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# Developing a Knowledge-Based Spatial Decision Support System for Urban Landuse Allocation

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**Abstract:** Landuse planning problems are categorized as complicated locational decision-making problems. This complexity makes us unable to solve such problems with common methods. It seems using intelligent systems such as expert systems and integrating those with decision support systems can help us to overcome with urban landuse planning problems. In this study, first it will be shown why a knowledge-based spatial decision support system is suitable for solving urban planning problems and EALUA that has been designed and developed by researcher with aforesaid architecture for encounter with urban problems will be introduced. Finally, result of using EALUA will be evaluated.

**Key words:** Expert system, geographic information system, urban landuse planning

## INTRODUCTION

Landuse planning (LUP) is the systematic assessment of land and water potentials for alternative landuses considering economic and social conditions in order to select and adopt the best landuse options (FAO, 1993). Following this definition and from a more general point of view, LUP can be considered as a systematic evaluation of all land recourses for different landuses considering economic, environmental and social factors in order to allocate the best combination of landuses to a collection of land pieces. Landuse planning in general and urban landuse planning (ULUP) in special, are categorized as complicated locational decision-making problems. This complexity is mainly due to the fact that a huge amount of influential factors or variables have to be considered and that the interactions and internal dependencies between these different factors are sometimes difficult to understand (Witlox, 2005). Biophysical, climatic, demographic, economic and political variables, all directly or indirectly influence landuse practices (Turner *et al*., 1995).

Because of the complicated nature of LUP problems, they are known as ill-structured or unstructured problems. Lack of structure means that there is no procedure or algorithm for automated solving of LUP problems. In other words, they can not be solved only with an application written by a procedural programming language. Since Expert Systems (ESs) or more broadly Knowledge-Based Systems (KBSs) emulate human reasoning to reach the answer, they can be utilized in problems like LUP, where conventional programming methods are not adequate for solving them. Expert systems are especially useful when the knowledge domain for solving problem is specialized and narrowly focused (i.e., domain specific). Although, it is true that many urban planning problems are poorly defined and institutionally complex, that doesn't mean expert systems will have no role to play in planning (Ortolano and Perman, 1987). In fact, due to the generality of knowledge domain in LUP problems, the better approach is first developing a Decision Support System (DSS) to catch the problem and then extending some special aspects of existing system with inference capability of ES.

As discussed by Witlox (2005) the initial idea of integrating KBS (or ES) and DSS to create more powerful, so called intelligent and useful computer-based systems may be traced to the study of Mintzberg (1976). Mintzberg asserted that in managerial decision making, an important advantage may be realized when a problem handling approach is followed that is both analytical (i.e., use of a DSS) and intuitive (i.e., use of an ES). This idea has been given much attention recently and various names have been suggested for the integrated system such as Intelligent DSS (IDSS), Intelligent Support System (ISS), Expert DSS (EDSS), Expert Support System (ESS), or Knowledge-Based DSS (KBDSS).

So far, many urban planners have recommended the benefit of using integrated systems and on the basis of this idea numerous systems have been developed such

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as systems developed by Davis and Grant (1987), Armstrong *et al.* (1990), Reitsma (1990), Han *et al.* (1991), Okubo *et al.* (1994), Jungthirapanich and Benjamin (1995), Arentze *et al.* (1995) and Witlox (2003). In spite of many advantages of these systems, their main weakness is that many of them have no link with a Geographic Information System (GIS). GIS is a computerised system that facilitates the phases of data entry, data analysis anddata presentation especially in cases when we are dealing with georeferenced data (By *et al.*, 2000). Because of spatial essence of LUP problems, integrating a DSS with GIS, in order to supporting spatial decision-making, seems to be beneficial. The DSS enhanced by a GIS, also called Spatial Decision Support System (SDSS), has been discussed recently by several researchers, including (Cederborg and Tosetti, 1982; Tomlin and Tomlin, 1985; Gilbert *et al.*, 1985; Han and Kim, 1990; Wright, 1990; Witlox, 2005). Wright (1990) states that the role of the GIS in the proposed implementation environment would be to store, generate and manage all of the data required for landuse allocation model such as computation of distances between geographical units, the determination of areas and adjacency relationships and etc. However, more important and analytical roles can also be considered for GIS in such integration. Examples are the modeling of the changes in the effects of one parameter based on distance and the calculation and modeling of all topological relationships such as inclusion and overlap between different phenomena.

