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GIS for spatial decision making

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GIS for spatial decision-making

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ABSTRACT

GIS for spatial decision making

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The motivation for this research is based on the recognition that Geographic Information Systems still suffer from certain shortcomings that prevent their utilization as fully-fledged spatial decision support systems. These shortcomings are mostly related to: (1) inappropriate logical foundation, not allowing for any imprecision in information, and (2) low level of intelligence in terms of handling declarative and procedural knowledge. To overcome these shortcomings and to provide a better and more flexible environment for complex spatial problem solving, current GIS will have to be integrated with decision-making tools drawn from other disciplines.

The purpose of this study was to develop a practical approach for the integration of GIS and Knowledge Based Systems (KBS) to support site suitability assessment and environmental impact prediction. This integration is seen as important for spatial decision-making because spatial problems are often unstructured requiring heuristics and other knowledge based techniques.

In an effort to meet the above requirements this study proposes a prototype Knowledge-based GIS (KBGIS) that would be able to anticipate conflicts between development and environment at an early stage of project planning. This prototype KBGIS is based on an evaluation model developed by UNEP/UNCHS (habitat). The objective of this research was to reconfigure this initial model and to convert it into the aforementioned prototype KBGIS.

In essence, the whole research revolved around the idea of building an integrated set of computer-assisted procedures into a system that can be used as a tool to anticipate possible conflicts between development and environment. To fulfil such a task it was necessary to integrate the basic functionality of GIS with elements of a Knowledge Based System. A study of related literature revealed a number of models for the integration of GIS and KBS. The aim of this research was to develop an example of a fully integrated model of GIS and KBS by including elements of KBS techniques as one of the subroutines of a GIS. The idea of the proposed prototype KBGIS was to put the model, data, domain knowledge, as well as the system's knowledge acquisition and reasoning mechanism together in a GIS environment and within one single application with shared communication routines, a common interface and data structure.

The study shows that integrating different information technologies - in this case GIS with KBS is a very useful approach in supporting ill structured spatial problem solving tasks.

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INTRODUCTION

1.1 Background

Identifying the suitability of particular sites for urban development is one of the critical issues of urban and regional planning. The evaluation is usually made by means of identifying a complex array of physical and socio-economic factors, influencing the suitability of a site for urban development. The cumulative effect of these factors determines the degree of suitability and also helps in further classification of space into different priorities for development.

The determination of site suitability can also be accomplished by analysing the interaction between three sets of mutually related factors: namely ***locations, development actions and environmental effects*** (J. Lyle, P. Stutz, 1990). This means that when carrying out certain development actions and control of specific environmental effects, it is possible to identify the most suitable location for these actions and also the potential environmental effects (conflicts) that could result from these actions. This approach incorporates a close connection between ***site suitability assessment and environmental impact prediction***, introducing environmental compatibility criteria as one of the fundamental determinants in the site selection process. It assumes that variation in environmental character of a landscape renders some areas more suitable for supporting certain development actions than others and that the difference can be very important to environmental quality.

Environmental compatibility assessment in site selection processes, as described above, is a task that requires consideration of a comprehensive set of factors. Therefore, its effective use requires a flexible system capable of storing; manipulating and transforming a large volume of spatially oriented data into usable information. With the recent development of computer hardware and software technology, Geographic Information System (GIS) has emerged as a useful computer-based tool in supporting a variety of location and planning tasks. The major benefits of GIS come from their powerful capabilities in the fields of spatial data management, spatial analysis and visualisation. These advantages are reflected in two general areas:

1) Improved and flexible management of location-related data and,

2) Effective and faster data manipulation and preparation of information to facilitate location-related decision making tasks.

The latter is manifested primarily through the ability of GIS to support more precise and faster spatial overlay analysis, and consequently, the effective testing of a greater number of possible options. In contrast, the traditional manual decision-making processes often skipped this part due to the tedious nature of developing and testing alternative solutions.

Many researchers in planning and environmental management tend to define GIS as a decision support system (DSS). There is however little agreement on what a DSS is and what a DSS actually constitutes. The more widely accepted definitions of DSS identify it as an interactive system, providing the user with easy access to data and decision models in order to support semi-structured or unstructured decision-making tasks. As the above definition implies, the interaction between user and the system is very important in DSS. The system provides the tools (database management tools, application specific models and modelling capabilities) along with a user-friendly interface, while the user (decision-maker) incorporates objectives, criteria, judgement and relevant data to solve the problem at hand.

In terms of these definitions of DSS, it seems that GIS cannot be regarded as a fully developed DSS. In spite of the significant capabilities, GIS lacks support for the use of problem oriented decision models usually required by planners and all others with interests and responsibilities in planning and environmental management. Common to all definitions of DSS is the requirement that they must provide explicit models and capabilities to support particular types of decision. In other words, while GIS systems may contain data and information that can be more readily accessible and more flexibly modified to meet the needs for location-related decision-making tasks, they are usually general-purpose data management and analysis systems. As a result, few current GIS systems provide any particular problem related models usually needed to fully support decisions in various fields of human activities, including site selection and environmental compatibility assessment.

Another reason why a GIS is not completely suitable as a DSS is connected to the complexity of the GIS technology built upon a variety of scientific disciplines (cartography, remote sensing, computer science, statistics, etc). Consequently the use of GIS requires not only expertise for problem solving but also an extensive background in digital data management and mapping science as well as the technical knowledge to use the available GIS system. Because of this complexity, standard GIS tends to divert the process of decision making away from decision makers into the hands of the GIS specialist and a host of other highly trained technology experts.

To improve the above-mentioned situation the concept of a GIS based Spatial Decision Support System (SDSS) is receiving increased attention. The reason for this is the acceptance that GIS has the potential to assist spatial decision-making. This concept extends the present use of GIS as a DSS, to a situation where GIS can be used as a generator to build DSS for a specific spatial problem domain (P.Keenan,1997). As defined by Densham (1990), a SDSS can conceptually be thought of as providing an integrated set of flexible capabilities in supporting semi-structured or ill-defined location problem solving tasks. The key to a useful SDSS is basically the integration of GIS and its analytical capabilities with statistical and other application specific models. Such integration seems to have the necessary power and flexibility to assist decision-makers in the process of solving various specific spatial problem-solving tasks.

One example of integration is the linkage between GIS and expert systems (ES), often referred to as an intelligent SDSS, or a knowledge based GIS. Expert systems (or Knowledge based systems) have evolved as a branch of Artificial Intelligence (AI) and from a GIS perspective they seem to be the principal area of AI applications in GIS. In general, an ES can be regarded as a kind of computer system that attempts to behave in an intelligent manner by the explicit incorporation of human knowledge for the problem at hand (S. Openshaw, 1997). The essence of ES is that it attempts to incorporate the judgment, experience and intuition of human experts into problem solving. What actually makes ES a powerful approach is an appropriate use of heuristics or heuristic rules as a set of tools for problem solving whenever mathematical, statistical and other formal methods would be less effective or impractical for deriving optimal solutions (Ignizio, 1991). One of the typical characteristics of heuristics is its screening, filtering or pruning mechanisms by the use of IF...THEN statements that represent knowledge or guidelines through which the system may operate (Ignazio, 1991).

Incorporating a knowledge-based approach to enhance GIS has been found particularly valuable in site suitability assessment, specifically in the environmental domain. This is because the decision-making process in these spatial problem-solving areas is very often ill structured, requiring heuristics, and therefore knowledge based techniques to be applicable. The idea is to use GIS as a proper tool for visualisation, manipulation and analysis of spatially referenced data and their attributes for the problem at hand, while ES would provide a basis for catching the essential information from database and converting it into practical advice.

1.2 Research Objective

The purpose of this research is to see how GIS can be used to support site suitability analysis for urban development. This is done by using an existing manual decision-making process developed by UNEP-UNCHS (Habitat) and converting it into a spatially enabled decision support system – a Knowledge Based GIS (KBGIS). The UNEP model is essentially based on a checklist of problems and can be seen as a screening and diagnostic process for the identification of interactions between three sets of mutually related factors, namely location, development actions and environmental settings. It involves the assignment of qualitative labels to site-specific development-environment conflicts based on the available data on the physical environment and the planned development action, as well as a set of generic rules (facts) for assessing and grading the likely consequences. The UNEP model was developed to promote environmentally sound planning and management. It has been implemented on several occasions, but within the framework of manual processing techniques.

This proposed prototype system is intended to function as an intelligent - computer-based consultant in assisting screening and diagnostic processes in site suitability assessment and development-environment impact prediction. The purpose of its development is twofold, namely:

1) To present a practical example of using GIS in automating problem specific and ill-structured decision making tasks, and what is even more important,

2) To illustrate the usefulness of incorporating the elements of knowledge based techniques to enhance the level of intelligence of current GIS systems and their ability to assist decision-makers in the process of deriving facts from existing data and conditions.

This research is based on the recognition that the usefulness of a "conventional" GIS in automating the above-mentioned model for development-environment compatibility assessment could be improved by incorporating (embedding) the elements of knowledge based systems (KBS). The model and the evaluation approach it supports are in that regard seen as an appropriate problem domain that can be facilitated by integrating the strength of GIS and KBS. Such integration seeks to provide a decision-support environment that can be effectively utilized by both:

1) Users with limited (if any) knowledge of GIS at a practical level, and

2) Users lacking the experience in the area of site suitability assessment and environmental impact prediction.

1.3 Organisation of the Document

This document is structured into five chapters. The present chapter covers the introduction to this research. It provides the background, problem statement as well as the objective and motivation for the research.

Chapter 2 seeks to clarify the directions of this research. It is divided into four parts. The first part explains the strength of GIS technology in supporting spatial problem-solving tasks. The second part discusses the concept of a Spatial Decision Support System (SDSS). Emphasis is put on the role of GIS in providing a decision support framework for ill-structured spatial problem solving. This includes a review of the different approaches to the integration of GIS with analytical and modelling tools drawn from other disciplines as well as some relevant empirical examples. The third part is focused on issues concerning the integration of GIS and KBS in an effort to provide an intelligent decision-making tool for spatial problem solving. It starts with an overview or the basics of a KBS system and includes a description of its components and a summary of the essential steps involved in its development. Finally, the relevance of the different approaches as it applies to the purpose of this research is summarized.

Chapter 3 outlines the model for the identification of development-environment conflicts at the early (screening level) stage of the project planning process. The chapter starts with an explanation of the purpose of the model, and a description of its fundamental components. It ends with the presentation of a typical evaluation session supported by the model. The purpose is to illustrate the organisation of the information system as well as the evaluation approach and procedures. Material in this chapter constitutes the basis for the development of the proposed prototype KBGIS.

Chapter 4 explains the strategy followed in this research to develop the prototype KBGIS. It firstly deals with the components of the information system that supports the model, focusing on the issue of their organization, form and format within the prototype KBGIS environment. The second part of this chapter seeks to explain the GIS-KBS interfacing strategy. It also includes a brief illustration of the prototype KBGIS structure along with a description of its basic components and functions. The chapter ends with a detailed presentation of the system's modules and capabilities.

The final chapter provides a summary of the more important findings and achievements of this research.

CHAPTER 2

GIS AND DECISION SUPPORT

A REVIEW OF LITERATURE AND PREVIOUS RESEARCH

2.1 Spatial Decision Making and Computerized Support

Information plays a crucial role in the decision-making process in the planning, site selection and environmental management domain. It is well known that planning starts with the collection of data and information to describe the state and condition of the real word. The purpose of gathering, processing and integrating data and producing information is to understand the environment wherein the planning activities take place. It is accepted that a better understanding of the environment facilitates better planning and decision-making (Harris, 1987). As indicated by O'Hare (1983) poor location decisions in facility placing may result from a variety of factors, the most common of which is an uninformed land use planner.

Some authors (Hopkins and Schaeffer, 1985) see planning, site selection and environmental compatibility assessment as information-producing activities that are performed to reduce the inherent uncertainties in decision-making. Here the major role of a planner and/or analyst is to produce and analyse quality information to aid effective decision-making.

Catanese (1979) and Harris (1987) have clarified the meaning of information by constructing a hierarchy of data (Figure 2.1). They emphasize a progression from observation to data, data to information and information to intelligence. As shown in Figure 2.1 data may be explained as a one-to-one relationship between observation and real word phenomena under concern, while information, on the other hand, is organized data resulting from aggregation, manipulation and other statistical, mathematical, or algorithmic manipulation of data. Information is derived from data to develop specific knowledge necessary to solve a problem or to show patterns or directions.

