001). For more conceptual and technical information regarding the system design and development, the reader is referred to Demetriou et al. (2011, 2012a, 2012b, 2012c, 2012d, 2012e, 2012f). The focus of this paper is the operational part of the system and its application to a case study area in Cyprus (Demetriou et al. 2011) for assisting planning practitioners.

2 The Development Framework

A widely accepted decision-making model proposed by Simon (1960) involves three major phases: intelligence, design and choice which can also be utilised as a planning and decision-making framework for the systematic support of spatial planning problems (Sharifi et al. 2004). Specifically, the critical questions for each phase regarding land consolidation are shown in Fig. 1.

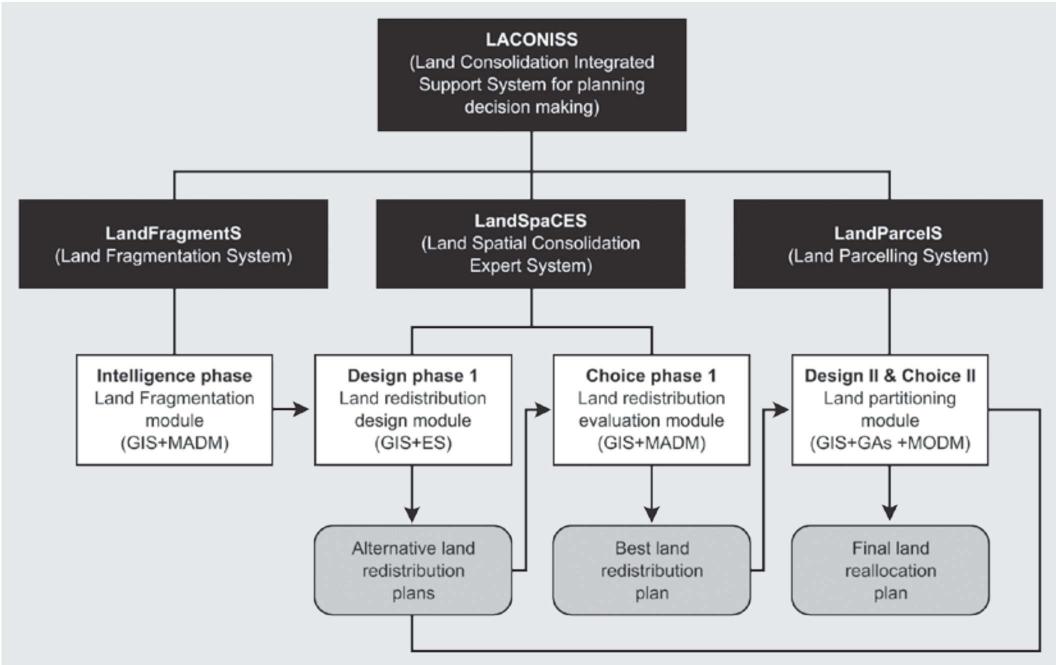
Based on this model, the operational framework of LACONISS (Fig. 2) consists of three sub-systems: LandFragmentS (Land Fragmentation System) representing the "Intelligence phase" of the process that involves building an appropriate GIS model and scanning the current land tenure system by utilising multi-attribute decision-making (MADM) methods to measure the extent



Adapted from Simon 1960

◄ Fig. 1: Simon's decision-making model applied to land consolidation

▼ Fig. 2: The operational framework of LACONISS



Demetriou et al. 2012b

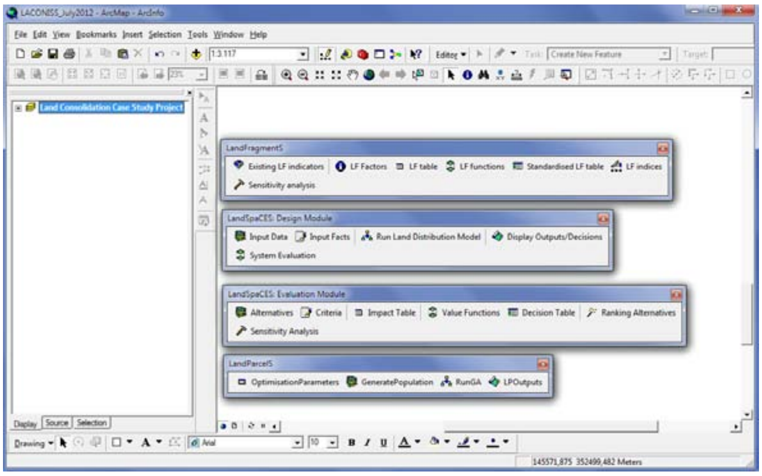


Fig. 3: The LACONISS interface

of land fragmentation. LandSpaCES contains (i) a Design module that integrates the GIS with an ES and generates alternative land redistribution plans ("Design phase I"), and (ii) an Evaluation module that uses GIS and MADM to evaluate alternative redistribution plans to identify the most beneficial one ("Choice phase I"). Finally, the best plan is passed as an input to the LandParcelS module which automatically generates the new parcels in terms of shape, size and land value constituting the final land reallocation plan. LandParcelS integrates GIS with a GA and MODM method ("Design and Choice phase II").

