A Framework for Developing an Integrated Planning and Decision Support System for Land Consolidation

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1. Introduction

Land fragmentation is a major problem in many countries around the world. Traditionally, land consolidation has been the primary land management approach for effectively solving this problem, involving changes in land tenure and public infrastructure. Land reallocation is recognised as the most important, complex and time consuming process of land consolidation (Sonnenberg 2002; Essadiki et al. 2003; Van Dijk 2003; Thomas 2006; Ayranci 2007) and a literature review has indicated the requirement for developing integrated planning and decision support tools for land reallocation. This paper presents a framework for the development of a land consolidation integrated planning and decision support system for Cyprus.

2. Problem statement

Land reallocation, sometimes referred to as land readjustment or reallotment, can be split into two main sub-processes: land distribution and land partitioning. *Land distribution* comprises the preparation of a preliminary plan which involves decision making regarding the general restructuring of 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. *Land partitioning* involves the subdivision of land into smaller ‘sub-spaces’, i.e. land parcels, which is conventionally a trial and error process based on legislation, the existing land structure, empirical design criteria, constraints and rules of thumb.

Both sub-processes involve the concept of evaluating alternative solutions to produce a near optimal land reallocation plan. In addition, the evaluation of existing land fragmentation and its consequences must precede land reallocation. These tasks can be used to formulate a major part of the *ex-ante* evaluation framework for land consolidation, which is a legal EU requirement for rural development programmes (European Commission 2004).

3. Related research

Research in this area has been occurring since the 1960s (Rosman and Sonnenberg 1998) and significant progress has been made, especially with the development and application of GIS and other geoplanning tools. However, the support provided to the planner is still not sufficient as GIS does not have the capability to support complex spatial planning and decision-making problems (Carver 1991; Stillwell et al. 1999; Batty 2008; Geertman and Stillwell, 2009) such as land reallocation.

The studies that have attempted to automate the problem of land distribution treat it as a mathematical optimisation problem (e.g. Kik 1990; Avci 1998; Ayranci 2007). Thus, although results are sometimes optimal in terms of efficiency, they are not realistic or applicable. Moreover, studies dealing with the land partitioning problem (Buis and Vingerhoeds 1996; Tourino et al. 2003) have produced operationally encouraging results but solutions are far from experts' expectations and thinking. Furthermore, the available indices for measuring land fragmentation take into account only some spatial factors and non-spatial factors are ignored, and there is no flexibility regarding the selection of factors that need to be taken into account or to the assignment of different weights to these factors. Land consolidation evaluation studies (Coelho et al. 2001; Crecente et al. 2002; Sklenicka 2006) also suffer from a lack of models capable of providing the necessary data for an *ex-ante* project evaluation. Finally, the evaluation process needs to be a part of an integrated planning and decision-making framework able to provide a systematic approach for supporting land consolidation.

4. Aim and objectives

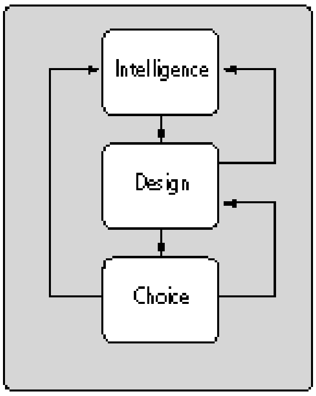
This research aims to develop a prototype integrated planning and decision support system (IPDSS) for land reallocation by exploiting the synergy of GIS, artificial intelligence (AI) techniques, i.e. expert systems (ES) and genetic algorithms (GAs); and multi-criteria decision methods (MCDM), both multi-attribute (MADM) and multi-objective (MODM). There are four main objectives involving the development of: a new methodology for measuring land fragmentation; a new land distribution model; a new land partitioning model; and a new methodology for evaluating land reallocation plans.

This research is expected to provide a significant original contribution in theory and in practice by discovering new knowledge and developing better tools and methods for land consolidation. The research also contributes to the field of spatial decision making and optimisation by exploring the potential to harness the power of state-of-the-art technologies and methods.