One of the major shortcomings of most of already developed systems for urban landuse planning is that they only provide a land with one or more proposed landuses. If a special landuse is considered as not suitable for a land, the reasons of the judged unsuitability can not be explained to the user. Consequently and in addition, no suggestion can be provided for the improvement of the conditions of the land for such a landuse.

As stated above, it seems that the integration of ES, DSS and GIS into a Knowledge-Base Spatial Decision Support System (KBSDSS), can be a proper solution to the complex and ill-structured problem of urban landuse planning. As part of such a solution, a system called Expert Advisor for Landuse Allocation (EALUA) has been developed. In the following sections we will focus on architecture and functionality of EALUA.

## EALUA

The EALUA, as mentioned is a Knowledge-Based Spatial Decision Support System (KBSDSS) designed to help urban planners in assessing the suitability of different landuses for pieces of lands. In general, the system helps the decision makers by performing the following three actions:

- It compares the present conditions of the site with the conditions required for the proposed landuse, which is specifically stored in the knowledge base of the system. Then result of the comparison reported to the user
- If the land is not suitable for the proposed land use, the reasons of unsuitability and how this conclusion has been gained are reported to the user
- The system is capable of proposing proper solutions to overcome the shortcomings of the land conditions, according to the violated regulations

In general, EALUA can be considered as a decision support system, whose its model base part is replaced by an expert system. In other words, it can be regarded as a tightly-coupled integrated system.

**Architecture of EALUA:** Figure 1 shows the architecture of EALUA representing its main components and subsystems. As described earlier and shown in Fig. 1, EALUA is composed of two main subsystems: the Expert System (ES) and the Spatial Decision Support System (SDSS). In fact, the ES is intuitive component of EALUA and the SDSS is the analytical part of it. That is the reason why the ES component and the SDSS part of EALUA are developed using a logical programming language (Prolog) and a procedural programming language (C#.NET), respectively.

The expert system part of EALUA is developed using visual prolog. Prolog is a logical programming language with backward reasoning. It uses First Order Predicate Logic (FOPL) for representing knowledge and a special method called resolution for reasoning. Today, prolog is more than a programming language and it has been accepted as a tool for designing and developing expert systems. Its latest version, the visual prolog, includes tools for the interactive entering and editing of both rules and facts, debugging, designing user interface, code compiling, integration with other environments that are compatible with COM protocol and many other development tools.

The other component of the EALUA-the decision support system-is in fact an extension developed in ArcGIS Desktop environment. ArcGIS Desktop is one of the most popular GIS software that provides the user with the capabilities of editing, processing, management, analysis and visualization of geo-referenced data. ArcGIS is fully extendable software. It can be customized and