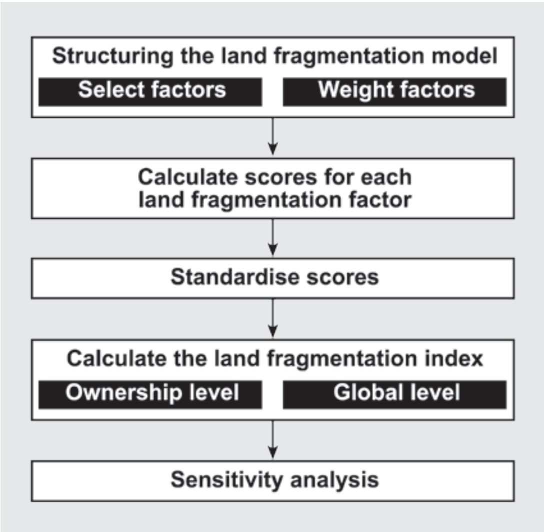
The development platform of LACONISS is ArcGIS and the development tools are Visual Basic for Applications (VBA) and ArcObjects (Zeiler 2001a, 2001b). Fig. 3 shows the LACONISS interface, which consists of four toolbars within ArcGIS corresponding to the four modules noted above.

3 LACONISS Components

3.1 The LandFragmentS Module

The LandFragmentS module (Demetriou et al. 2012c, 2012e) is operationalized as a toolbar consisting of seven icons (Fig. 4). Each icon launches a separate window including relevant functionalities. With the exception of

▲ Fig. 4: The LandFragmentS toolbar



Demetriou et al. 2012b

◄ Fig. 5: Stages of the land fragmentation module

the first icon that provides the calculation of the two most popular existing land fragmentation indices (Simmons and Januszewski), the remaining icons are in the order in which they must be executed following the MADM process.

Traditionally, MADM is a selection process between a discrete and limited number of alternative solutions which are described by attributes (or criteria) (Malczewski 1999). Instead, this method is used for measuring the performance of an existing system (i. e. land tenure) compared to an ideal status of this system ranging from the worst (0) to the least (1) amount of land fragmentation. In particular, the process involves the following main steps as shown in Fig. 5.

Initially, the planner has to structure the land fragmentation model by selecting the land fragmentation factors for incorporation into the model from the following six: 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 (when land and trees and/or water belong to different landowners) (F5) and shared ownership (where the land belongs to different landowners) (F6). In addition, a relevant weight for each factor (w_j) needs to be assigned representing its importance. Two methods are available for this task: direct rating of a numerical value and qualitative rating. The latter involves a seven level ordinal scale (to facilitate the choice) which is then transformed to a numerical scale. In both methods, the sum of the weights should equal 1.

The system then automatically calculates a score for each ownership i and factor j called (f_{ij}) and builds the land fragmentation table (including factors in columns and ownerships in rows), which is then standardized to values between 0 and 1. Standardisation is carried out by utilising value functions (Beinat 1997) which represent human judgement in a mathematical form and have been constructed by a group of land consolidation experts. Based on this standardized table, a land fragmentation index *(LFI)* is calculated for each ownership by utilising the weighted summation method (Eq. 1), and then a global land fragmentation index *(GLFI)* is calculated for the whole area as the average of the *LFI*s (Eq. 2), where n is the number of ownerships:

$$LFI_i = \sum_{i=1}^{m} f_{ij} w_j, \qquad (1)$$

$$GLFI = \sum_{i=1}^{n} LFI_i \,/\, n. \qquad (2)$$

Furthermore, the percentage contribution of each factor is also calculated at ownership and global level. At the end of the process, a sensitivity analysis (SA) tool is available to identify how sensitive the weights are on the outcome. In particular, the system recalculates the land fragmentation indices based on selected one-at-a-time increases or decreases (for various percentages from 10 to 100 %, at increments of 10 %) 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. Then, the final outcome, i. e. the *GLFI*, can be regarded a first indication of whether land consolidation is needed. If confirmed to be the case, the planner may then proceed to the design of alternative land redistribution plans by employing the next module.

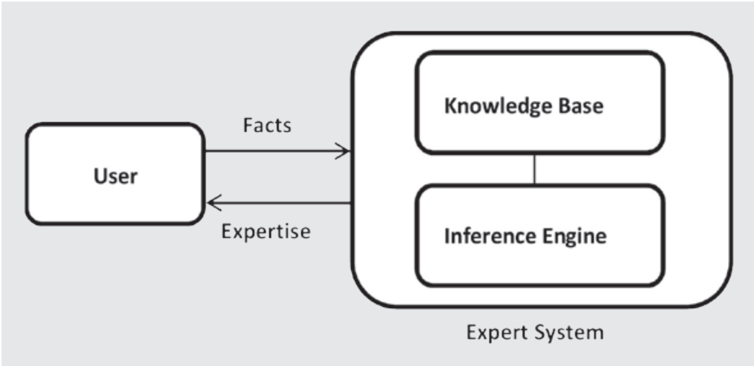
3.2 The LandSpaCES Design Module

The LandSpaCES Design module (Demetriou et al. 2011) integrates GIS and ES. The toolbar of this module, which consists of five icons, is shown in Fig. 6.

ES is the most traditional AI (artificial intelligence) technique that attempts to emulate human reasoning for solving complex decision-making problems such as land redistribution. An ES consists of two main components: a knowledge base and an inference engine (Fig. 7).

The knowledge base for this module contains 74 IF-THEN rules regarding the problem which have been extracted from legislation, the experience of the planners,

Fig. 6: The LandSpaCES Design module toolbar



Adapted from Giarratano and Riley 2005

Fig. 7: The basic components of an ES

rules of thumb and other related documents. An example of an IF-THEN rule is:

IF [The total area OR land value of a landowner's holding is < than the minimum completion limits set by the Committee AND the examined parcel is not "exempted" from relocation]

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 redistributed to other landowners]

System input involves GIS data (a cadastral map), databases (regarding land parcels, landowners and ownerships) and facts. Facts are decision variables defined by the planner representing different scenarios. The inference engine makes inferences by deciding which rules are satisfied by the facts, which are then returned as decisions (i.e. land redistribution maps) to the planner. A different set of facts results in a new land redistribution solution and hence the system can automatically generate a set of alternative solutions that are passed to the next module for evaluation.