The whole process of data/information collection and knowledge generation for the problem at hand is a time-consuming activity often requiring more than half of the resources available to the decision-maker. This is also one of the issues that have hampered planning practice.

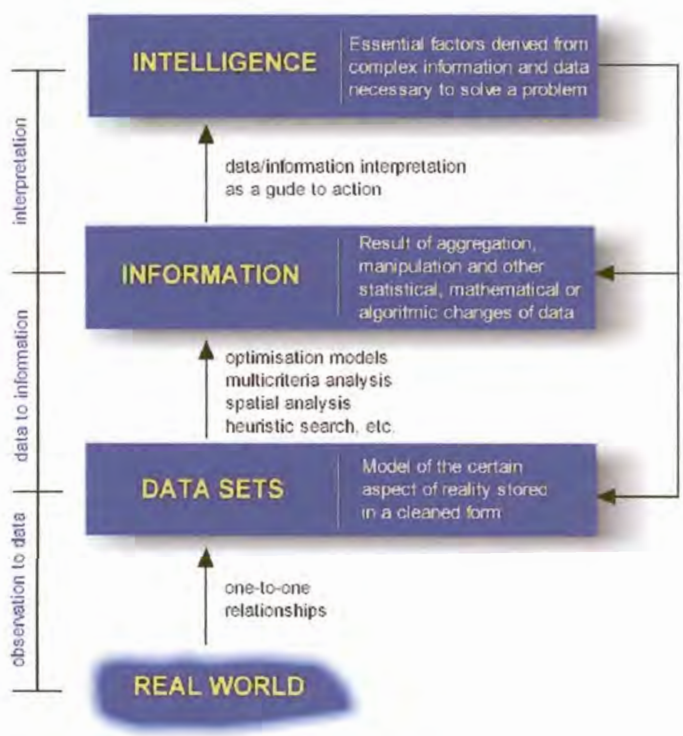

Figure 2.1. Hierarchy of Knowledge, Catenese (1979)

From the viewpoints mentioned above it is apparent that data and information plays an important role in any planning and environmental problem solving task. These tasks are usually information intensive and unstructured, and their effectiveness relies heavily on the availability of efficient tools for data and information manipulation.

General consensus exists in the relevant literature that the advancement of computer and information technology over the last few decades has had a very significant impact on planning, site selection and environmental compatibility assessment. This is mainly due to the extraordinary characteristics of microcomputers, especially in terms of their accessibility, high-speed computational ability and capacity for data/information processing. In addition to this, the development of various computer-based Information Technologies (IT), including Geographical Information Systems, has provided many new ways to work with the spatially related problem solving tasks.

According to *K. Foote and M. Lynch (1997)* many innovations in the application of information technologies in environmental and planning fields began in the late 1950s, 1960s and early 1970s. During that time, methods of sophisticated mathematical and statistical modelling, various environmental models, as well as location-allocation modelling techniques were developed and the first remote sensing data became available. Furthermore, researchers also began to envision the development of Geographic Information Systems. The mid-1970s to early 1990s was a period of far-ranging IT experimentation and development trying to determine how the innovation could be adapted to meet a wide variety of research and commercial needs (K. Foote and M. Lynch, 1997). The same authors emphasized that this was a time in which the development of powerful software coupled with the availability of inexpensive computers permitted many researchers to test new ideas and applications for the first time. In the early 1990s, or perhaps a bit earlier, many of these innovations gradually gained acceptance and were developed collaboratively. The strengths and weaknesses of many information technologies were by then apparent, and researchers began to work together to cultivate the most promising applications on a large scale (K. Foote and M. Lynch, 1997). Two of these IT innovations that attracted considerable attention are GIS and Decision Support Systems (DSS) along with their applications.

2.1.1 Geographic Information System (GIS)

For spatial problem solving tasks in general, and environmental modelling projects in particular, GIS is seen as a convenient and well-structured toolbox. Concepts and techniques of GIS have been extensively discussed in the literature. What follows is a brief discussion of these concepts and techniques.

One of the strengths of a GIS lies in its ability to store, relate and manipulate large volumes of spatial and associated attribute data from diverse sources and formats. GIS is not simply a computer-based system for making and manipulating maps. On the contrary, in respect of the data it deals with, it can be thought of as a special type of database management system (DBMS) distinctly different from the other types of database systems. What distinguishes GIS from other systems is the ability to handle spatial data, to perform spatial operations, and to create new information based on spatial relationships[1] (Cowen, 1988).

Because of GIS's ability to display spatial data in graphic form it is often confused with computer-aided mapping and design systems (CAM/CAD). Although CAD and in particular CAM systems can perform many operations similar to GIS, it is the analytical capabilities of GIS that distinguishes GIS from CAM/CAD.

The abilities of GIS to relate and integrate different data sets and to perform spatial operations on data provide planners and others responsible for location-oriented decision making tasks with a convenient tool for information management, analysis and visualization. Generally, GIS functions can be classified into four categories.

1) Data input
2) Data storage, retrieval, and query
3) Data analysis, and modelling,
4) Data visualisation and reporting

Data input includes functions for capturing, processing and transforming spatial data. The spatial data can be derived from existing maps, aerial photos, satellite images, direct digital inputs, map and image scanning, surveying and other sources. The data input component, and in particular, digitising (converting data from analogue format to one that can be used by GIS) is typically the major bottleneck in the implementation of GIS. It should be pointed out that the development of a large, inventory-related database is a time-consuming and, costly process. Data input, apart from data capturing or format transformation, requires editing operations to verify digital data against the original source.

The second group of GIS functions, that is data storage, retrieval and query aims to organize spatial data into a flexible and topologically structured format which permits it to be shared, updated, and quickly and effectively retrieved on the basis of either spatial or non-spatial queries. The storage and retrieval capabilities of GIS provide users with a superior filing system for a location-based inventory. Thus, large volumes of spatial data from diverse sources and formats can be organized into a single database and incorporated into a common base map. This prevents data redundancy and inconsistency problems often occurring when data are manually maintained and updated.

In addition to its role as a spatial database management and retrieval system, GIS also provides the means for supporting spatial analysis and modelling. This group of functions, unique to GIS, takes advantage of the GIS ability to bring spatial and attribute data together. They perform a number of tasks, such as map overlay, reclassification (changing the format of data through user-defined aggregation rules), proximity analysis, buffer zone generation, etc. These functions and the ability to integrate data justify the use of GIS for location-related tasks.

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[1] *Because a GIS can perform sophisticated data manipulation and spatial analysis it would be more appropriate to see DBMS is a part of GIS. Accordingly, GIS can be viewed as a collection of specialized tools (routines) linked to a relational database management system.*

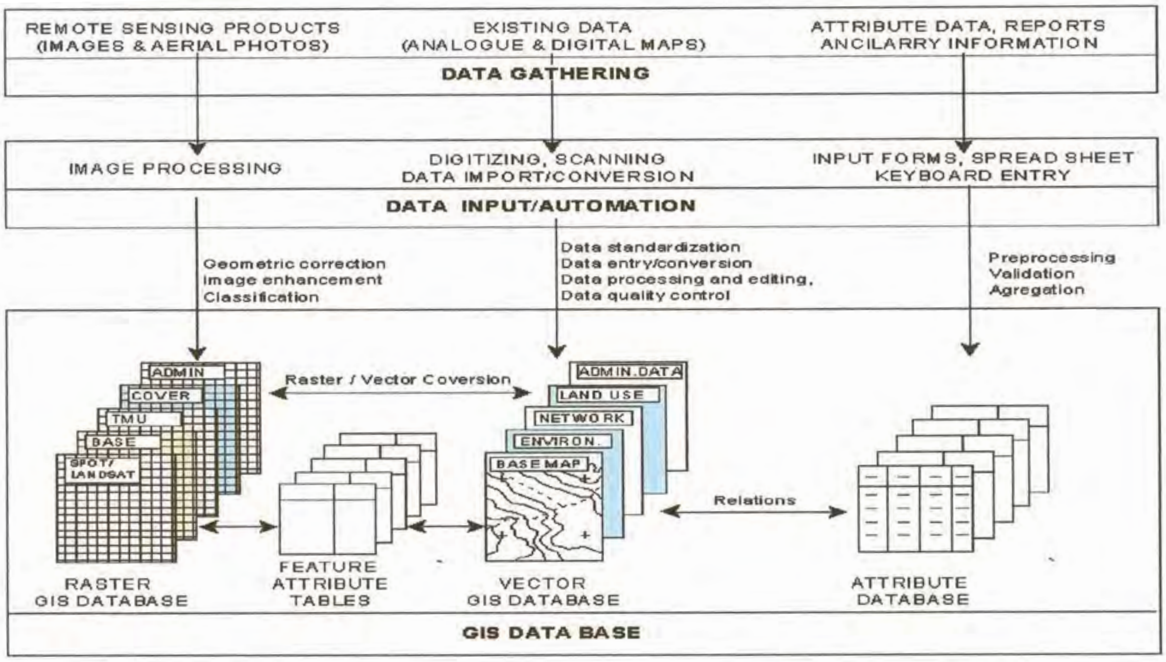

Figure 2.2 GIS data gathering and input procedures (After C. Valenzuela, 1988)

2.1.2 Spatial Decision Support Systems: Context, Concept and Definitions

Decision Support Systems in location and environmental planning fields began to appear during the 1970s and since then they have received a lot of attention in related literature. During this period DSS have been accepted as a specific field of study and practical applications have shown that there are advantages in using them for decision-making. The last decade showed the most rapid growth in DSS development. This development was made possible by the advances in computational capacity, clearer understanding of decision making, design of user-friendly software and operating systems, progress in artificial intelligence coupled with growing familiarity with computers among decision makers.

While there are many definitions of a DSS, there seems to be a general consensus that these systems are usually focused on specific types of decisions and on supporting rather than replacing the user's decision making process (P. Keenan, 1997). They are usually regarded as interactive systems providing the user with easy access to database management and problem specific analytical tools, as well as decision models capable of supporting unstructured decision-making tasks. As the above definition implies, the interaction between user and the system is very important in DSS. The system provides database management tools, application specific modelling capabilities along with a user-friendly interface, while the user (decision-maker) incorporates objectives, criteria, judgement and relevant data for the problem at hand. Their purpose, therefore is not only to automate the decision-making process, but also to aid decision makers in formulating alternatives, analysing their impacts, and interpreting and selecting appropriate options for implementation (Adelman, 1992).

In addition to the increased attention given to DSS there is also a growing interest in the concept of spatially enabled DSS or Spatial Decision Support System (SDSS). The development in SDSS represents an effort to address spatial problem solving and decision making. The term Spatial

Decision Support System implies capabilities for manipulating and analysing spatial data. From the functional point of view, they allow the representation and manipulation of complex spatial data structures, and they include analytical tools for spatial, geographical and other related analysis.

The concept of Spatial Decision Support System was initiated in the late 1980s (Densham and Armstrong, 1986; Densham and Goodchild, 1989). However, the most rapid growth of these systems has occurred in the last six to seven years. During this period many authors addressed the potential of SDSS to support location planning, site selection and environmental compatibility assessment (Densham, 1992; Fedra, 1994; Kim et al, 1993; Mejia-Navarro & Garcia, 1995; Keenan, 1995; Ehler, Cowen & Mackey, 1997). These authors pointed out that the SDSS concept is a feasible solution for improving decision-making processes in the location and environmental planning fields by providing users (decision-makers) with a flexible problem-solving environment. Here, the term "flexible problem-solving environment" refers to easy-to-use and interactive computer based systems that are capable of assisting decision makers to effectively formulate a set of alternatives on the basis of their consequences for the problem at hand.