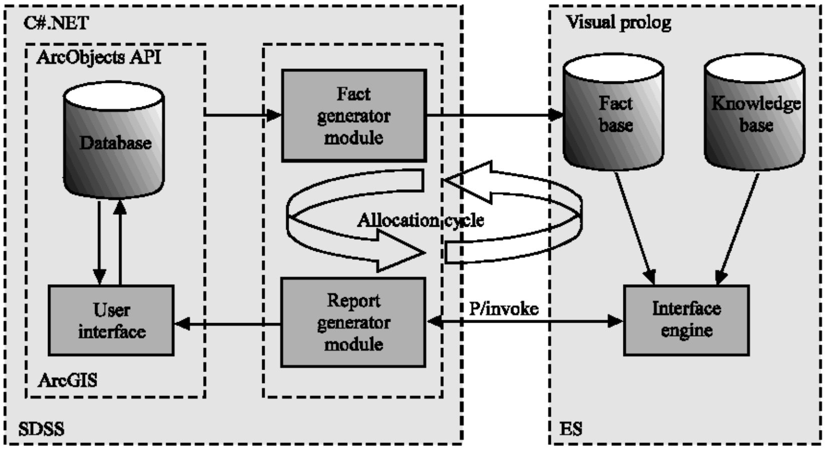

Fig. 1: EALUA architecture

extended for special applications using its application programming interface ArcObjects, which is in fact a collection of pre-developed components. The ArcObjects has been developed using COM protocol. Therefore, its components can be used in any COM compliant programming language.

## ALLOCATION CYCLE

The allocation process in EALUA is repetitive and is called allocation cycle. It can be understood from the relations between the components shown in Fig. 1.

At the beginning of the cycle, the planner specifies the proposed landuse along with some required settings via User Interface (UI) and selects a land unit for assessment in a map, interactively. Then, the Fact Generator Module (FGM) starts to build the Fact-Base (FB), using the Data-Base (DB) and the planner's options.

The fact-base of EALUA, which is actually the connector between its two main subsystems, consists of all the facts needed by the knowledge-base, including the lands, their characteristics and their interrelations. The facts are stored in the fact-base, in the form of propositions that are comparable with the knowledge stored in the Knowledge-Base (KB).

Another component of EALUA is its knowledge-base, which includes the knowledge about the conditions required for any landuse. Since, prolog is a rule-based expert system, the knowledge-base of EALUA includes a set of urban planning rules. Having the knowledge-base and the fact-base, the Inference Engine (IE) can compares the existing facts with the condition part of the rules in the knowledge-base and through reasoning, evaluates the suitability of the land for the proposed landuse.

In the next stage, prolog returns the evaluation results to the SDSS and then SDSS reports the results in a proper format to the user. In this study, if the land had been evaluated as unsuitable for the proposed landuse, the Report Generator Module (RGM) describes to the user what rules and why they have been violated. Along with this, the RGM proposes to user a set of solutions that are according to the violated rules. The SDSS also provides a set of tools that enables user to apply each solution and even combination of those interactively.

By applying the solutions, which might change the data-base, the allocation cycle is restarted and continued until either no more rule is violated or no more solution can be provided. In the former state, we say the cycle is completed successfully and in the later case, we say it is completed unsuccessfully. Figure 2 shows allocation cycle process in form of a flowchart.

**A closer look at the knowledge-base and EALUA assessment model:** As mentioned earlier, the expert system part of EALUA is developed using Prolog, which uses a backward reasoning. In backward reasoning, the reasoning starts from a hypothesis or consequent (a predicate that should be proved or disproved) and goes to the assessment of some conditions or antecedent that support it.

The backward reasoning is sometimes called goal-driven reasoning. In prolog, a rule is represented as a goal, which consists of several other sub-goals. A rule in this structure that is also called horn clause, shown as below:

$$P = P_1, P_2, \ldots, P_N$$

where, P is called the goal and $P_i$ are the sub-goals.