Crucial matters considered when building the land redistribution model were the way in which the preferences of the landowners are incorporated and the need to ensure equity, transparency and standardisation of the process in terms of the location and the allocation of the new parcels. Regarding the former, it is accepted that the most important concern for 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 property in the location of their "best parcel", then the next "best parcel" and so on (Sonnenberg 1998, Ayranci 2007). Practice has shown that the "best parcel" is perceived as that with the largest area and/or the highest land value per hectare (either market price or agronomic value) or a combination of these two factors. The parcel priority index (PPI) has been devised to take into account both factors and its role is to define two crucial land redistribution issues: the priority of each landowner-parcel pair in the whole project in terms of allocating a new parcel to that landowner in a certain location and the ranking of location preferences for each landowner's new parcels. Therefore, the Design module initially attempts to satisfy the preferences of all landowners and because this is not possible, conflicts arise during the process as a land block may not have enough land to allocate to all the landowners who wish to receive land there. Thereafter, the PPI defines which landowners have to be moved into another block and, in particular, the degree to which the landowners' next preferences are satisfied. Thus, no landowner can be sure about the location of her/his new parcels until the end of the process since the process involves a continuous movement of new parcels. As a result of the way the PPI works, it contributes to enhancing the equity and transparency of the process since it becomes structured, systematic and standardized in terms of the location and the allocation of the new parcels.

3.3 The LandSpaCES Evaluation Module

The toolbar of the Evaluation module (Demetriou et al. 2012c) is provided in Fig. 8.

This module involves the integration of GIS with MADM and thus follows a similar process to that of LandFragmentS. The classical form of MADM that is adopted by this module is illustrated in Fig. 9.

In particular, the planner selects a set of alternative land redistributions (options) for evaluation as well as a set of criteria to assess these alternatives. The available criteria are the following: the mean size of the new parcels (C1), the mean parcel concentration coefficient (PCC) (C2), the change in the number of landowners (C3), the percentage of ownerships "completed", that had less than the minimum size limit according to the Cypriot legislation, to which extra land is added to reach the minimum limit (C4). It is interesting noting that such a legislative limitation is not permitted in German legislation; and the mean landowner satisfaction rate (LSR) (C5). The PCC and LSR are new concepts that have been introduced by Demetriou et al. (2012c). In particular, the PCC is measured for each holding on a scale between –1 to 1. A value of zero indicates no change in the dispersion of a holding's parcels before and after land consolidation. The value of +1 refers to the situation of "perfect concentration" while –1 represents the "worst concentration". The calculation of the LSR involves determining which preferences of each landowner have been satisfied and assigns a proportional percentage of satisfaction (called the partial satisfaction rate, PSR) to each new parcel depending on the ranking of the preference satisfied, with a maximum of 100 %.

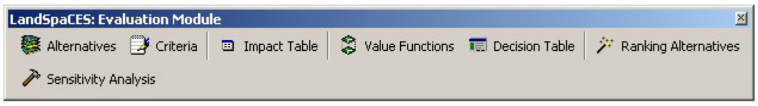
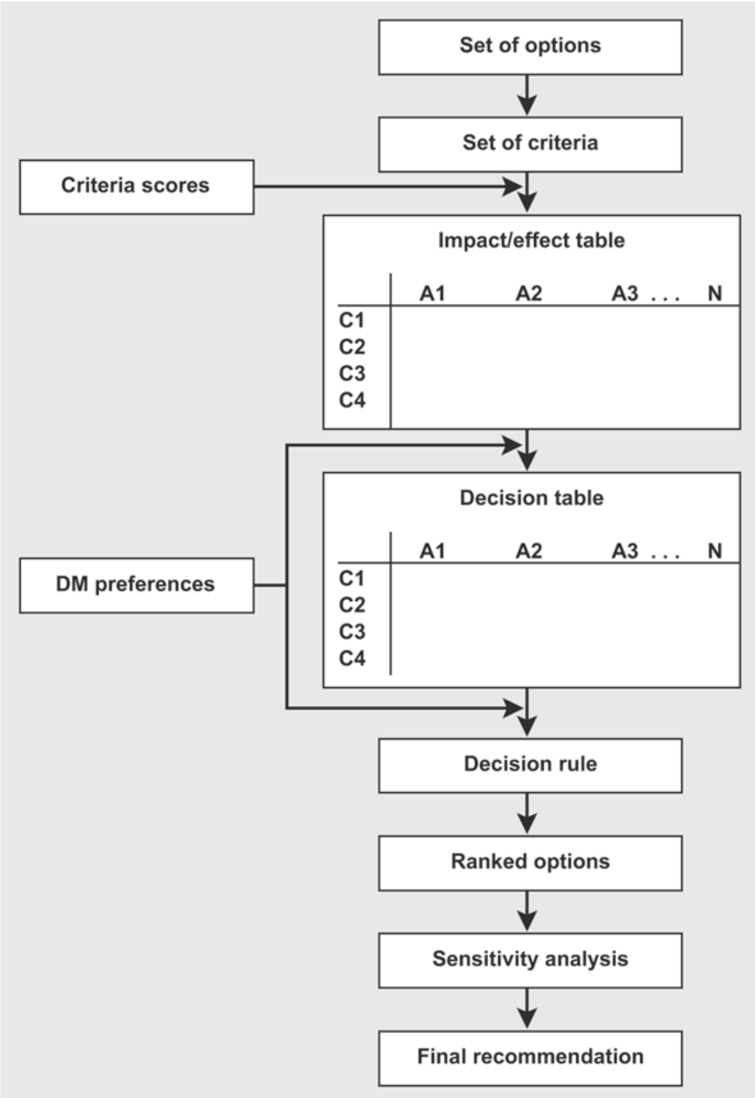