5. Research methodological framework

5.1 The planning and decision making framework

A widely accepted decision-making model proposed by Simon (1960) involves three major phases: intelligence, design and choice. The critical questions for each phase representing the decision-making process for land consolidation are shown in Figure 1. Sharifi et al. (2004) expanded Simon's model by formulating a planning and decision-making framework (Figure 2) which can be used as a systematic approach for supporting spatial planning problems.



The intelligence phase
"Is there a need for implementing land consolidation?"

The design phase
"What are the alternative land reallocation plans?"

The choice phase
"Which alternative plan is the most beneficial?"

Figure 1: Simons' decision making model applied to land consolidation

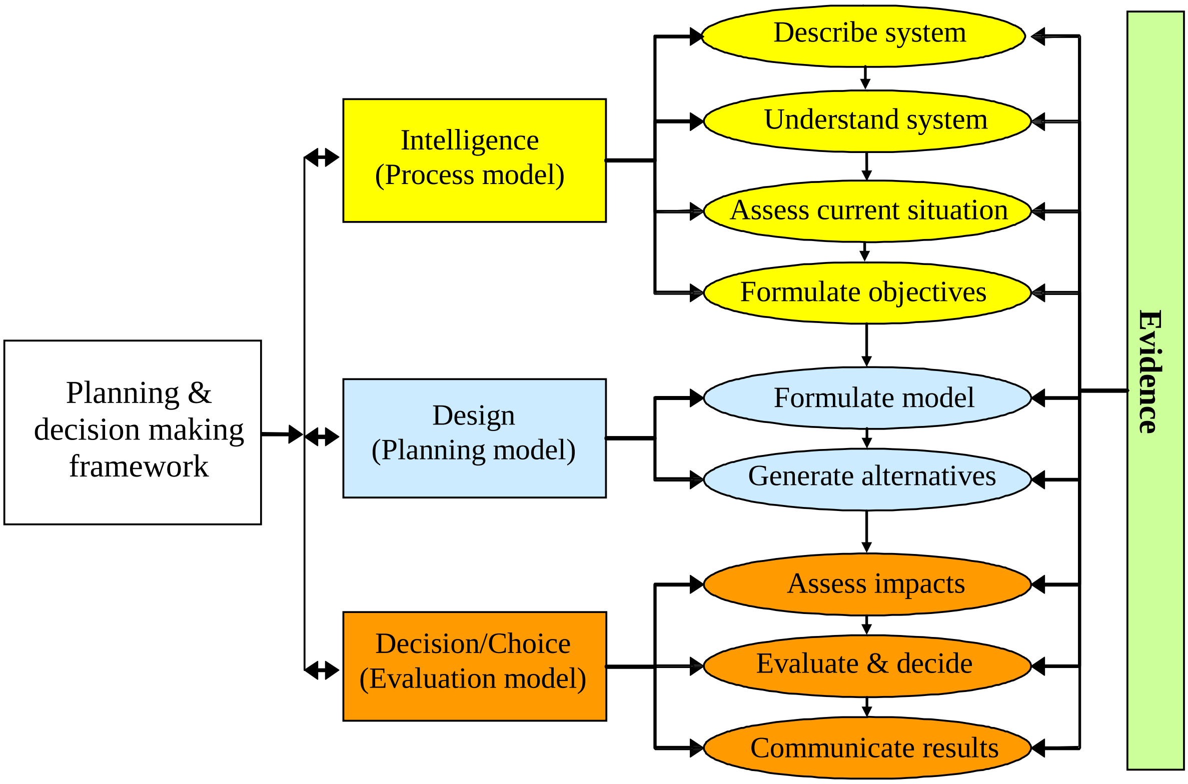


Figure 2: The planning and decision making framework (Adapted from Sharifi et al. 2004)

This research and in particular the conceptual and the operational framework of the system under development called LACONISS (Land CONsolidation Integrated Support System for planning and decision making) is based on this approach. The conceptual and the operational frameworks of the system are shown in Figures 3 and 4, respectively. The methodological rationale for each system module is summarised below. The development platform and the tools are ArcGIS, VBA and ArcObjects, respectively. Decision makers, that is, land consolidation planners will have a central role in the system operation by defining the various decision variables of each sub-system. However, these variables depend on the decisions and merely the preferences of the two other basic stakeholders of the land consolidation process, i.e. the Land Consolidation Committee and the landowners, respectively. System evaluation may involve the mentioned stakeholders, although in a different grade and way.