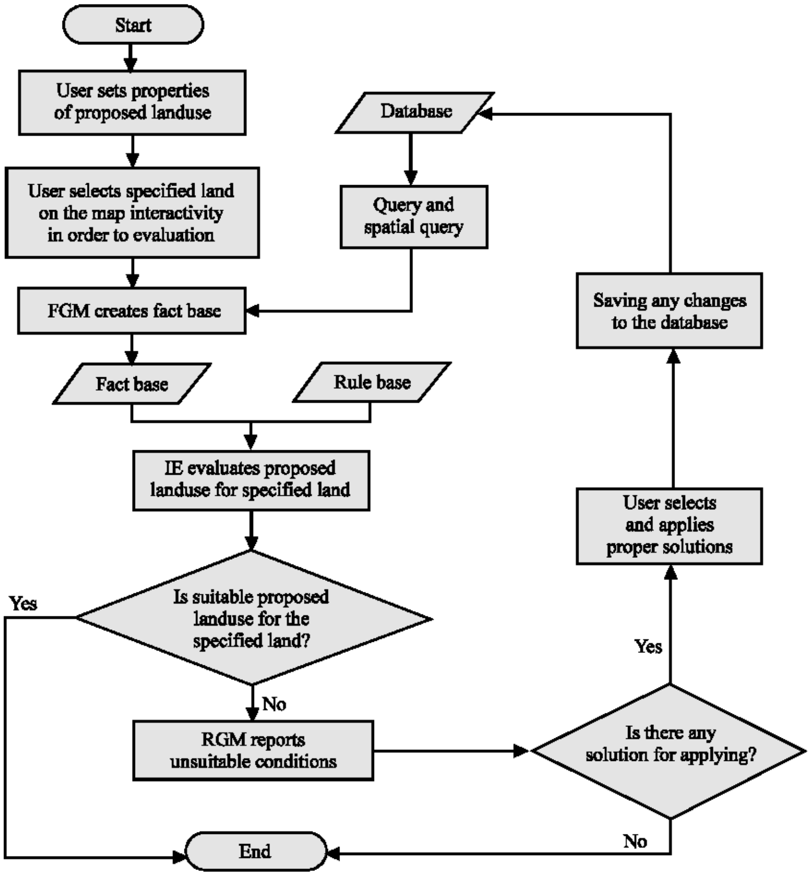

Fig. 2: Allocation cycle

Such rules indicate that the main goal is satisfied if and only if all its sub-goals are satisfied. Every sub-goal is might again satisfied through the satisfaction of some other sub-goals. This tree structure is continued until a reasoning chain is completed.

Every knowledge-base needs not only the knowledge but also a set of propositions that describe the conditions of the problem. Such propositions are called facts and a collection of them is called the fact-base. In prolog, every fact is represented as an always-true proposition and is stored in the fact-base as a rule without the condition part.

In EALUA, the knowledge-base includes a collection of urban planning regulations, collected from experts and other sources during knowledge engineering process. These rules describe the suitable conditions regarding each landuse and are specifically defined and stored as horn clauses in prolog. For example, for school landuse, two of these regulations are:

**Regulation 1:** School can not be adjacent with a main street.

**Regulation 2:** School should not have undesirable impact on its neighboring landuses.

Now, assume we want to develop a simple knowledge-base using these regulations and analyze an allocation process using this knowledge-base. To do this, first, the rules should be translated into horn clauses. But since prolog does not support location-based rules, therefore these rules with this signature can not be inserted in prolog directly. To overcome this problem in EALUA, the spatial parts of the rules are transformed to the fact-base and then the fact-base is built using GIS operators.

For example, for the above rules, the following spatial facts are defined in prolog:

**Fact 1:** Land (Lid, Lu, X, Y). This means that land with land identifier Lid has the landuse Lu and is located in position (X, Y).

**Fact 2:** Adjacent ($Lid_1$, $Lid_2$). This means that land with land identifier Lid1 is adjacent to the land with land identifier $Lid_2$.

**Fact 3:** nco ($Lu_1$, $Lu_2$, Dist). This means that land use type $Lu_1$ has undesirable impact on the landuse type $Lu_2$ up to the distance of Dist.

In addition, it is necessary to declare our predicates (goals that have sub-goals) before entering rules as follows:

**Predicate 1:** nss (Lid). This means that the landuse of school is not suitable for the land with land identifier Lid.

**Predicate 2:** Hui ($Lid_1$, $Lid_2$). This means that land with land identifier $Lid_1$ has undesirable impact on the land with land identifier $Lid_2$.