This definition of SDSS could however refer to almost any computer-based system capable of supporting spatial problem solving. Therefore a further clarification of SDSS is required firstly by emphasizing the fact that that these systems are designed to support specific subsets of spatial related problems. Geoffrion (1983) identifies six distinguishing characteristics of DSS that are also relevant to SDSS:

1) *"They are used to tackle un or semi-structured problems – these occur when the problem, the decision-maker's objective, or both, cannot be fully or coherently specified;*

2) *They are designed to be easy-to-use allowing, sometimes very sophisticated computer technology to be accessed through a user-friendly front end;*

3) *They are designed to enable the user to make full use of all data and models that are available, so interfacing routines and data base management systems are important elements;*

4) *The user develops a solution procedure using models as decision aids to generate a series of alternatives;*

5) *They are designed for flexibility of use and ease of adaptation to the evolving needs of the user;*

6) *They are developed interactively and recursively to provide a multiple-pass approach which is in contrast with the more traditional serial approach – involving clearly defined phases through which the system progresses."*

There is a general consensus that the development of the SDSS concept is an appropriate response to the problems that impede current practice and quality of a decision making processes in location and environmental planning fields. In spite of increased use of information technologies in these planning activities, it has been pointed out that most planners and/or decision-makers have not taken full advantage of the available technologies. The reasons for this are mostly connected to the issue of their complexity, which generally tends to divert the process of decision-making away from decision-makers into the hands of highly trained technology specialist and experts. Although there is a lack of case studies in which the performance of SDSS have been evaluated, it is generally believed that such systems could be a feasible solution for improving the linkage between available IT technology, data/information environment and spatial decision making. As indicated by various authors (Fedra, 1994, Klosterman, 1994, Saenz 1997) the major benefits of SDSS are the ability to extend the boundary of rationality and comprehensiveness as well as quicker and more objective decision-making, cost reductions and improved productivity.2

From a design point of view, many definitions of SDSS describe them as a combination (or integration) of different components. Densham (1992) for instance defines the components of a "true" SDSS as an integration of a spatial database management system with analytical modelling capabilities, a visualization component or graphical user interface, and the decision-making knowledge for the problem at hand. He argued that the development and implementation of such systems could be achieved by using a set of linked software modules capable to provide an integrated set of flexible capabilities for solving the specific spatial problem (See Figure 2.3)

The Spatial Decision Support System and Data Visualization Report (CIESIN, 1997) is another constructive effort to summarize the common key components of a SDSS reflecting both its architecture (structure) and its capabilities. These components are summarized in Table 2.1.

Table 2.1 - Common Key Components and Capabilities of a SDSS

Components	**Capabilities**
Model Management System	Allows for efficient iteration between design development and calculation of impacts, including feedback for the problem at hand; Allows for automatic calculation of attributes for each feature in the scenario design; Allows for automatic checking of compliance with constraints imposed on the design; Support the development of models as well as the use of existing models for the evaluation of scenario design; Allows the integration of spatial objects in the model components
Database Management System	Provides capability for spatial manipulation, and, Provides storage and retrieval capability of entire design scenarios and ability to track scenario development
Display and Report Generator	Provides automatic report generation with graphics and text; Provide links to other programs
User Interface	Provides a graphical user interface; Provides interactive scenario development; Allows user modification of scenario; Provides configurable links to geo-referenced models; Provides selectable user levels

Adopted from: Spatial Decision Support System and Data Visualization Report, 1997, CIESIN

[2] *It is worth to mention that a laboratory experiment undertaken by Mennecke, Crossland and Killingsworth (1998) to investigate the decision maker's performance when using SDSS speaks in favour of the above observations. That research, although unique, examined two independent variables: task complexity (i.e., low, medium, and high complexity, and SDSS use (i.e., no SDSS versus SDSS support) and the results confirmed that the use of a SDSS has an important impact on decision quality and solution time.*

Many authors (Armstrong and Densham (1990), Saenz (1997), Fedra (1994), Kim et al. 1993) feel that expert or knowledge-based systems and other artificial intelligence tools can complement the analysis and modelling capabilities of SDSS. It is also widely accepted that the use of these systems and tools can guide decision-makers in their spatial problem-solving task and also assist them in deriving new facts from existing data and conditions.

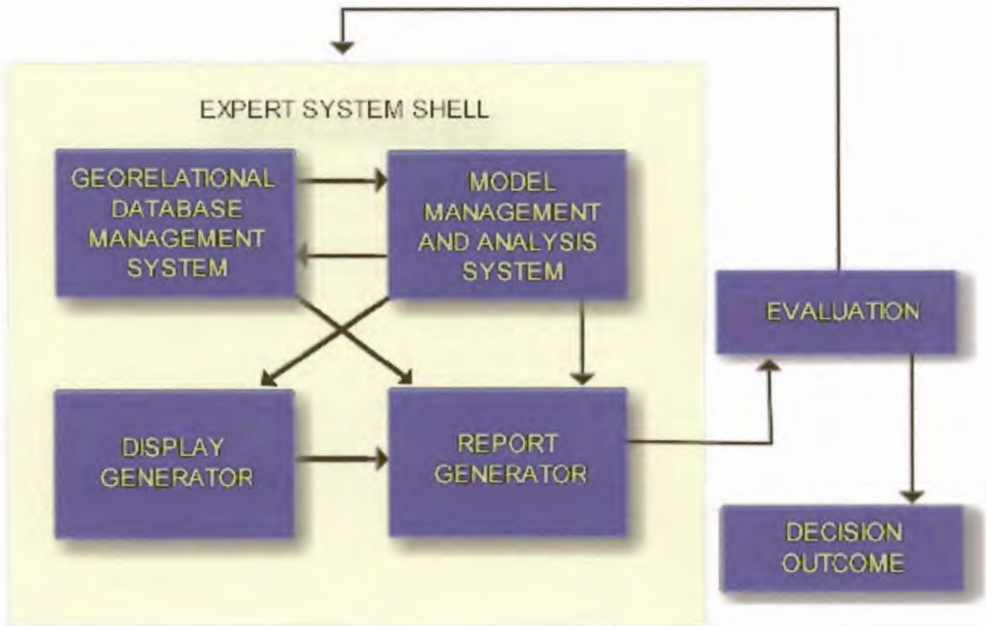

Figure 2.3 *Components (software modules) for Spatial Decision Support System (Adopted from Armstrong, Densham, 1990)*

Bearing in mind the multidisciplinary nature and the diversity of applications in the field of location and environmental planning, it is very unlikely that any SDSS will have all of the characteristics mentioned above. Some of them, depending on the goals of the system and the complexity of the spatial problem, might be simple and include only a few capabilities. The others might be more demanding, requiring the integration of various models and the use of expert systems and/or other artificial intelligence tools in order to provide effective decision support.

2.1.3 Geographic Information System as a Spatially Enabled DSS

The potential for growth of SDSS both in the field of research and practical application has been facilitated by the development of spatial technologies of which Geographic Information System (GIS) is the most important. Since the late 1980s, GIS has been recognized as the appropriate technology, or foundation stone for SDSS development. There is a general consensus that this technology provides users not only with an array of tools for managing and linking attribute and spatial data, but also for analysis and the visualization of model outputs. While many of these capabilities also exist in other systems, such as visualization and virtual reality systems, as well as CAM/CAD systems, GIS is unique. It is still the main spatial technology to date because of its emphasis on supporting analysis and providing users with a representation of objects in a common and cartographically accurate spatial system.

According to Armstrong and Densham (1990) SDSSs are evolving from GIS in the same way that DSS evolved from management information systems. Saenz (1997) also pointed out that of all computer-based technologies being integrated into DSS, GIS is perhaps the most popular. This is reflected in the increasing number of research and development papers referring to SDSS at various GIS conferences (ESRI International User Conferences 1996-1999; International Symposia on Spatial Data Handling, 1995; International Conference/Workshop on Integrating GIS and Environmental Modelling, 1997; Joint European GI Conference, 1997, etc.). Muller (1993), in his review of GIS, also identified SDSS as a growing area in the application of GIS. Fedra (1994) commented on the importance of GIS for SDSS development as follows: "in a hefty volume on Computerized Decision Support Systems for Water Managers (Libido et al., 1989) a conference proceedings, of close to 1000 pages, GIS is not mentioned once (at least according to the subject index). In contrast, and three years later, at a session of the 1991 General Assembly of the European Geophysical Society, dedicated to Decision Support Systems in Hydrology and Water Resources Management, more than half the papers discuss GIS as a component of the research method (EGS, 1991)". While this literature search was neither systematic nor exhaustive, it certainly indicates that GIS has become an emerging field with a lot of potential for SDSS development.

Many authors, relying on GIS for a variety of routine decision support and analysis applications, tend to go further and define GIS as a SDSS. Cowen (1988) for instance has characterized GIS as "a decision support system involving the integration of spatially referenced data in a problem-solving environment". Mennecke (1998) also identified GIS as a spatially enabled decision support technology. These definitions however seem to suffer from a lack of agreement on what a SDSS is and what it actually constitutes. Keenan (1997), Densham (1992), Fedra (1994), and many others argued that defining GIS as a type of SDSS is not supported by the DSS literature and that the capabilities of many of these systems are insufficient to assist decision makers in their deliberations. They also pointed out that GIS applications are often described as being SDSS because they where used for the collection or organization of data used by decision-makers. This is a reflection of the trend identified by Keen (1986) and many others that any computer-based system that somehow supports decision-making is (or could be) considered as being a decision support system.

The view of GIS as a SDSS is not however entirely without support and justification. It is considered important to stress the fact that decisions, as indicated by Simon (1977), fall in a continuum that ranges from highly structured (programmed) to highly unstructured (un-programmed) decisions. Structured decision processes as indicated by Simon refer to routine and repetitive problems for which standard solutions exist. For example, land development, land use control and similar activities regarding monitoring the state and changes in an area could be seen as routine and repetitive problems. The objectives of these activities are to keep control over the space and to register phenomena and trends of interest for planning and management. These activities are regarded as structured, data driven decision processes that do not require substantial modelling components as provided by the majority of GIS systems. Consequently, the technology of GIS with its facilities for storing, retrieving, manipulating, displaying and analysing spatial data and related attributes could be considered as a SDSS for structured decision making activities. In addition, Saenz (1998) argued that a GIS by itself could indeed function as a SDSS but only in the situation where the spatial analysis and modelling functions it provides are sufficient or adequate to support a particular spatial problem solving task and related decision making process.

As pointed out in the above definitions, a common requirement for SDSS is the availability of explicit models and capabilities to support a particular type of spatial problem solving which in practice tends to be a semi-structured or ill-defined. Complexity, uncertainty and even conflicting objectives usually characterize these problems and, as indicated by Spargue (1982) they cannot be solved by structured computerized decision support. Decisions for this class of problem can be understood as revolving around a choice between different options (Fedra, 1997; Armstrong and Densham, 1990). It is well known that site selection and similar problems often involve a number of possible solutions requiring a decision-making process to decide on the final solution. In principle, each decision means acceptance of one solution and rejection of a number of other solutions that are also feasible. It would normally be more effective if the selection of one solution out of a number of potential solutions could be based on exact criteria. For this type of decision there are often neither generally accepted criteria, nor the possibility to test all the possible solutions before making a final choice. In practice the usual approach would be to select one solution from a set of options that appear workable (Armstrong and Densham, 1990). Furthermore, the decision-making process for this class of problem is usually judgmental, iterative and integrative. As such, it requires more analytical competence as well as the availability of multi-criteria and other application specific models and modelling techniques capable of supporting the respective tasks.

From this point of view, there is widespread agreement that GIS systems, in spite of their significant contribution in assisting decision makers, could not be regarded as a fully developed SDSS, since they obviously lack the modelling tools required to adequately explore the solution space of semi-structured problems. This is specifically applicable to various fields of human activities, including location planning, site selection and environmental compatibility assessment (Openshaw, 1997).

Another widely cited criticism concerning GIS as being a fully developed SDSS is based on the issue of the complexity of the technology, specifically the framework and language for dialogue between decision-maker and computer system (man-computer interface). Albrecht (1998) in his overview of universal GIS operations for environmental modelling argued that current GIS systems are so difficult to use that it requires some expertise to handle them and that it could take up to a year to master a GIS. According to Albrecht (1998) and many others, these systems are cumbersome for occasional users (decision-makers) who require decision-support environments (man-computer interface) that are interactive, flexible and easy to use. In other words, various actors in the decision making process do not wish to be immersed in the technicalities of a full-blown GIS. What they usually desire is a fairly simple command structure with an understandable language and graphical user interface along with the ability to answer complex spatial questions.

2.1.4 The Role of GIS as a SDSS Generator

The abovementioned deficiencies that are preventing GIS to be used as a decision support system for spatial problems has attracted increased attention in related literature. Keenan (1997) defines of-the-shelf GIS as a GIS system that can be used as a generator to build a SDSS for a specific problem domain. There is strong evidence in the SDSS literature that GIS technology can be used as a generator for a SDSS. This is mainly due to the continuous development of GIS abilities to integrate diverse spatial and non-spatial data and information from various sources. This is one of the major requirements for the development of a SDSS. GIS also provides an appropriate, usually called "geo-relational" database management system characterized by comprehensive facilities for storing, retrieving and manipulating spatial and non-spatial data. Furthermore, it provides an interactive user interface, as well as a link between the interface and database which can be customized to allow actors in a particular decision making process to easily query spatial and related attribute data. Spatial visualisation is another fundamental capability of GIS that is also of particular importance in supporting spatial problem solving. However, the main issue that is preventing the acceptance of GIS as a complete SDSS generator for a full range of spatial problem solving tasks, is the almost complete absence of problem-specific models and modelling techniques developed to support decision making even before the emergence of GIS (Carver, 1991; Keenan, 1997). Some of these models (location-allocation techniques, uncertainty analysis, multi-criteria evaluation) are however of interest to potential users of spatial decision support system.