Fig. 8: The toolbar of the Evaluation module of LandSpaCES



Demetriou et al. 2012c

Fig. 9: Stages of MADM

Thereafter, an impacts/effect table is produced with the alternatives in columns and the criteria in rows. The performance of each alternative for each criterion is represented by a score that constitutes an element of the table. The scores are standardized to values between 0 and 1 (representing the worst and best performances of alternatives, respectively) by utilising appropriate value functions as shown in Fig. 10 and the outcome is the decision table. In addition, weights are chosen for each criterion by the planner by utilising the two available methods noted for LandFragmentS. Then, a decision rule, i.e. an aggregation model, is employed to calculate the overall performance of each alternative and rank the alternatives. Afterwards, sensitivity analyses for both the weights of the criteria and the performance scores are carried out by employing the method developed by Triantaphyllou (1997), which assesses the robustness of the ranking order followed by the output of a final recommendation about the most beneficial solution. The basic outputs of the SA are the "percent top critical criterion" (that may alter the ranking of the best alternative), the "percent any critical criterion" (that may alter the ranking of any alternative) and a sensitivity coefficient for each criterion. Finally, the most beneficial solution is passed to the next module for automated land partitioning.

3.4 The LandParcelS Module

The LandParcelS module (Demetriou et al. 2012f) is operationalized as a toolbar (Fig. 11) consisting of four icons that integrate GIS, GAs (genetic algorithms) and MODM. GAs are stochastic optimisation techniques based on the Darwinian theory of evolution utilised for solving complex non-linear optimisation problems. GAs have already been used in spatial problem domains since the 1980s, such as for location modelling, spatial interaction modelling, suitability modelling, aggregation, data mining, generalization of spatial data, display of continuous data, etc. (e.g. Krzanowski and Raper 2001, Van Dijk et al. 2002). 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. The MODM approach provides a framework for designing a set of alternatives, each of which 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 defined by a set of decision variables and limited by a set of constraints imposed on the decision variables. In mathematical terms, a multi-objective decision problem can be formulated as a minimization or maximization function(s) that is subject to a number of constraints. In particular, land partitioning can be formulated as a multi-objective problem with three objectives and a primary constraint, i.e. generate parcels with regular shapes, a predefined size and land value subject to the constraint that parcels should have access to a road. It should be noted that, further to this constraint, 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

Fig. 11: The toolbar of LandParcelS

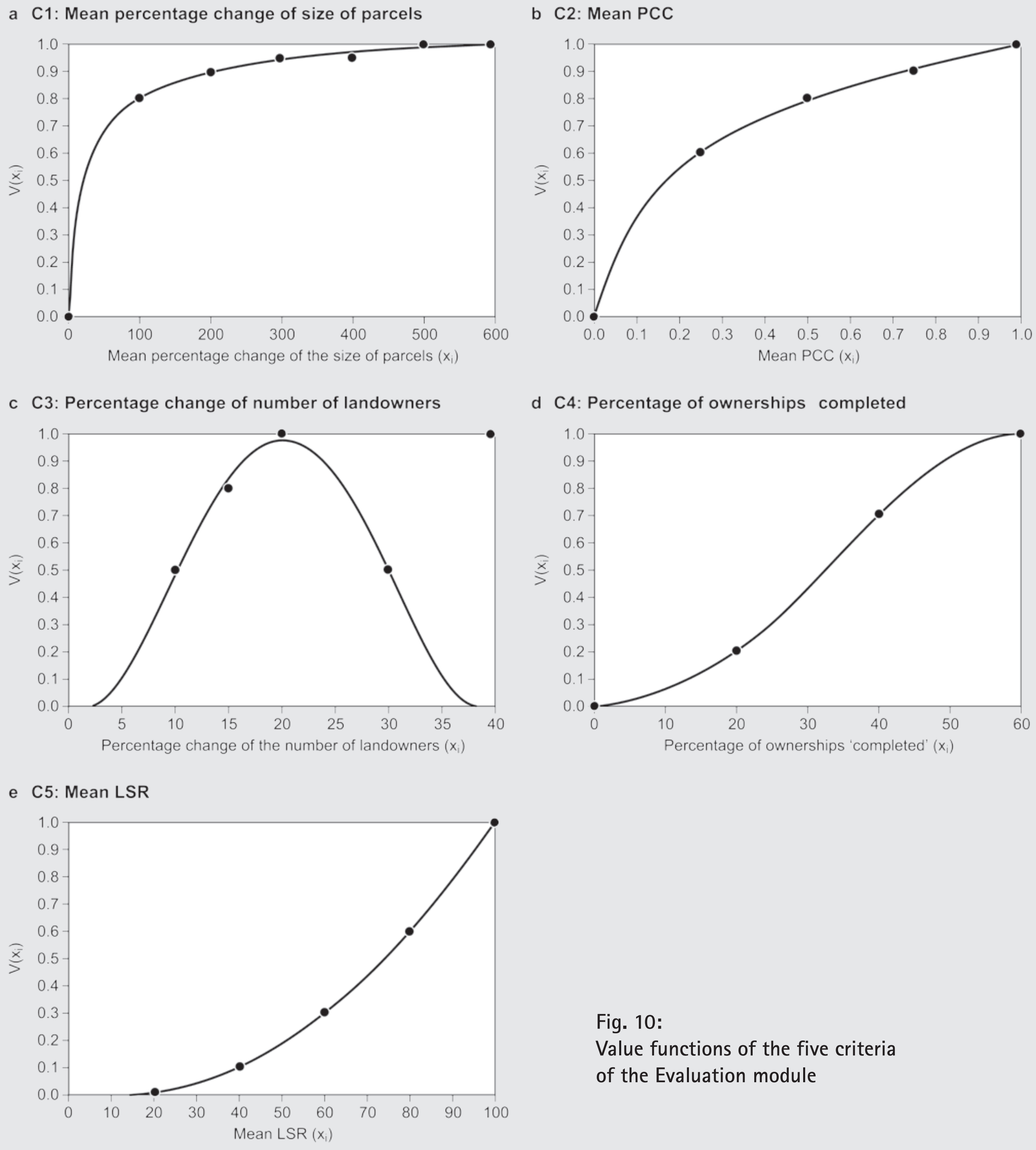


Fig. 10:
Value functions of the five criteria of the Evaluation module

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 in its fundamental form and then include the additional constraints.