Now, regarding the regulation 1 and 2, the following rules can be asserted:

(1) nss (Lid) = Rule 1 (Lid),
Rule 2 (Lid)
(2) Rule 1 (Lid) = Land ($Lid_1$, $Lu_1$, $X_1$, $Y_1$),
$Lu_1$ = Main street,
Adjacent (Lid, $Lid_1$)
(3) Rule 2 (Lid) = Land ($Lid_1$, $Lu_1$, $X_1$, $Y_1$),
Hui (Lid, $Lid_1$).
(4) Hui ($Lid_1$, $Lid_2$) = Land ($Lid_1$, $Lu_1$, $X_1$, $Y_1$),
Land ($Lid_2$, $Lu_2$, $X_2$, $Y_2$),
nco ($Lu_1$, $Lu_2$, Dist),
$((X_2-X_1)\hat{}2+(Y_2-Y_1)\hat{}2)<Dist\hat{}2$

Having the knowledge-base accomplished, now the fact-base should be completed. For example, suppose the situation shown in Fig. 3. Assume that the planner wants to assess the suitability of the land with land identifier 1 for school landuse.

Also suppose that we know according to the urban planning regulations, the distance between a school and a hospital should be at least 200 m. As discussed, at first, EALUA translates the problem situations into a set of facts and stores them in the fact-base using FGM. For example, for this condition FGM create following fact:

(1) nco (School, Hospital, 200)

Since, the FGM is connected to GIS, it can extract the required spatial information, such as the adjacency and proximity relations from spatial data-base, using GIS operators. Such information are also translated to facts and stored in the fact-base. For example, according to the Fig. 3, the following facts are generated:

(2) Land (1, School, $x_1$, $y_1$)
(3) Land (2, Hospital, $x_2$, $y_2$)
(4) Land (3, Major road, $x_3$, $y_3$)
(5) Adjacent (1, 3)

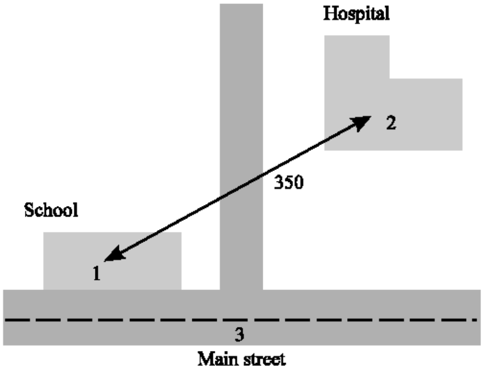

Fig. 3: Land map

Now, the system is ready for the assessment of any land against school landuse. For example, to assess the land identified as 1 we could ask the system:

?- nss (1)

This question tries to prove that the land 1 is not suitable for school. Since the land is adjacent to a main street, the answer to the question is positive, meaning that the land is not suitable. Obviously, rule 2 isn't violated, because the distance between hospital and school is more than 200 m.

After this assessment, the RGM explains the results to the user and the also provides the user with some suggestions for solving the problem, using the meta-knowledge. For example, one of the solutions could be to split the land into two lands, such that one of them is not adjacent to the street. Such a splitting is done interactively, using a user interface in GIS.

Applying any of the provided solutions, the database and the fact-base might change. As a result, some of the rules might be satisfied, while some others may be disobeyed. For example, by splitting the land, the resulted fragmented lands may be smaller than what is needed for a school, which necessitates the allocation cycle to be repeated.

Therefore, the process of allocation in EALUA is repetitive and also supervised. It means that the system with contribution of planner, in a repetitive process completes allocation cycle.

## CONCLUSIONS

In this study, it was shown that the integration of ES, DSS and GIS into a Knowledge-Base Spatial Decision Support System (KBSDSS), can be a proper solution to the complex and ill-structured problem of urban landuse planning.

Most of the earlier developed systems for urban landuse planning can only provide a land with one or more proposed landuses. In the system resulted from this research, the planner can verify the suitability of any landuse for a piece of land. If the land is evaluated as not suitable for that landuse, the reason for that can be explained and reported to the planner.

In addition, proper suggestions can be provided for improving the conditions of the land for such a landuse. The planner can try any of the provided solutions and see the results interactively. Implementing any of the solutions the allocation cycle is repeated and the new problems, if any exists, are reported again. In such a repeating interaction between the human expert and the system the realistic suitability of the land for the considered landuse is evaluated. This approach has the advantage that the land with minor and trivial shortcomings are not simply looked over and assessed as unsuitable. They will have the chance to improve and make up for their limitations regarding a special land use.