One possible example where modelling is required, is site selection and similar problem solving tasks. As pointed out above, these spatial decision problems have to do with choices between various options (possible locations) that are usually analysed, compared and ultimately ranked according to a number of user defined objectives and relevant criteria. The selection process is then based on a comparative analysis of the ranked options (possible locations) and on the selection of those that appear to be the most workable. For this type of problem, the majority of GIS systems only allow the decision-maker to identify (through a map overlay process) a list of sites meeting a predefined set of criteria. What is missing is a mechanism for representing choice and priority in the context of evaluating conflicting criteria and objectives. This is usually accomplished by implementing multi-criteria evaluation techniques such as the analytical hierarchy process (AHP). This restriction in terms of choice or preference makes GIS a very static modelling environment and thus reduces its scope as a decision support tool (Heywood et al., 1994).

In respect of the aforementioned examples in the field of location planning and environmental modelling, many researchers have advocated the perspective that some sort of extensions to proprietary GIS are needed in order to achieve the desired level of problem solving (Goodchild at al, 1992; Openshaw, 1991; Fedra, 1995; Burrough, 1992; Anselin, 1993, Armstrong and Denham, 1990; Keenan, 1995; etc.). In other words, in order to be used as a SDSS generator for a full range of spatial problem solving, GIS software must provide a mechanism for incorporating appropriate models and modelling techniques drawn from other disciplines (Keenan, 1997). From this point of view, the key to useful SDSS is basically an integration of proprietary GIS with other application specific models (software) through direct and indirect links (see Figure 2.4).

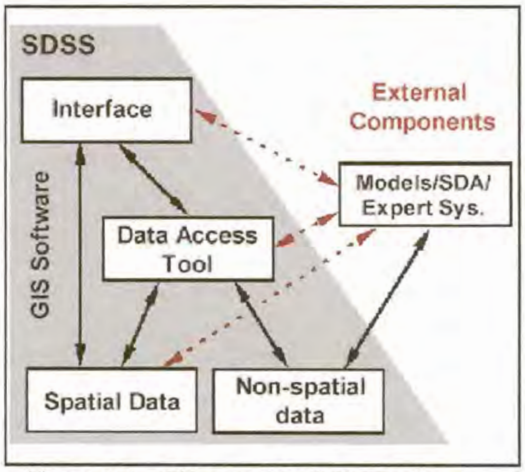

Figure 2.4 GIS as a SDSS Generator (Keenan, 1987)

From the literature review, it appears that such integration essentially seeks to fuse capabilities available in the individual systems and to provide some desired level of usability. Therefore, as argued by many authors (Grimshaw et al. 1996, Fedra, 1994, Goodchild at al. 1992) integration of specialist software supporting spatial and non-spatial data analysis and modelling with GIS through direct and indirect links is a key to useful SDSS. Such integration seems to have the necessary power and flexibility to assist decision-makers "in sorting out their perceptions and preferences after the information gathering stage" (Grimshaw, 1996).

2.1.5 GIS Integration (Classification of Systems Integration)

Integrating GIS with data analysis and modelling software drawn from other disciplines provides a method for communication between these systems so that they can share resources. It usually deals with issues related to data/information exchange. For instance, how can data be shared or exchanged effectively and precisely between different systems? The purpose of integration as indicated in related literature is to develop an environment in which users (decision-makers) are able, in a user-friendly manner, to access all functions from the systems being integrated in order to implement their analytical and problem solving deliberations.

The problem of integrating (or linking) analytical and modelling tools to proprietary GIS has over the past decade begun to emerge as an important research area (Goodchild et al., 1992; Anselin and Getis, 1992). Various logical ways of coupling spatial data analysis and models with GIS have been identified and there is still work underway to explore them. The most frequently cited classification is the architectural basis for integration, where the integration is expressed in terms of the closeness or the extent to which two separate systems are interfaced (Goodchild et al, 1992; Fedra, 1994). According to Goodchild (1992) three major approaches can be distinguished, namely:

1) Loosely coupled integration between proprietary GIS and spatial/non spatial analysis and modelling software.
2) Close coupling between spatial data analysis and modelling software and GIS;
3) Full integration of spatial analytic procedures and modelling techniques with the GIS;

(1) Loosely Coupled Integration

Loosely coupled integration is the simplest and by far the most frequently adopted approach for using GIS in many applications. In this approach problem specific models (specialist software) and GIS are used as two separate (independent) applications that just exchange files (see Figure 2.5). The data resulting from one system are fed into another through direct-link transmission or using other, indirect ways. When using this approach, GIS is very often employed as a pre-processor (preparation of model-input data), and as a post-processor (display and possibly further analysis of model results). Each system therefore complements the other - the model reads some of its input data from GIS files and produces some of its output in a format that allows further processing and display with GIS.

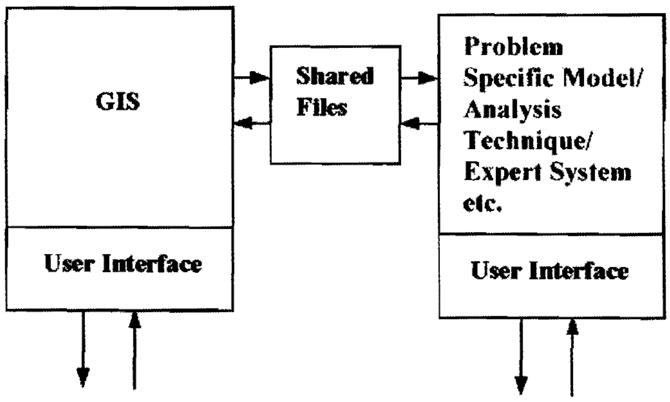

Figure 2.5
Loosely Coupled Integration
(After Chulmin,J. 1999)

From the software engineering point of view, loosely coupled integration seems to be a rather common and by far, perhaps the most straightforward approach of linking different application (software) components. It requires little if any software modification and customisation. The disadvantage of this integration method is usually related to issues of exchange of input and output data between applications. Many authors (Fedra, 1994; Singh and Treleaven, 1998,) argued that a solution based on files shared between two separate applications could be sometimes lengthy and cumbersome, especially in performing iterative modelling over a large number of problem (spatial and non-spatial) variables with sufficient speed. They indicated that although modelling may be fast, the process of data transfer can be slow and even error prone. It has also been pointed out that importing GIS data into other applications and vice versa is not always straightforward requiring either use of special products or development of software routines to convert (pre-process) the data into proper formats.

Recently however these shortcomings, particularly in applications running under the same operating system, are becoming less prominent mostly due to the IT improvements in the field of inter-application connectivity. Examples are:

- *DDE (Dynamic Data Exchange) - an object oriented technology which is an MS Windows supported method of exchanging data fairly rapidly amongst applications on the same computer;*
- *OLE (Object Linking and Embedding)- MS Windows supported technology which permits an object of one application to be either linked or embedded within another, from where it may be edited directly;*
- ODBC (Open Database Connectivity standard) - Microsoft's open interface for accessing data in a heterogeneous environment of relational and non-relational database management systems.
- RPC (Remote Procedure Calls) – an inter-application communication protocol most commonly found on UNIX platforms.

(2) Close Coupling Integration

A close coupling approach involves deeper integration of a problem specific model(s) with GIS. With this approach different applications (software systems) share not only the communication files but also a common graphical user interface (GUI). The GUI provides the veneer to assist and guide the user through the whole modelling process. Apart from the common user interface, closely coupled systems provide transparent file and information sharing and, therefore easy and error-free data/information transfer between the respective SDSS components (Figure 2.6).

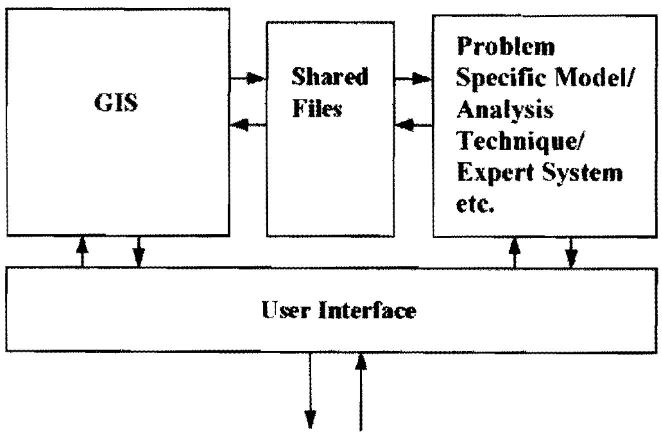

Figure 2.6 Close Coupling Approach (After Chulmin, J.1999)

An example of close coupling that draws together GIS and problem specific models is the Integrated Planning Decision Support System (IPDSS) (Mejia-Navarro and Garcia, 1995). IPDSS, as described by the authors, represents an Unix based SDSS designed to assist communities in the evaluation of geological hazards, vulnerability and risk, as well as to assist urban planners in analysing, modifying and re-evaluating spatial information within land-use planning activities. As such, it can be viewed as a computerized framework that is used to support complex decisions based on spatially distributed information. IPDSS incorporates the GIS named GRASS (Geographic Resource Analysis Support System), various problem specific numerical models and multi-criteria analysis techniques within the common graphical user interface (GUI). While this architecture is in fact the collection of diverse, independent software tools, the IPDSS GUI is assembled in such way that the analyst always has an impression that he/she is interacting with a single coherent system.

Another example of closely coupled integration is the Land-Use Change and Analysis System (LUCAS), developed during the "U.S. Man and Biosphere project" in the Computer Science Department of the University of Tennessee (Berry et al. 1996). LUCAS, as defined by its authors, is a prototype computer based SDSS specifically designed to integrate the multidisciplinary data stored in GIS (GRASS) and to simulate the land-use policies prescribed by the incorporated analytical models. It was implemented as an "object-oriented" C++ application to promote modularity and to allow different or additional software modules to be added to existing code easily, as the needs of investigators changed. The central component of LUCAS is a common, user-friendly graphical user interface capable of extracting different types of data for addressing research questions concerning land use and its impacts. The types of data include spatial and tabular data, results of mathematical models, spatial models, maps and/or visualization of land-use simulation exercises, etc.

It is worth mentioning that the macro languages of GIS software such as MapInfo's MapBasic, Arc/Info's Arc Macro Language (AML), ArcView's Avenue, makes it possible to employ GIS as generators by providing a common interface capable not only of invoking external programs (models) from the GIS environment, but also to secure transparent file and information sharing. One of the most recent examples is the utilization of ESRI's Arc Macro language (AML) in development of a graphical user interface for the incorporation (close coupling) of Soil and Water Assessment Tools (SWAT) with ARC/INFO. As describe by Zhou and Fulcher (1997), the menu interface provides a tool to identify the relative contribution of different watershed areas to agricultural non-point source pollution and evaluate the effects of alternative land use management practices on surface and ground water quality at the watershed scale.

(3) Full Integration

Full integration implies the coupling of problem specific models and GIS within one single application with shared memory and communication routines (Figure 2.7). The focus of this approach is on the system consistency (common data structure and data model, data handling and visualization) that obviously guarantees optimal system performance, particularly in comparison with the loosely coupled integration approach. However Fedra (1994) argues that the most elegant form of integration is also the most costly one in terms of development efforts since it requires appropriate programming knowledge as well as a good understanding of proprietary GIS and other application development environments.

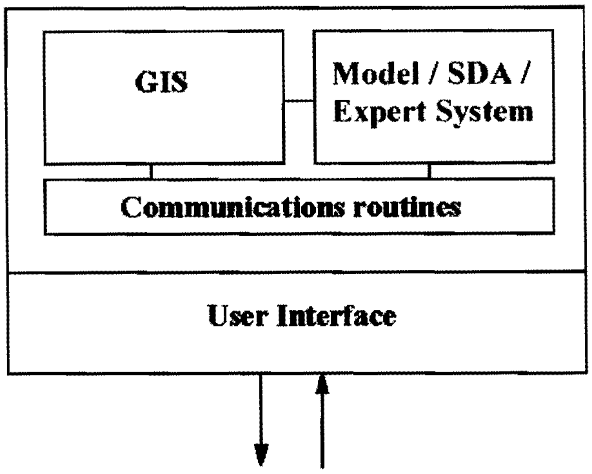

Figure 2.7 Full Integration (After Chulmin, J. 1999)

From the available research and practical applications it is apparent that full integration can be achieved by different methods. One method is to use a proprietary GIS-based programming language to create and implement a problem specific model that consequently becomes one of the analytical functions of the GIS. Examples are desktop GIS packages such as ArcView and MapInfo. Both of them provide macro-programming languages that enable their functionality to be extended by writing new programs or customisation of the user interface. There is evidence that third party developers are creating powerful extensions that can be added to these GIS desktop systems. The majority of them are designed to support many types of either data-driven or the model-oriented spatial problem solving tasks.