5.2 LandFragmentS

This model will be developed using GIS and MADM. Traditionally, MADM is a selection process between a discrete and limited number of alternative solutions which are described by attributes (or criteria) (Malczewski 1999; Sharifi et al. 2004). Instead, this method will be used for measuring such a multi-attribute problem, at a scale of two extreme absolute values representing best and worst. Different planners and different project objectives may produce varying land fragmentation indices that can be used for evaluating the current system status. GIS will be used for calculating the various attributes. In particular, the process involves four main steps which are illustrated in Figure 5. Initially, the planner has to structure the land fragmentation model by selecting the land fragmentation factors that he/she wishes to incorporate in the model and by assigning a relevant weight for each one that represents its importance. The system will then automatically calculate a score for each factor, which is then standardised to value between 0 and 1. Finally, the process will calculate the land fragmentation index at the ownership and global level.

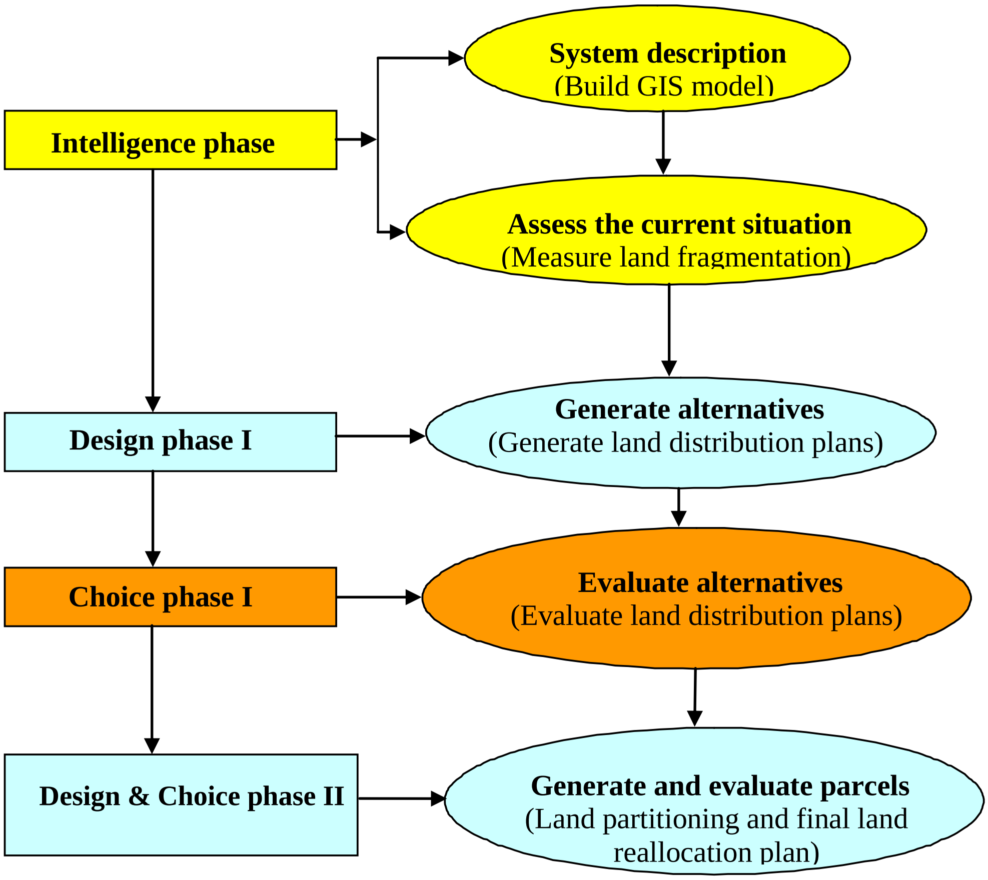


Figure 3: The conceptual framework of LACONISS

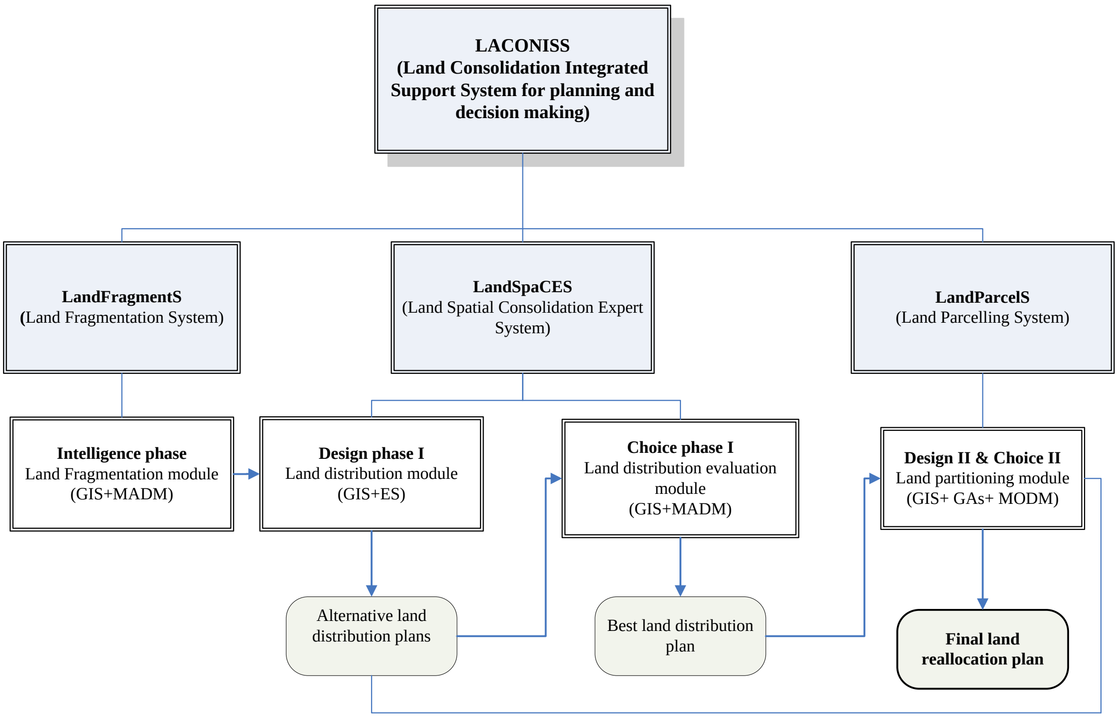


Figure 4: The operational framework of LACONISS

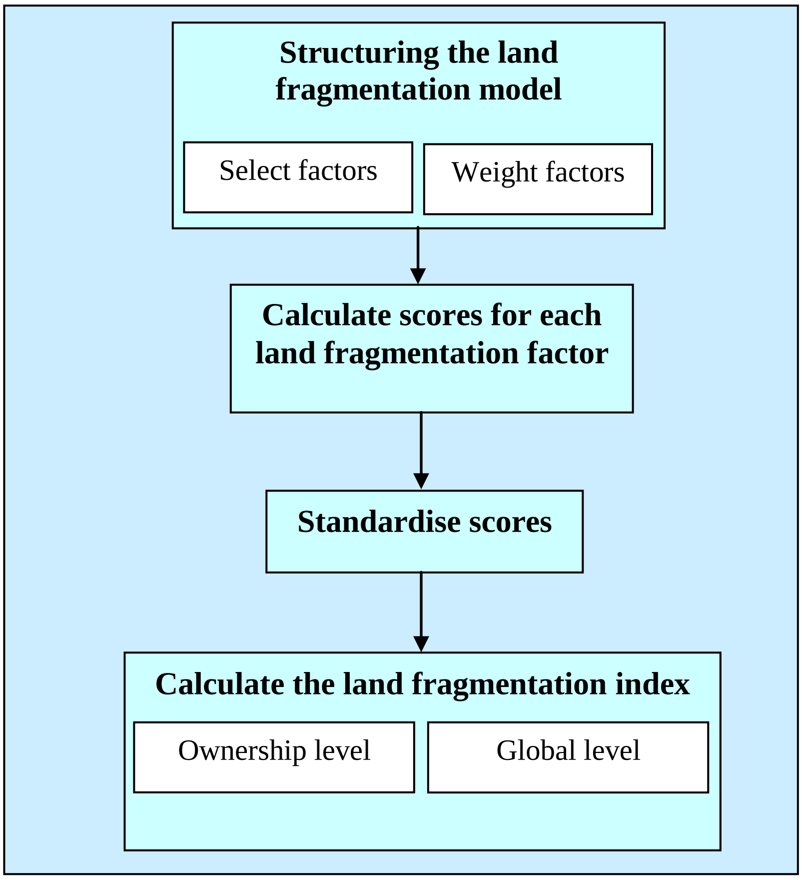


Figure 5: The stages of the land fragmentation model

5.3 LandSpaCES

This model will consist of two modules: the Design and Choice modules. The *Design module* has already been developed using ES and GIS. ES are computer programs that try to emulate the human reasoning process to solve difficult decision-making problems (Giarratano and Riley 2005). The process has been split into seven sub-problems, which can be represented by decision trees. The basic decision tree (Figure 6) ends in six land distribution cases. After constructing the decision trees, IF-THEN rules are extracted to build the knowledge base of the system. Module evaluation has shown impressive results that are very close to the planners' decisions, namely, between 63% and 100% for nine criteria.

The *Choice module* will be developed using GIS and MADM where MADM will be used in a traditional way (Figure 7). Initially, a set of alternative land distributions can be provided by the Design module. The planner may then set the evaluation criteria to assess these alternatives. An effect table is then constructed with alternatives in columns and criteria in rows. The performance of each alternative for each criterion is represented by a score. Scores are standardised and weights for each criterion may be incorporated. Decision rules comprise the evaluation method utilised in order to rank alternatives, followed by a sensitivity analysis aiming at assessing the robustness of the ranking order. Eventually, the output will be a final recommendation about the most beneficial solution.