Icons appear on the toolbar in the order in which they must be executed. Initially, the planner needs to select the optimisation parameters regarding the new parcels, namely, shape (F1), size (F2) and land value (F3) to compose an appropriate fitness function (Demetriou et al. 2012d). If more than one input parameter is to be optimised, then a weight is required for each one representing its importance in the optimisation process. In addition, a penalty function (R) can be involved in the process that penalizes infeasible solutions, i.e. solutions that do not provide parcels with access to roads. Ideally, the fitness function equals zero if all parcels of a block have: the optimum shape (F1 = 0) which reflects a rectangle with a length: breadth ratio of 2:1 (Demetriou et al. 2012d); the predefined size (F2 = 0); the predefined land value (F3 = 0) and accessibility to a road (R = 0). 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. It is noted that during the evolutionary process, random or new solutions are generated using Thiessen polygons, a concept which has been widely applied for space partitioning problems in a variety of disciplines (Dong 2008, Gong et al. 2011). An example of

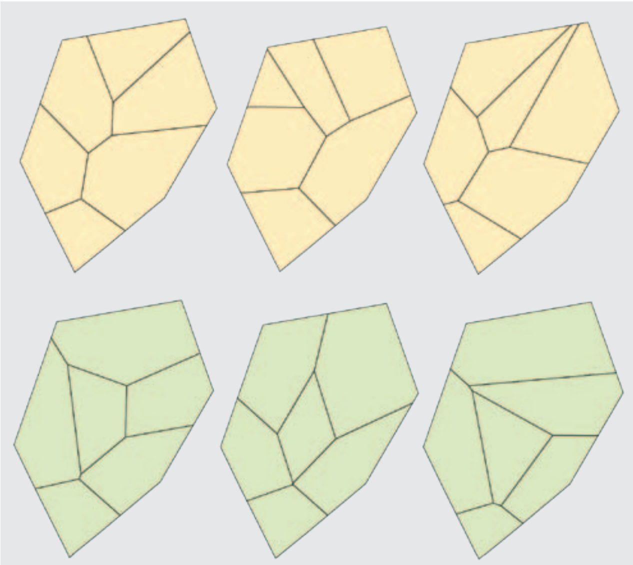


Fig. 12: An example of a random population consisting of six subdivisions

a random population consisting of six subdivisions of a small land block is illustrated in Fig. 12.

The GA is then run by defining the number of generations (iterations) and the elitist factor which is the percentage of the best solutions from each generation that will be directly transferred to the next one. In particular, an iterative process begins by utilising a selection method called tournament (Deb 2001) to fill a mating pool with the same number of individuals as found in the initial population based on their fitness value. Thereafter, new individuals (offspring) are created by applying the genetic operators to parent individuals. Specifically, 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 and hopefully the best solution is returned. Otherwise, the iterative process continues and so on. Once the optimum solution is obtained, the last icon displays two database tables containing useful information regarding the evolution of the process for each generation. The resulting subdivision of each block can then be visualised in the GIS environment. By running the system for all land blocks in the case study area, the final land consolidation plan is produced.

4 System Implementation

LACONISS has been implemented using a case study area in Cyprus (Demetriou et al. 2011). The outputs for each module are presented and discussed. The case study area showing the situation before and after land consolidation is illustrated in Fig. 13 and in particular for ownership of the landowner AAK.