Full integration can also be achieved by creating user-specified analysis and modelling routines through high level programming languages such as Fortran, C, C++ and adding them to the existing tool box of the proprietary GIS. Examples include integration of multi criteria evaluation techniques into GIS such as the Simple Weighted Linear Combination Procedure embedded into the SPANS GIS software and Saaty's Analytical Hierarchy Process (AHP) added to IDRISI.

Another frequently cited and recently the most prominent method for achieving full integration is the method of incorporating GIS functionality into models through the use of a variety of development frameworks including popular programming environments such as Visual Basic, Delphi, Visual C++, and others. This method of integration, however, requires a sufficiently open GIS architecture capable of being accessed by other software applications. To facilitate this type of development, GIS software developers have recently adopted application development environments based on trends and technologies from various other fields such as computer sciences and data engineering. More specifically, GIS systems are moving towards a true distributed, object-oriented geo-processing environment, sufficiently modular to permit their integration with other software components within one single application. An example is ARC/INFO's Open Data Environment (ODE) on both UNIX and PC platforms. ODE allows developers to access ARC/INFO (GIS) functionality from different non-geographic information system applications or through a custom created interface. This approach means that the applications incorporating GIS functionality could be developed in more modular fashion and within programming environments other than Arc Macro Language (AML – Arc/Info's platform scripting language and interface toolkit).

At the PC level, GIS software developers (ESRI, MapInfo, for instance) are rapidly adopting and making available so-called ActiveX controls and a collection of programmable ActiveX Automation objects. As reusable and programmable software components, these controls and automation objects allow application developers to add required elements (or subsets) of mapping and GIS functionality to applications developed in another programming environment outside a GIS. A good example of this type of GIS tool is the software "What If?" developed as a cooperative effort by LDR International Inc, Data Chromatic and Prof. R.E. Klosterman. (1997). It represents an interactive, easy to use GIS-based SDSS that, as described by the authors, supports all aspects of the land use planning process (land use suitability analysis, projection of future land use demand, evaluation of the likely impact of alternative policy choice and preparation of a land use plan). *"What if?"* incorporates various site selection and planning models and modelling techniques into a fully integrated and portable MS Window application. It was developed in Microsoft's Visual Basic programming environment. Required mapping and GIS functionality were integrated into the application by using ESRI's MapObjects GIS component software.[3]

All the approaches to integration described above have certain advantages and disadvantages. It is therefore difficult to draw a conclusion as to which approach is superior. Bailey (1994) for instance is somewhat pessimistic about the prospects of tight integration of statistical and other models with GIS. He advocates a form of loose coupling based on open-systems computing environments wherein a GIS, statistical and other analysis package would be accessed simultaneously but independently on the same GUI. Fedra (1994) furthermore argued that fully embedded models into GIS appear to be rather simple and restrictive. Batty (1998) also pointed out the limitations of available GIS scripting languages, notably the size of problem that they can effectively handle. He argued that complex spatial problem solving tasks can only be handled by combining (linking) GIS with independent software tools (models) through a common interface written in some high level language outside the GIS environment (close coupled approach). Likewise, Djokic (1993) made a strong case for the use of available software tools within a SDSS shell. He argued that the one-off effort of developing an interface between software components would require much less effort that customizing existing or writing new software. On the other hand, Walsh (1993) emphasized the need for an open architecture and interdisciplinary collaboration in the development of SDSS with fully integrated GIS functionality.

As can be seen from the above, any decision concerning an appropriate integration approach is obviously case-driven. It depends on many factors such as contents and complexity of the problem to be supported by SDSS, availability of software components required, system characteristics and performance, available resources, data requirements etc.

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[3] *ESRI's MapObjects is an ActiveX Control bundling a large number of programmable ActiveX automation objects. They provide application developers with powerful mapping and GIS capabilities which can be used in a wide variety of development frameworks including popular programming environments such as Visual Basic, Delphi, Visual C and others.*

2.2 GIS and Knowledge Based Systems

2.2.1 What is a Knowledge Based System?

Expert systems (ES) or, interchangeably Knowledge based systems (KBS) have evolved as a branch of Artificial Intelligence (AI)[4] and from a broader perspective they are apparently the principal area of AI applications in various fields of human activities.[5] They have been successfully introduced for decision support in many areas, notably medicine, chemistry, engineering, military, finance etc. Recently, however KBS techniques have also been seen as a useful complement to SDSS analysis and modelling tools.

KBS technology was conceived during the 1960s and up to the late 1970s it was limited to the academic scene as a field of AI enquiry and research. By the 1980s it began to appear as a commercial application. As indicated by Turban and Anderson (1998), this was the result of substantial efforts made to develop approaches and techniques that embodied languages or tools allowing the construction of programs capable of closely resembling human reasoning.

In the literature one can find a broad spectrum of definitions and/or functional and structural descriptions of expert systems. As observed by Fedra (1991), they range "from rather narrow automata selecting pre-defined expert answers to better-than-human reasoning performance in the complex problem domains". In general, however, KBS can be regarded as "a class of interactive computer software that uses human expertise in a narrow, problem specific area (referred to as a domain) in order to perform functions similar to those normally performed by a human expert(s) in that domain (Goodall, 1985). They are fashioned along the line of how an expert would go about solving a problem and are designed to provide expert advice (Fedra, 1991). Like any other model, KBS can vary from an extreme simplification to a knowledge intensive encapsulation of expert knowledge for the particular problem domain.

As can be seen from the above definition the essence of KB systems is in that they attempt to incorporate human expertise and imitate the expert's reasoning process. What actually makes KBS feasible is an appropriate use of task-specific, empirical knowledge usually in the form of rules or heuristics and the availability of inference mechanisms for utilizing this form of information in order to derive either workable solution or expert advice for the problem at hand (Ignizio, 1991; Fedra,1991).

In the related literature one can find two principal approaches to developing a KBS. The first approach includes the use of a programming language and writing original code for the particular KBS. When this approach is selected, nearly any higher level programming language can be used, although some have been more popular than others. Generally, Prolog, SmalTalk, Lisp, and C were often called AI languages due to their characteristics. The new generations of object oriented programming

[4] *The term Artificial Intelligence is used to collectively group differing sets of techniques, which as their main common goal, strive to build computer software capable to mimic human knowledge.*

[5] *It should be also pointed out that many other AI techniques, besides ES, have also been utilized successfully for a wide class of problems, namely Neural Networks, Genetic Algorithms, Fuzzy Logic etc. However, those intelligent systems techniques are out of the scope of this research.*

languages are, however, considered even more useful for a KBS development as they allow new routines to be added to a program without modifying existing codes.

The second approach relies on the utilization of one of the tools developed specifically to aid the construction of a KBS. These tools are called Expert System Shells (or frameworks). They are composed of editing facilities for the construction of the knowledge base for a particular domain, general control mechanism for knowledge processing, as well as a facility for building a man-computer interface. Various shells of this kind are currently available. Examples are CLIPS (C language Integrated Production System) developed by NASA at the AI Section of the Johnson Space Centre, JESS (Java Expert System Shell), recently developed by Friedman-Hill at Sandia National Laboratories in Livermore and many others with different levels of sophistication in supporting KBS construction and implementation.

2.2.1.1 Components of the Knowledge Based System

As shown in Figure 2.8, a KBS can be described as a programming environment that contains all of the necessary utilities for developing and running the system. From the structural point of view it usually consists of the following components:

- **Knowledge base** – collection of domain specific information,
- **Inference engine** - the knowledge processor, that works with available information on a given problem in order to draw conclusions or recommendations,
- **Blackboard (Working memory)** – contains data (facts) entered by the user or inferred by the expert system during a consultation,
- **User interface** - a user friendly system front-end that controls and guides communication between user and system, allowing him/her to provide necessary input data to the system,
- **Explanation facility** - provides explanations on the reasoning of the system.
- **Knowledge acquisition** - usually seen as a subsystem for transformation and accumulation of problem specific expertise from experts and other documented knowledge sources to a computer program in order to initialise or expand the system's knowledge base.

The first three components, i.e. knowledge base, inference engine and working memory, along with the user interface are usually indicated as the generic components of KBS.

The **Knowledge base** is one of the essential parts of a KBS. It can be understood as a collection of facts representing knowledge on various known aspect of the KBS's subject area. It can otherwise be thought of as a collection of generic rules (facts) that direct the use of knowledge to solve, or provide advice for a specific instance of problem in a particular domain. The information in the knowledge base is incorporated into a KBS by a process usually called **knowledge presentation**, which will be discussed later.

If the knowledge base could be viewed as the heart of a KBS, then **the inference engine**, also known, as control mechanism is the brain of the system. This component is essentially a computer program composed of a set of procedures and algorithms for the manipulation of information contained within the system's knowledge base and its working memory in order to infer or draw conclusions. The most common strategy for drawing conclusions is based on logical deduction of conclusions from a set of facts and rules. They are very often provided in the form of "IF (premise) THEN (consequences)". This component also includes procedures and directions on how to use the system's knowledge base, as well as which facts to obtain by querying the user.

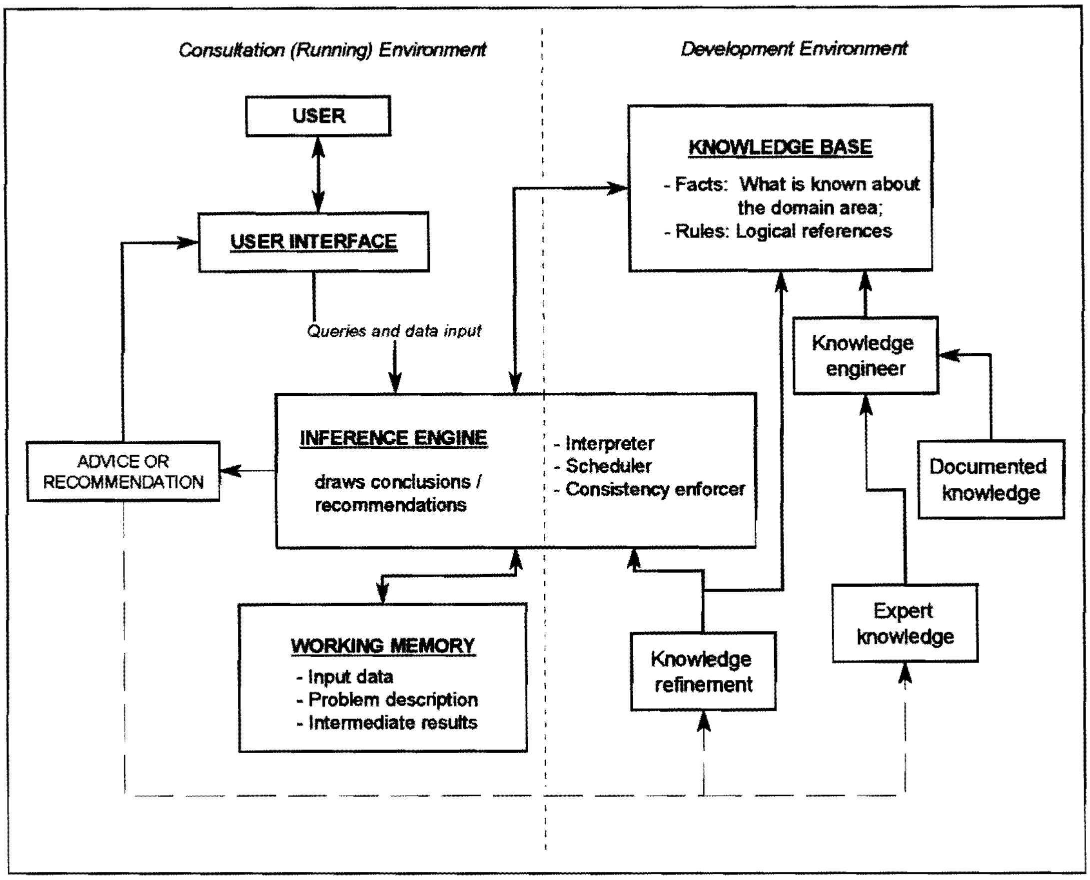

Figure 2.8 Structure of a Knowledge Based System (Turban & Aronson, 1998)

Besides the knowledge base and the inference engine a KBS system typically has a so-called "Blackboard". It is usually perceived as an area of the system's working memory set aside for both, namely the description of the current problem-solving task, as specified by input data, and for recording the system's intermediate results.