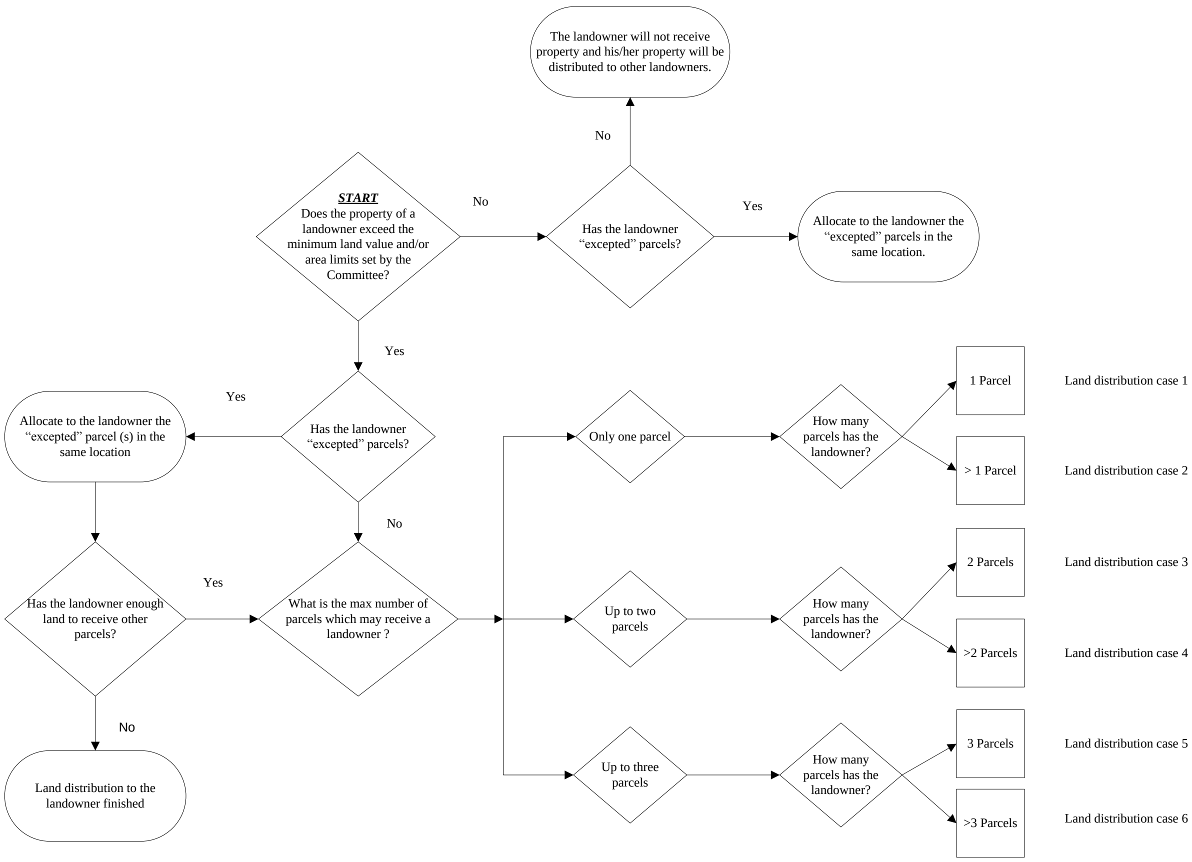


Figure 6: The basic decision tree for the Design module of the land distribution model

5.4 LandParcelS

This model will be developed using GIS, GAs and MODM. GAs are stochastic search and optimisation techniques used to find optimal or near optimal solutions based on Darwinian theory (Goldberg 1989; Deb 2001). MODM is a design process with a continuous search space looking for the best solution among an infinitive or a very large set of alternatives (Malczewski 1999; Sharifi et al. 2004). The land partitioning problem can be formulated as the minimization of the objective function and of the violation of the seven constraints for N number of parcels as shown in Equation 1.

$$\min \sum_{i=1}^{N} \left| \frac{1}{16} - \frac{area(Pi)}{perimeter^{2}(Pi)} \right| \qquad \min \begin{Bmatrix} value \\ area \\ frontage \\ corners \\ linearity \\ verticality \\ continuity \end{Bmatrix} \tag{1}$$

The aim is to create parcels with orthogonal shapes. In an ideal land partitioning plan, this objective function will equal zero. The representation of this model will be based on the following hierarchical raster-based structure: population-individual-chromosome-gene; representing a set of land partitioning plans, a land partitioning plan, a parcel and a grid cell, respectively. A graphical representation of this structure is illustrated in Figure 8.