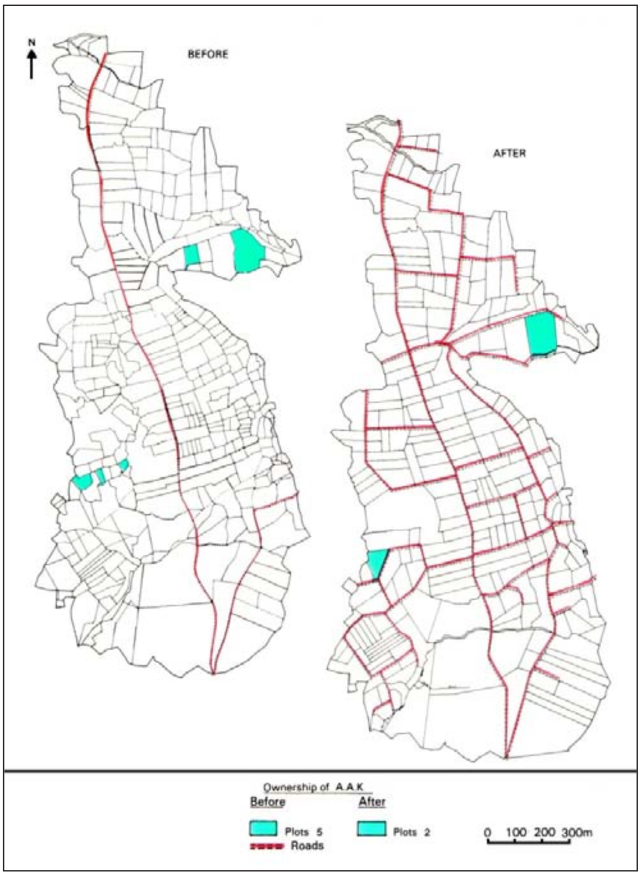
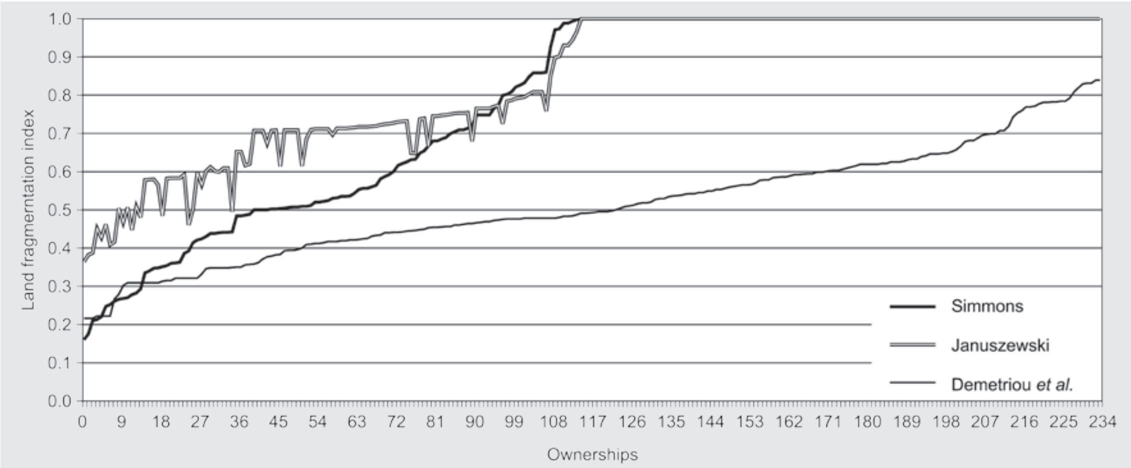


Fig. 13: The case study area before and after land consolidation

4.1 The LandFragmentS Module

LandFragmentS was run for the case study area in Cyprus considering equal weights for all factors. The resulting distributions for the two most popular existing indices (Simmons and Januszewski) and the new LFI are presented in Fig. 14 for all ownerships of the case study area. The two existing indices present very similar patterns. However, the Januszewski index gives higher values with a minimum of 0.364 and an average of 0.841. In contrast, the Simmons index gives lower values with a minimum of 0.160 and an average of 0.785. On the other hand, the new index *(LFI)* clearly results in considerably lower values compared to both existing indices, i.e. a minimum value of 0.216, a maximum of 0.839 and an average of 0.512. In addition, contrary to both existing indices in which around 50 % of ownerships have resulted in the highest value of 1, no holding achieves an *LFI* of 1.



Demetriou et al. 2012e

Fig. 14: The comparison of Simmons, Januszewski and LFI's distributions

The above outcomes indicate that both of the existing indices underestimate the problem of land fragmentation (with an average around 0.8) compared to the new index. This is due to the fact that the latter takes six critical factors into account instead of only two. As a result, the policy decisions made from using these existing indices will be wrong. In contrast, the *GLFI* outcome of around 0.5 empirically suggests that the area concerned has a land fragmentation problem. It is interesting to note that land consolidation was actually carried out in this study area which is a decision closer to the *GLFI* and not to both existing indices. The *GLFI* is therefore more reliable because it overcomes all the deficiencies of the existing indices (Demetriou et al. 2012e). However, the system could be more flexible by allowing for more factors to be added by the user or to allow construction of the value functions interactively.

4.2 The LandSpaCES Design Module

The validation of the "Design module" involves measuring the system performance by comparing the agreement between the solution generated by the system and the solution of the human experts for the case study area. The outputs involve a land redistribution map and three associated database tables containing information regarding the new parcels, landowners and ownerships. An example of the former is illustrated in Fig. 15 showing a set of centroids representing the approximate location of each new parcel for various blocks. The ratio above each centroid denotes Parcel_ID and Owner_ID. The results are very encouraging since the system reproduces the human expert decisions with an agreement of between 62.6 to 100 % for the nine validation criteria (Demetriou et al. 2011). Furthermore, a small survey carried out on ten expert land consolidation technicians showed that an individual expert needs about 30 working days to solve this particular land redistribution problem whilst the "Design module" needed only six minutes, which is an impressive time reduction for this task.

Despite the successful results, further improvements could still be made by providing an editable knowledge base and by adding more rules to enhance performance. In addition, the direct incorporation of extra data (e.g. the actual landowners' preferences) needs to be considered. Moreover, the development of an explanation facility regarding decisions made would be very useful for the communication between the planners and the landowners. Moreover, testing the system with more case studies may also provide more robust conclusions regarding its performance.

Finally, the system was run with ten different sets of facts to generate ten alternative land redistributions representing different planning scenarios which are evaluated in the next module. An example of four different alternative land redistributions are illustrated in Fig. 16 for land blocks 14, 15 and 16 (underlined numbers). The number above each centroid represents the landowner's ID. It can clearly be seen that there is a difference between the alternative solutions in terms of the number of parcels allocated, their location, and the landowners' IDs for each block.