Separation of the knowledge base and the inference engine is yet another key feature that distinguishes KBS from conventional programs. This separation, usually referred to as a "plug-in" KBS architecture, allows the existing knowledge base to be detached from the system and a new one containing different sets of rules and facts to be inserted into a system. This characteristic is a basis for generic KBS software known as an expert system shell. As already indicated above the expert system shell usually consists of a general control mechanism (inference engine) along with editing facilities for entering the knowledge base for a particular subject area.

2.2.1.2 Knowledge Acquisition, Representation and Implementation

Knowledge acquisition, representation and implementation (inferencing) are the essential steps in developing a KBS. In the problem related literature they are usually defined as "knowledge engineering".

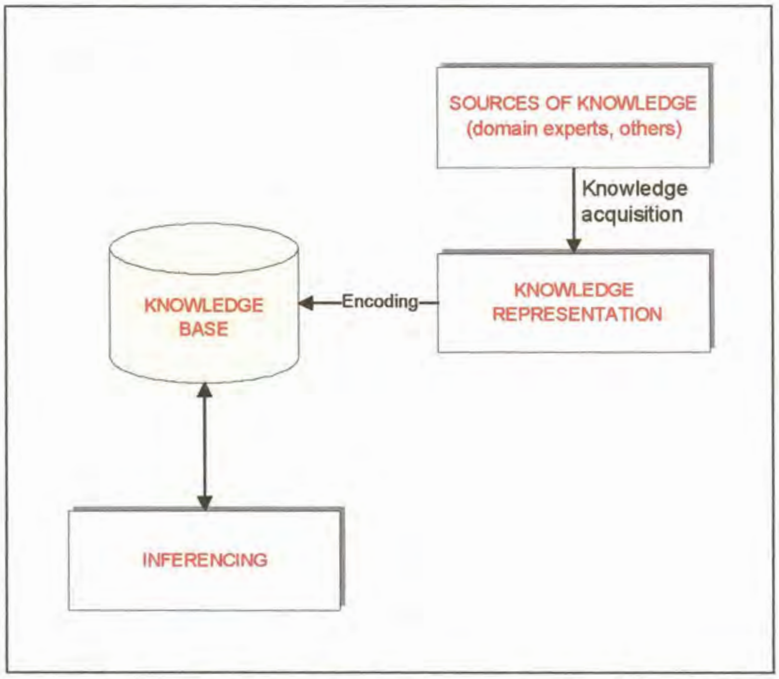

Figure 2.9 Process of Knowledge Engineering (Turban & Aronson,1998)

Knowledge acquisition involves the process of knowledge extraction from "documented" and "undocumented" sources of expertise and its transfer to the knowledge base. Usually, however, this process is accomplished through meetings between the developer (knowledge engineer) of the system and domain experts, during which the experts' knowledge is elicited, refined and encoded in the knowledge base. The elicitation of knowledge from experts is done with the aid of different methods. They can generally be classified in three categories, namely, manual, automatic, and semi-automatic.

Manual methods are structured around some kind of interview with domain experts, as well as through tracking their reasoning process and observing specific problem-solving procedures. What is typical for these methods is that they are usually very slow, expensive and sometime even inaccurate due to the fact that experts are typically asked to perform tasks that they do not ordinarily do. In that regard there is a trend in the research and practice to automate the knowledge acquisition process through development and implementation of various computer-aided methods (i.e. rule induction, case based reasoning, neural net, and intelligent agents).

Among the different techniques implemented so far, an *interactive, expert driven knowledge acquisition method* is of particular interest for this research. As illustrated in Figure 2.10 it supports experts by allowing them to build a knowledge base for a particular problem domain without the involvement of a knowledge engineer. As such it can be understood as a smart computer-based tool for capturing the expert's knowledge, distilling it, and then automatically generating a knowledge base. In addition, its purpose is to help experts in bypassing their cognitive defences and biases, as well as to identify relevant criteria and level of knowledge needed in supporting the subject area of a KBS.

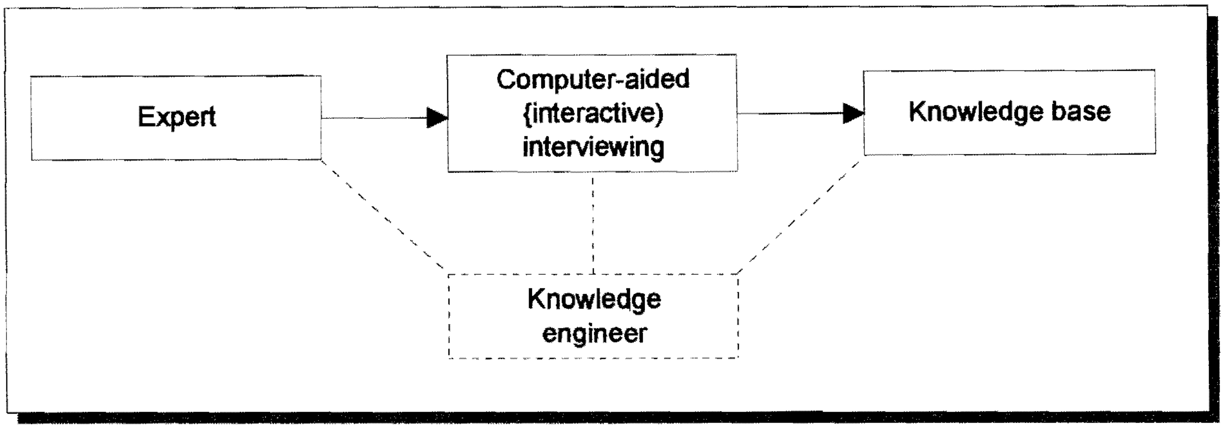

Figure 2.10 Schematic representation of an interactive, expert-driven knowledge acquisition method implemented in this research (Turban & Aronson, 1998)

Knowledge presentation is a process of defining the approach (form and format) that will be used in a KBS program to represent domain knowledge collected during a knowledge acquisition session.

As indicated in the related literature, knowledge is represented in various forms and formats including semantic networks, frames, attribute value lists, decision tables, conventional programs, etc. These knowledge representation schemes usually follow diverse algorithms and software construction in the process of building a knowledge base. Among them, *production rules (rule-based programming)* seem to be by far the most commonly used and the most directly understandable form of knowledge presentation. In this programming paradigm, rules are used to represent heuristics, or "rules of thumb" which specify a set of conclusions/advice for a given situation and/or condition. The basic idea of knowledge representation is simple. Knowledge is namely represented as IF_THEN and/or IF_THEN_ELSE rules. These are essentially association pairs; i.e. IF is a particular fact (premise/condition), THEN (ELSE) is the conclusion or action to be taken or expert advice for the problem at hand. An example is given below:

Rule1:	*Rule2:*
IF soil = type A	*IF potential = high AND flood potential = high*
THEN erosion potential = high	*THEN environmental suitability = low*

As can be seen from the example above, rules are basically a formal way of specifying how an expert reviews a condition, considers various possibilities and recommends conclusions and/or advice.

In this research however the form of knowledge presentation in supporting the proposed KBGIS model will be based on a so-called domain decision (or the truth) table approach, rather then on production rules. More detailed discussion concerning this issue is provided in the chapter 4.

Knowledge implementation can generally be understood as the process of translating the organized knowledge into an operational KBS system. It basically relies on the existence of the computer algorithm (program) that controls and carries out the reasoning process. As mentioned before, that program is called the inference engine or the problem processor. Its major task is to direct the search through the knowledge base in order to:

- Draw (infer) conclusions from a set of expertise (facts) about the problem area stored in the knowledge base;
- Reports solution, provide expert advice for the problem at hand and explain the line of reasoning;
- Interact with the user for additional information.

The process usually involves the application of various inferencing techniques (inference rules, case-based reasoning, model-based reasoning etc.) that attempt to mimic reasoning similar to those of experts. Among them, the application of inference rules is of particular interest for this research.

Inferencing with rules normally involves implementation of a so-called **modus ponens** reasoning procedure for drawing conclusions/actions. In this procedure, given a rule ***"IF A and B, then C"***, and the fact that ***"A"*** and ***"B"*** are true, then it is valid to conclude that ***"C"*** is also true. In the terminology of logic, one can express this as:

A B

PREMISE → ACTION

IF premise is true THEN action is valid

(Premise could be one or more conditions)

To understand this reasoning procedure, especially from the point of view of this research one can consider the following example of an inference rule in its generic form:

```
IF   < Premise 1> AND <Premise 2>
THEN  <Inference 1> or <Inference 2>   .........
```

As can be seen from the example above when both premises (conditions) are found true the conclusion, using modus ponens, is considered valid. Under such circumstances one can say that the rule fires. In other words, firing a rule occurs only when the rule's entire hypothesis (the IF parts) are satisfied. The interface engine then acts appropriately searching the knowledge base and infers conclusions that can be either reported or stored in the system's working memory as a premise for other inference rules.

From the above example, it is clear that the inference engine contains rules that differ from those of the knowledge base. Knowledge base rules (sometimes called declarative or production rules), when implemented relate to a specific domain or expertise stating the facts and relationships about the problem. On the other hand, inference rules pertain to a more general control and search strategy for deriving actions and/or conclusions. These rules are usually called procedural rules referring to an algorithm (mechanism) on how to search the knowledge base and infer conclusions /actions, given that certain facts are known.

There are two fundamental modes of search strategy used by an inference engine, namely: *a backward chaining strategy and* a *forward chaining strategy*. The basic mechanism of the *forward chaining strategy* is reasoning from a given set of premises or rules hypothesis (the IF parts) to derive conclusion or action that follows them. On the other hand, the *backward chaining* is reasoning form conclusion/action (the THEN side of the rule) to the premises that caused them. Accordingly, a backward chaining strategy is termed a goal-driven approach, while forward chaining is usually called a data-driven approach. The latter is of particular interest for this research.

2.2.2 Knowledge Based Systems in Spatial Problem Solving

Application of KBS in location planning, environmental compatibility assessment and other spatial problem solving tasks began to appear during mid 1980s and have since than been discussed in the related literature (Robinson, 1987; Frank, 1987; Karimi, 1987; Kim, 1990; Wiggins, 1990; Wright, 1990; Fedra, 1997; Openshaw, 1997). This was the result of an increasing demand for such systems especially in problem solving situations where formal mathematical models appear to be less effective or impractical for deriving workable solutions (Ignizio, 1991; Fedra, 1991; Han and Kim, 1989). Another reason for this growth is related to the increased availability of a number of software tools (expert system shells) for building and speeding up the construction of KB systems that are not software and hardware specific and can be run on standard desktop computers.

It should, however be pointed out that the application of KBS in supporting location planning has not yet reached maturity. The most fundamental reasons, as argued by Kim and Han (1989), are disparities between the type of problems that decision-makers in spatial planning deal with and the type of problems for which the problem-solving approach of KBS is suited. Another reason can be an absence of information on successful practical application of KBS. In this regard Fedra (1991, 1994) argued that most of the KBS being described in the related literature were in a so-called research and development stage and that the number of operational ones in spatial problem solving seems to be rather small.

An overview of the literature has generally pointed to two basic types of KBS applications in the spatial problem-solving domain, namely:

1) Purely knowledge driven systems, and

2) KBS coupled with other systems either as intelligent front ends or fully embedded knowledge based models for a specific problem domain.

Purely knowledge driven systems could be seen as standalone KBS based on an empirical "model" or "qualitative understanding of how things work". They rely on sizable domain knowledge usually represented in the form of rules or heuristics, and on inference mechanisms for utilizing this form of information in order to derive either workable solution or expert advice for the problem at hand. One of the most popular areas in applying these types of KBS refers to land use control and management. This, typically well structured, spatial problem solving area appeared to be appropriate for implementation of the KBS's problem solving approach (Fedra, 1994; Turban and Aronson, 1998; Han and Kim, 1989). A typical example of such a KBS is the Decision Aid Planning Tool (ADAPT), described by Davis and Grant (1990) as a knowledge based DSS system specifically designed to assist land-use planners in producing a local government zoning scheme. Other cases utilizing standalone KBS for solving location-based problems include applications in the site selection and suitability analysis. Examples found in the related literature are: SISES (Site Selection Expert System, Findikaki, 1990), ESTMAN (Expert System for Manufacturing Site Selection, Suh et al., 1990), ESSAS (Expert System for Site Analysis and Selection, Han and Kim, 1988), ETCON (Expert System for Conservation Land Use Planning, Ahma et al., 1994).