## REFERENCES

Arentze, T.A., A.W.J. Borgers and H.J.P. Timmermans, 1995. The integration of expert knowledge in decision support systems for facility location planning. Comput. Environ. Urban Syst., 19: 227-247.

Armstrong, M.P., S. De, P.J. Densham, P. Lolonis, G. Rushton and V.K. Tewari, 1990. A knowledge-based approach for supporting locational decision making. Environ. Plann. B, 17: 341-364.

By, R.A., R.A. Knippers, Y. Sun, M.C. Ellis and M. Kraak *et al.*, 2000. Principles of Geographic Information Systems. ITC Educational Textbook Series, Netherlands, ISBN:1567-5777.

Cederborg, E.A. and R.J. Tosetti, 1982. Site selection for low level radioactive waste disposal sites. Proceeding of the Symposium on Waste Management Arizona, Technical programs and public communications Ltd., pp: 215-233.

Davis, J.R. and I.W. Grant, 1987. ADAPT: A knowledge-based decision support system for producing zoning schemes. Environ. Plann. B, 14: 53-66.

FAO, 1993. Guidelines for Land Use Planning. FAO Development Series 1, Rome, Italy, ISBN: 1020-0819.

Gilbert, K.C., D.D. Holmes and R.E. Rosental, 1985. A multiobjective discrete optimization model for land allocation. Manage. Sci., 31: 1509-1522.

Han, S.Y. and T.J. Kim, 1990. ESSAS: Expert System for Site Analysis and Selection. In: Expert Systems: Applications to Urban Planning, Kim, T.J., L.L. Wiggins and J.R. Wright (Eds.). Springer-Verlag, UK., ISBN: 0-387-97171-8, pp: 145-158.

Han, S.Y., T.J. Kim and I. Adiguzel, 1991. XPLanner: A knowledge-based decision support system for facility management and planning. Environ. Plann. B, 18: 205-224.

Jungthirapanich, C. and C.O. Benjamin, 1995. A knowledge-based decision support system for location a manufacturing facility. IIE Transactions, 27: 789-799.

Mintzberg, H., 1976. Planning on the left side and managing on the right. Harvard Bus. Rev., 54: 49-58.

Okubo, T., K. Kubo, M. Hosomi and A. Murakami, 1994. A knowledge-based decision support system for selecting small-scale wastewater treatment processes. Water Sci. Technol., 30: 175-184.

Ortolano, L. and C.D. Perman, 1987. A planner's introduction to expert systems. J. Am. Plann. Assoc., 53: 98-103.

Reitsma, R.F., 1990. Aspects of site suitability assessment in a decision support environment. Ph.D. Thesis, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Tomlin, S.M. and C.D. Tomlin, 1985. Computer-assisted spatial allocation of timber harvesting activity. Proceeding Auto-Carto 5. Crystal City, Aug. 22-28, Virginia, pp: 677-689.

Turner, B.L., D. Skole, S. Sanderson, G. Fischer, L. Fresco and R. Lemans, 1995. Land use and land cover change science research plan. IGBP Report No. 35 and IHDP Report No. 7, Stockholm and Geneva. http://www.ihdp.unibonn.de/html/publications/reports/report07/luccsp.htm.

Witlox, F., 2003. MATISSE: A relational expert system for industrial site selection. Expert Syst. Appl., 24: 133-144.

Witlox, F., 2005. Expert systems in land-use planning: An overview. Expert Syst. Appl., 29: 437-445.

Wright, J.R., 1990. ISIS: Toward an Integrated Spatial Information System. In: Expert Systems: Applications to Urban Planning, Kim, T.J., L.L. Wiggins and J.R. Wright (Eds.). Springer-Verlag, UK., ISBN: 0-387-97171-8, pp: 43-66.