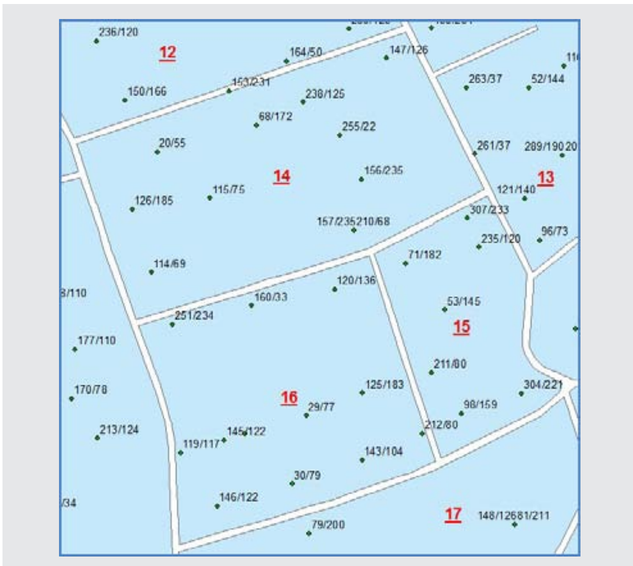


Fig. 15: An example of a part of the land redistribution map

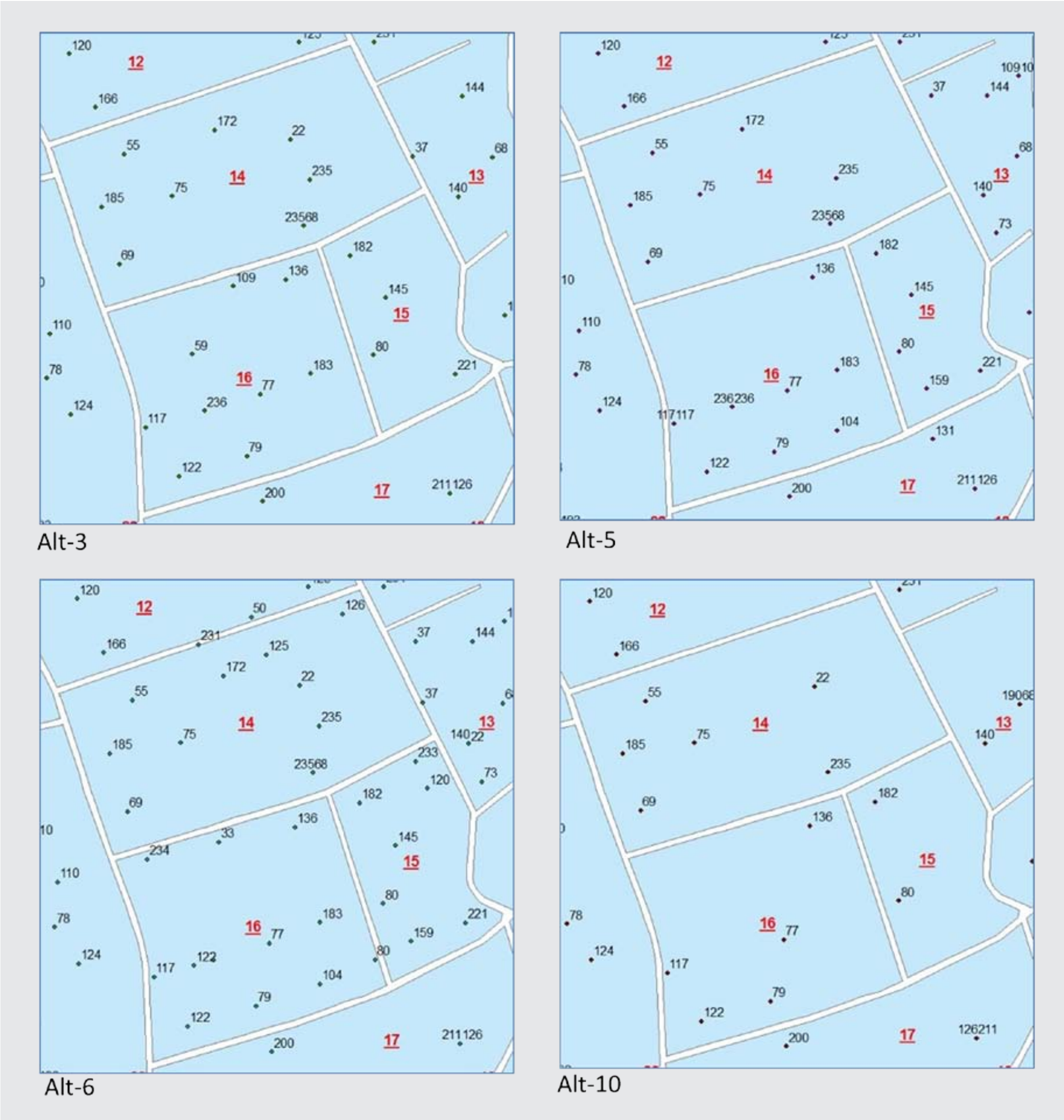


Fig. 16: Four alternative land redistributions in blocks 14, 15 and 16

4.3 The LandSpaCES Evaluation Module

Ranking the ten alternatives generated in the "Design module" is carried out using four different weighting schemes called scenarios (1–4) described as: equal weights, descending order of weights, ascending order of weights and expert judgment, respectively. The results of the ranking are shown in Fig. 17.