Although these and other similar examples demonstrate that KBS could be a useful tool or approach in supporting spatial problem solving, various references in related literature, revealed specific limitations. One limitation of a standalone system for spatial problem solving is that they were not able to represent relationships between non-spatial data and spatial locations. These relationships are crucial particularly when decision rules built into these systems depend strongly on geographical location (Chulmin, 1999). Another, even more important limitation is that the typical multidimensional problem solving methods in location planning are difficult to articulate and encapsulate in the existing forms of knowledge presentations within a KBS. Kim and Han (1990), Fedra (1991) and many others argued that the nature of location planning problems, including their complexity and spatial orientation, makes purely knowledge driven systems unsuitable for a wide range of applications mainly due to their current technical limitations. They furthermore pointed out that only by integrating KBS with other information systems could one hope to effectively support a wide range of location tasks. The idea to combine the unique capabilities of KBS with other systems and vice versa has recently gained widespread attention.

2.2.3 Coupling KBS with GIS – Knowledge Based GIS

One example of functional integration that is of particular interest for this research is the linkage between GIS and expert systems, also referred as knowledge based GIS (KBGIS). The goal of this type of integration is to produce more useful computer tools that can assist in spatial problem solving, not only by conventional computing, but also by some sort of reasoning similar to those of human experts (Han and Kim, 1990).

Research efforts to couple KBS with GIS, and in the process overcome the deficiencies of GIS as a spatially enabled decision support technology, have rapidly increased since the late 1980s. (Borrough, 1986; Robinson at al, 1987; Wright at al., 1990; Kim and Han, 1990; Fedra, 1997; Densham and Armstrong, 1990; Coulson, 1992; Cowen et al., 1994; Miller, 1994; Openshaw, 1997; Matthews and Sibbald 1998; Lam, 1998, etc.).

In an effort to develop and intelligent GIS for natural resource management, Coulson (1992) noted that the usefulness of a proprietary GIS can be notably enhanced by incorporating the elements of AI techniques, especially the rule based reasoning and the expert system concept. They pointed out that for the purpose of natural resource management a GIS is an exceptionally useful tool for representation and analysis of landscape elements in the form of geographically referenced and related attribute data. However, they found a GIS an inferior tool for representing and analysing relationships among landscape elements since it does not provide any decision making and/or pattem matching modules that can reason about these relationships. Therefore individuals should have their decision rules in place before GIS can be utilized. In other words, the relations between landscape elements cannot be interpreted without the intervention of an expert. To resolve these limitations they developed a so-called Intelligent GIS (IGIS). This was accomplished by preparing a KBS containing rules or heuristic knowledge of a domain expert and, then linking it with GIS database developed with the aid of GRASS GIS software.

Leung (1993) demonstrated that the KBS concept could be an appropriate approach for approximating human reasoning and consequently enhancing the level of intelligence of current GIS systems. Through their work they argued that current GIS systems suffer from certain conceptual shortcomings that prevent their successful development as a spatially enabled decision support technology. Among these shortcomings inappropriate logical foundations and the low level of intelligence are the most important and require immediate attention. In respect of the logical foundation, they indicated that current GIS systems are predominantly based on Boolean logic which gives no room for imprecision in information, human cognition, perception and thought process. Regarding the level of intelligence, they claimed that human knowledge and expertise have not been effectively integrated into current GIS systems. To overcome these conceptual shortcomings of the present day GIS systems they developed a flexible, general purpose and fuzzy-logic based Expert System shell (FLESS) as a tool for construction of a GIS with a higher level of intelligence. The prototype of the shell has been tested on two simple knowledge-based GIS systems prepared as didactic examples. The first dealt with remote-sensed data and land-type classifications, while the second was focused on climatic classifications with regular GIS data layers. The two examples have clearly illustrated the possibilities and usefulness of the KBS approach in providing an "intelligent GIS system's front end" that could be effectively used to build a knowledge base model for a domain specific spatial problem-solving task.

Another example where a KBS is used as an intelligent front end for a GIS is the SDSS for Rural Land Use Planning developed by Matthews and Sibbald (1998). As described by the authors, the system was developed to assist rural land managers in the examination of land use/ allocation options and the potential impacts of land use change. It includes Smallworld GIS software, a land use and impact assessment model management system as well as an intelligent interface overlaying the GIS database. The interface contains a control mechanism capable of passing data from GIS to the model management system and also to capture essential information from both databases and to derive or deduce conclusions regarding land-allocation that meet the preferences of the land manager. In contrast with the earlier example, this one illustrates the role of the KBS approach in providing a descriptive dialogue between the user and the system.

Rosenblit and Jankowski (1991), Fedra (1995), Saenz (1997) and many other authors argued that the KBS concept can also be useful in designing intelligent front ends in the form of advisors and in the process minimizing or even avoiding misuse of complex models running under the GIS environment.

The incorporation of knowledge and heuristics into the GIS environment has resulted in the development of a so-called "fully embedded expert system" utilising a KBS to support spatial problem solving. In contrast with intelligent front ends designed to enhance human-system communication and the use of models and data in the decision-making process, these fully embedded knowledge based systems tend to enhance models and decision-making results. Therefore they are typically problem oriented rather than method oriented. What makes these systems useful is the appropriate use of domain specific knowledge or heuristics embedded into a GIS as a set of tools. These tools, in combination with other conventional modelling techniques available within the GIS environment, add a considerable amount of flexibility to problem solving and representation (Fedra, 1991; Ignizio, 1991).

Yialouris et al (1997) gave an example of such a flexible system. They designed an Integrated Expert Geographical Information System (EXGIS) for the assessment of land suitability for agricultural uses. The EXGIS, as described by the authors, is a modular designed knowledge based GIS that combines the capabilities of a commercial GIS - pcARC/INFO (used for spatial data storage and processing) with the rule-based knowledge system specifically developed for this project. The KBS was implemented in CLIPPER to allow transparent data transfer with pcARC/INFO. Its knowledge base contains more than 600 rules. Both the FAO system for soil evaluation and the local experience and knowledge of soil and climatic conditions were combined for the formulation of production rules of the EXGIS knowledge base. Integration of the system's components (KBS and pcARC/INFO) under the common operating environment was done through the interface developed with the aid of SML - the macro language provided by pcARC/INFO. EXGIS has been applied to study soil suitability and climatic conditions for five crops within an area of about 30,000 ha. Its evaluation, as claimed by the authors, showed satisfactory results since the conclusions drawn by the system match those of an expert.

Incorporating a knowledge-based approach to enhance GIS and spatial decision-making has been found particularly interesting in the environmental domain. Tasks in this spatial problem solving area are very often unstructured allowing heuristics, and therefore knowledge based techniques to be applied. The idea is to use GIS as a proper tool for visualisation, manipulation and analysis of spatially oriented data, while the KBS should provide a basis for catching the essential information from the database and converting it into practical advice. An example found in the literature is MEXSES - an expert system for environmental impact assessment (Fedra et al., 1991). It combines a GIS with the rule-based KBS in order to provide support for a screening level assessment at the early stage of projects planning. The KBS, as described by the authors, is composed of hierarchical impact assessment (EIA) checklists designed to guide the analyst through a reasonably complete set of expected impacts for a given project type. The checklists are combined with the inference mechanism that also includes an explanation function and a knowledge based browser connected to a hypertext system. The inference mechanism can, when necessary obtain the required data from the GIS and ask the user to choose or set values for a project type. The knowledge and explanation browser displays rules in a form transparent to the user, while hypertext links them to a handbook style definition and explanation of the term and concepts used by the system.

Another example is the Ecosystem Management Decision Support System (EMDS) recently developed by USDA Forest Service (Reynolds, 1998). The EDMS, as noted by the authors, integrates ArcView GIS and knowledge-based reasoning technologies in the Microsoft Windows environment. To conduct an assessment with the EMDS, the user is requested to: (1) prepare and/or design a template view that includes all required GIS themes; (2) construct knowledge bases that describe relations among ecosystem states and processes of interest to the assessment. To support these activities the EMDS basically integrates two key applications: (1) the NetViewer that provides a knowledge base development environment, and (2) the EMDS extension to ArcView that includes system objects and methods for processing knowledge bases in a GIS application.

Considering the above examples, it seems that KBS for spatial problem solving tends to become more sophisticated and useful when they are combined with GIS and other conventional models. Many authors argued that KBS should not be seen as a substitute for methods and models already applied within the GIS environment but rather as complementary techniques that can improve the performance of GIS in supporting spatial problem solving.

2.3 Conclusion

The purpose of this chapter was to examine how modern information technologies can provide better support for solving spatial problems. Various approaches to the integration of GIS with other decision support tools were reviewed. The intention was to examine different ways to logically integrate these systems and identify trends in system integration and thus providing the theoretical background for this research.

As indicated in the previous sections of this chapter, GIS technology is recognized as a very useful technology for most spatial problem solving tasks. However, in spite of their significant contribution, current GIS systems still suffer from certain deficiencies that prevent them from being used as full-fledged spatial decision support systems (SDSS). These deficiencies include the absence of explicit analytical and modelling capabilities, the absence of a logical structure and a low level of intelligence in terms of declarative and procedural knowledge.

To overcome these deficiencies certain extensions to current GIS have been advocated, primarily through the integration with decision-making tools drawn from other disciplines. The remedy from the GIS developers is essentially related to substantial improvements of their products, which are rapidly moving towards true distributed, object-oriented tools, sufficiently modular and programmable to permit their integration with other decision supporting tools.

Various logical ways of coupling GIS with other decision support tools have been identified, ranging from the simplest "loosely coupled integration" that only exchange files between systems, up to a so-called full integration of problem specific models into the GIS environment and vice versa. The loosely coupled integration has by far been the most frequently adopted approach in both the research and application environment, while only a limited number of attempts of coupling problem specific modelling tools and GIS within a single application have been found. It appears, however, that exploration and practical application of this "fully integrated approach" is gaining widespread attention especially in circumstances where GIS software packages are becoming sufficiently open and programmable to permit their full integration with other tools.

The concept of an intelligent GIS as a feasible solution for improving complex spatial problem solving tasks obviously exceeds the capability of present day GIS and therefore calls for the integration of expert system methods with GIS. The concept of linking the two systems has also emerged as an important research area although this has not yet reached maturity. As argued by many authors the majority of intelligent spatially enabled systems based on the integration of GIS and KBS are still in the research and development stage and the number of operational system seems to be rather small.

This research can therefore be regarded as appropriate and timely since it aims to attend to the deficiencies mentioned above and apply the concepts to a practical problem-solving situation. Firstly it aims at presenting a practical example of using a GIS to automate an existing decision-making situation. Secondly it examines how the usefulness of a "conventional" GIS in supporting the decision-making situation can be improved by incorporating (embedding) elements of artificial intelligence and knowledge engineering. Thirdly, it represents an effort to illustrate a practical example of the actual integration of the elements of artificial intelligence and knowledge engineering into a GIS. This level of GIS-KBS integration is known as the fully integrated approach and it seems quite possible even when using desktop-GIS. These desktop-GIS provide various types of utilities for file transfer and macro programming that makes it possible to extend their functionality. It is hoped that this attempt to develop a prototype KBGIS system will play a modest part in extending the knowledge and experience in integrating GIS and KBS for spatial decision-making.

CHAPTER 3

THE UNEP/UNCHS MODEL FOR EVALUATING COMPATIBILITY BETWEEN DEVELOPMENT AND ENVIRONMENT

3.1 Introduction

A growing emphasis on environmental quality has prompted many counties to adopt legislation and guidelines that will ensure the consideration of the natural environment in land-use planning and site selection processes. This has resulted in considerable research and development of models and techniques that can support the spatial planning and decision-making processes. One example is a system developed by UNEP/UNCHS that assists the planners to identify and predict potential conflicts between development and environment at an early stage of the planning project. The model was developed as part of a joint effort to promote environmentally sound planning and management. It has been applied on several occasions but within the framework of manual processing techniques. The methodological and conceptual background of the model is described in the following publications:

- UNEP/UNCHS (Habitat), 1987, Environmental Guidelines for Settlement Planning, vol.II, Environmental Considerations in Metropolitan Planning and Management, Nairobi, Kenya;

- UNEP/UNCHS (Habitat), 1987, Environmental Guidelines for Settlement Planning, vol.III, Environmental Considerations in Regional Planning and Management, Nairobi, Kenya.