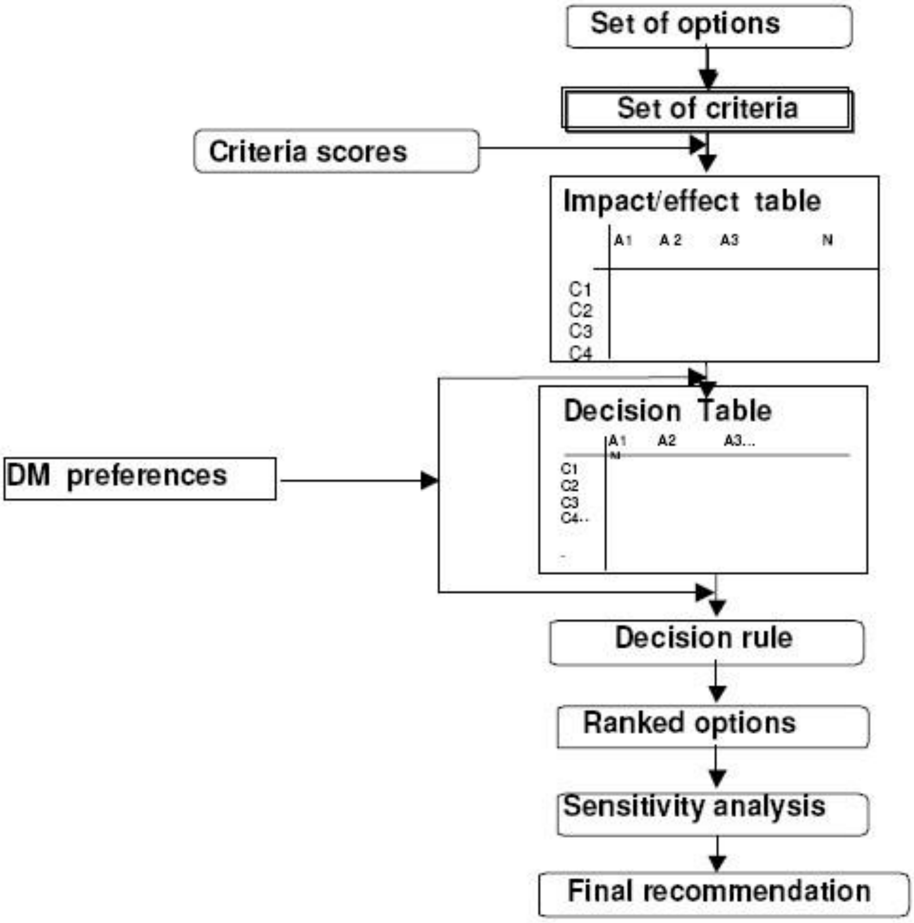


Figure 7: The stages of the Choice module of the land distribution model (adapted from Sharifi *et al.* 2004)

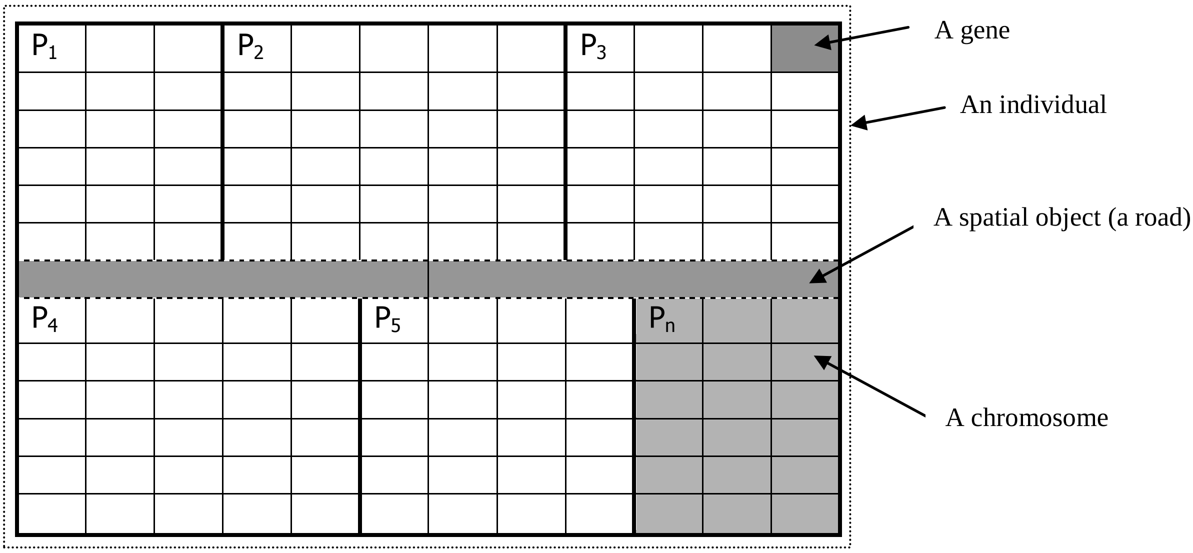


Figure 8: The structure of the land partitioning model for n parcels

6. Conclusions

This paper has set out the methodological framework for developing an IPDSS for land consolidation. The objectives are ambitious and the development of the system will prove challenging. However, the geotechnology tools and methods now available provide the means by which such a hybrid theoretical framework can be achieved.

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