Some interesting findings can be noted. Alternatives 2, 3, 4 and 9 outperform alternative 1 (which represents the solution actually given by the experts) for all four scenarios. This indicates that the system is capable of producing better solutions than the experts. In addition, no one alternative was found to be the best in all scenarios. In particular, alternative 3

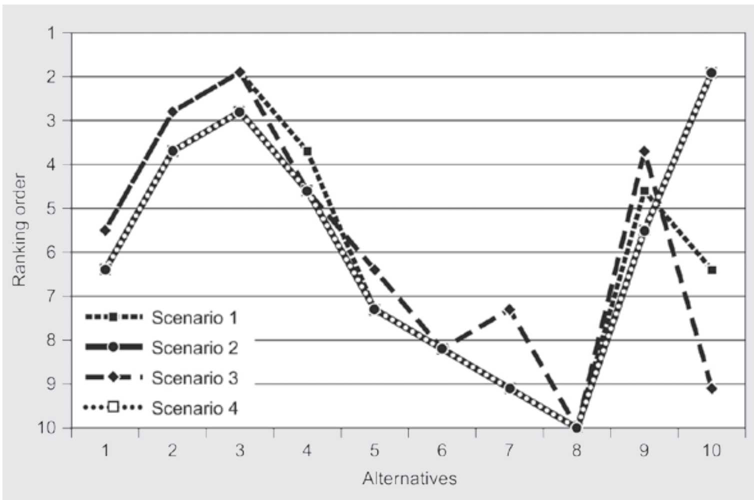


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Fig. 17: Ranking of alternatives for four different criteria weighting scenarios

is ranked the best in scenarios 1 and 3 while alternative 10 is ranked the best in scenarios 2 and 4. Alternative 10 ranks third and seventh in scenarios 1 and 3 while alternative 3 is ranked second in scenarios 2 and 4. Thus, alternative 3 achieves a better balance in terms of performance scores, i.e. a trade-off between all criteria. Therefore, clearly alternative 3 is the best since it presents the most stable behaviour in terms of ranking order in all scenarios and thus is passed as an input to the next module.

4.4 The LandParcelS Module

LandParcelS has been applied to two typical land blocks in the case study area, which reflect different levels of complexity. Block I contains six parcels with a size equal to about 3 ha, while block II contains 10 parcels with a size of around 5 ha. Land partitioning was handled as a multi-objective optimization problem with two or three objectives as follows: shape and size (F1 and F2), shape and land value (F1 and F3), and shape, size and land value (F1, F2 and F3). It should be noted that, in contrast to single-objective optimization which involves a unique optimum solution, multi-objective problems with conflicting objectives involve a different optimum solution for each objective. As a result, the final outcome is a set of solutions that are all optimal in varying degrees of trade-off between the objectives (Deb 2001). Graphically, these optimal solutions lie on a curve called the Pareto-optimal front.

The results were encouraging and indicate a step forward in solving this complex spatial problem. Specifically, in the case of 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. Namely, 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 whilst they are close to optimum for shape. A similar picture is presented in the case of optimizing three objectives (shape, size and land value) simultaneously.

In particular, Fig. 18 shows the final subdivision of block I for optimizing shape and size (Fig. 18a), shape and land value (Fig. 18b) and shape, size and land value (Fig. 18c). For instance, case b 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. In accordance with this, Fig. 19 shows the Pareto-optimal front (dashed line) for case (b). The best solution, which is the solution that dominates all the others based on a certain weighting scheme, is marked with a triangle and falls on the Pareto-optimal front. All the other solutions belong to the non-Pareto-

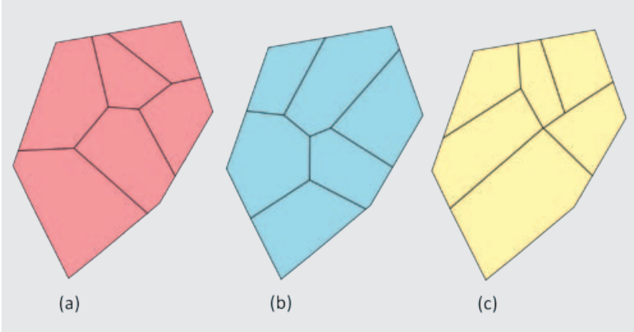

Fig. 18: The final outcome for block I for three optimisation cases

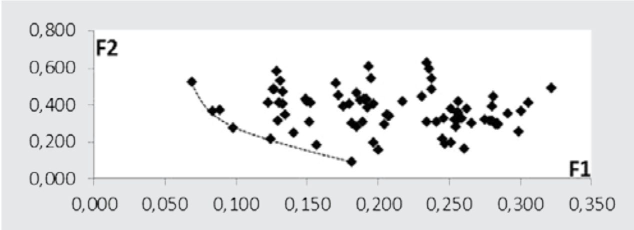

Fig. 19: The Pareto-optimal front for case b

optimal set. Similarly, in case (a), the parcel shape (F1) and size (F2) are on average only 18.1 % and 9.4 % from the optimum, respectively, and in case (c), the average is far from the absolute optimum by 13.8 %, 17.6 % and 11.3 %, for shape, size and land value respectively.

Although the above outcomes are encouraging, undoubtedly there is a need for improving the performance of the algorithm both in terms of the final outcome and the computational time, which takes approximately five to ten hours for each land block. The former can be achieved either by developing a new generic space partitioning algorithm where the parameters will be directly involved in the optimization process (in contrast to the current process) or by introducing a so-called guidance (or learning or local) optimiser within the current optimisation process. The latter can be improved either by utilizing parallel computing or redeveloping the algorithm using a more powerful language.

5 Conclusions

This paper has outlined a prototype IPDSS for land consolidation. In particular, the new system uniquely involves an integrated planning and decision-making framework for land reallocation that has been transformed into a systematic, automated, transparent and efficient process by integrating GIS, AI techniques and multi-decision making methods. As a result, the new system is capable of alleviating basic problems in the process. Further research and development can be focused in two directions: improving each module of LACONISS to overcome the limitations noted earlier in each relevant section and converting LACONISS from a prototype single country system into generic commercialised or open source software that could be adjusted by a user to fit the land consolidation legislation and practices of the country concerned. The construction of such a system has been an aim of many researchers since the 1960s. LACONISS has the potential to become the foundation for reaching this ambitious goal.

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Author's address

Dr. Demetris Demetriou
District Land Consolidation Department of Larnaca-Ammochostos
18 Stratigou Timagia street, 6051 Larnaka, Cyprus
demdeme@cytanet.com.cy