These publications were the product of a major joint UNEP/UNCHS (Habitat) project designed to compile available knowledge about the relationships between the natural and the man-made environment and to provide guidelines for planners and decision-makers that would help them use that knowledge in settlement planning and management. This chapter briefly reviews and summarizes the model, along with its fundamental conceptual elements.

3.2 Purpose of the Model

The main purpose of this model is to support the process of anticipating potential conflicts between proposed developments and the environment at an early stage of the planning process. The model offers the possibility to identify potential problems and introduce environmental and social concerns. The early identification of these problems and concerns allow the planners to study them and resolve the conflicts. The model has been found to be useful for regional or general development planning activities but also for independent site suitability analysis. Because this model is applicable to the early stages of a development project it requires very little data.

The model has been used on several occasions as a part of environmental planning and management routines with the main aim to make urban, regional and metropolitan development planning more responsive to environmental considerations. One of the examples is its application within the framework of Lagos Metropolitan Area Master Plan (UNCHS/Habitat/UNDP, 1980). There, as pointed out by J. Eigen (UNEP/UNCHS (Habitat), 1987) it contributed to at least two tasks of the Master Plan effort, namely:

1) *Definition of Future Urban Development Pattern:* where the model was used for defining growth patterns that preserve significant environmental resources and prevent damages from natural hazards.

2) *Establishment of Development Controls:* where the model contributed to the identification of potential development-environment conflicts and establishment of development control procedures at the very early stage of plan making.

3.3 Conceptual Elements of the Model

From the user perspective the model can be understood as an early-stage procedure supported by an appropriate information system. It contains data and facts for determining compatibility between the environment and development within the area concerned. As illustrated in Figure 3.1, this information system is composed of the following components:

1) *Environmental Zone Map* - the composite map identifying all critical issues relating to environmental resources and hazards for each location within the study area.

2) *Projects (Development actions) Impact Identification Checklists* grouped into two categories:

   (i) Impact of development (development actions classified by their potential impact on environmental sensitivity);

   (ii) Sensitivity of development (development actions classified by their susceptibility to environmental hazards and resource shortages).

3) *Interaction Matrix* relating resource-related sensitivities and hazard-related risks within the study area to development actions and their implications.

Once the above components of the model are adequately prepared and organized, the identification of potential development-environment conflicts can than be formalized and applied. Identification is done by relating the site-specific environmental resource/hazard characteristics to the proposed project, i.e. to its development implications that might affect environmental sensitivities or might be affected by environmental hazards. As illustrated in Figure 3.1 the evaluation procedure is based on:

1) Available data on environmental constraints/hazards found at the project location (*Environmental Zone Map*),

2) Potential implications/sensitivities of the proposed development action (*Project's Impact Identification Checklist*),

3) Set of pre-defined facts for assessing and grading the likelihood of potential development – environment conflicts (*Development-Environment Interaction Matrix*).

The outputs are reports containing the following information:

1) Environmental constraints/hazards found at the project location;

2) Potential development implications/sensitivities for the proposed project;

3) A list of potential environmental conflicts that can be expected for the proposed project (development actions) at the selected site.

In this evaluation approach (Figure 3.1) the emphasis is placed on the analysis of the interaction between three sets of mutually related factors namely, location, development actions and environmental settings. It means that in the case of processing certain development proposals it is possible to identify the most and least suitable sites for those proposals, or if the location and proposed development is known, then the potential conflicts can be qualitatively listed. This concept incorporates a close connection between site suitability assessment and environmental impact prediction and at the same time casts both in a larger perspective.

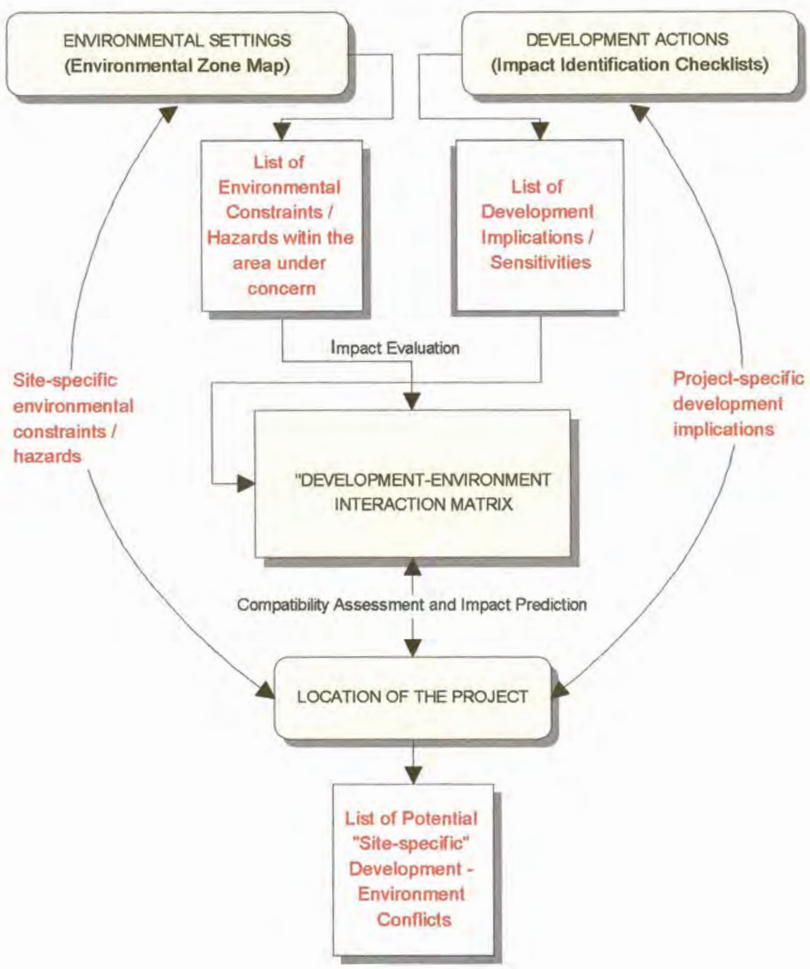

Figure 3.1 *Flow diagram illustrating components and procedures for development- environment compatibility assessment*

3.4 Steps in developing the Model

The development of the model typically consists of two steps, namely:

1) Environmental Zoning of the area concerned (Establishment of the Environmental Zone Map);

2) Identification of potential interactions between the proposed development activities and the environmental resources/hazards (Establishment of the Projects Impact Identification Checklists and Environment-Development Interaction Matrix).

The following sections provide a more in-depth description of these steps.

3.4.1 Environmental Zoning of the Area Concerned

The overall objective of this step is to divide the study area into zones based on the sensitivity of the environment to development actions (UNEP/UNCHS Habitat, 1987). The process actually begins with the collection of relevant information resulting in an inventory of environmental resources and hazards within the area of concern. The type of information usually required for the environmental zoning task is illustrated in Box I.

BOX I. Type of Information Required for Environmental Zoning

Natural Resources:

- ***Water Supply Sources*** (e.g. surface water and their catchment areas, ground water and their recharge areas);
- ***Land with Agricultural Potential*** (e.g. soils quality, suitable land for traditional farming, rained crop production, etc.);
- ***Forest Resources & Pasture Land*** (e.g. area under forests, potential priority areas for afforestation, grassland etc.)
- ***Fishery & Aquatic Resources*** (e.g. lakes, rivers, estuaries, wetlands, fishing grounds etc.);
- ***Areas with Recreation & Tourism Potential*** (e.g. areas of particular natural beauty, scenic areas, water fronts, etc.);
- ***Natural Heritage Resource*** (e.g. valuable habitats and species, areas with important ecosystem functions etc.);
- ***Minerals And Energy Resources*** (e.g. exploration areas, potential row material finds etc.)
- ***Air Quality*** (e.g. extreme and prevailing winds-direction and velocity, urban air-shed etc);

Environmental Hazards:

- ***Floods*** (e.g. flood prone areas, flood plains, flood ways etc.)
- ***Earthquakes*** (e.g. seismic zones and micro-zones characteristics, earthquake prone areas etc.)
- ***Slope And Soil Related Hazards*** (e.g. land prone to subsidence, landslides, erosion, engineering constraints etc.);
- ***Man Made Hazards*** (e.g. air pollution, noise pollution, areas prone to conflagration, landfill sites and Other areas with unsanitary environmental conditions etc.)

Land Use and Man Made Heritage:

- ***Land Use*** (e.g. existing land use, planned land use characteristics and policies, zoning regulations etc);
- ***Man Made Heritage*** (e.g. archaeological, historic, cultural and landscape resources etc.);
- ***Demographic Areas*** (e.g. population distribution, population density etc.)

Adopted From: Environmental Guidelines for Settlements Planning and Management, Vol II.. UNCHS(Habitat)/UNEP, 1987.

To avoid unnecessary data collection and data redundancy, the first step is to formulate general "environmental objectives" and rank them according to their significance for the study area. For illustration purposes a set of environmental objectives could be as follows:

Preservation of resources

- Water supply;
- Agricultural resources;
- Forest resources;
- Wildlife and recreational resources;

Avoidance of hazards

- Erosion hazard
- Slope constraints
- Terrain stability

The "environmental objectives" should also be translated into a set of environmental factors that could be surveyed and documented (e.g. site slope, land formation, soils carrying capacity, prevailing winds etc.). These environmental factors in turn need to be ranked and mapped according to their significance for each of the "environmental objectives". The final products of this procedure are separate maps showing individual environmental sensitivities/constraints and their ranking in respect of a single resource/hazard concern (environmental objective). An example of the environmental factor maps prepared for the Lagos Metropolitan Area Master Plan is provided in Box II.

BOX II

EXAMPLE OF A LIST OF ENVIRONMENTAL FACTOR MAPS AND THEIR RANKING WITH RESPECT TO A SINGLE RESOURCE/HAZARD CONCERN (ENVIRONMENTAL OBJECTIVE)

ENVIRONMENTAL FEATURE [FACTOR MAP]	ENVIRONMENTAL OBJECTIVE	RANKING OF ATTRIBUTES BY DEGREE OF CONSTRAINTS
Land Formation	Avoidance of Unconsolidated Land	0 – Coastal Plain Sand 1 – Older, Consolidated Dune 2 – Alluvial Plain 3 – Unconsolidated Dune
Soils and Subsoil	Avoidance of Unstable Soils	0 – Normally no Constraints 1 – Moderate Foundation Constraint 2 – Severe Foundation Constraint
Soils and Subsoil	Preservation of Agricultural Potential	0 – Soils Not Suited for Agriculture 1 – Soils with Fair to Good Agricultural Potential
Drainage Conditions	Avoidance of Floodplains	0 – Dry Land 1 – Reclaimed Land 2 – Area Flooded as a result of Urban Develop. 3 – Naturally Flooded Area 4 – Areas with Severe Reclamation Constraints
Catchment Areas	Preservation of Water Supply Sources	0 – Outside Critical Catchment Area 1 – In Catchment Area 2 – Wetlands in Catchment Area 3 – Wetland in Catchment Area close to Intake
Flora and Fauna Fishing Community	Preservation of Fishery Resources	0 – No Identified Significance 1 – Fishing Grounds 2 – Wetlands Significant for Subsistence Fishing 3 – Access to Fresh Water Habitat 4 – Wetlands Significant for Fresh
Noise Pollution	Avoidance of Noise Zones	0 – Below 25 Noise Exposure Factor (NEF) 1 – NEF 25-30 2 – NEF 30-40 3 – NEF > 40
Existing Agriculture and Forestry	Preservation of Agricultural Potential	0 – No identified Significant Farming 1 – Traditional Farming 2 – Mechanized Farming 3 – Forest Reserves
Prevailing Wind	Preservation of Clear Air-shed	0 – Outside Air-shed 1 – Areas from which Air-mass is generally replaced
Site Slope	Avoidance of Slope Constraint	0 – No identified Significance 1 – Too Flat (Run-off Constraints) 2 – Hilly terrain 3 – Steeply Dissected Terrain
Air Pollution etc.	Avoidance of man-made Hazards	0 – No identified Significance 1 – Areas Affected by Emissions 2 – Unsanitary Environmental Conditions

Adopted From: Environmental Guidelines for Settlement Planning and management, Vol. I, UNCHS(Habitat)/UNEP, 1987.

With these environmental factor maps, environmental zones can then be defined by combining (overlaying) these maps and by delineating areas within which the environmental characteristics are homogenous. The overall result of this procedure is a composite map (Environmental Zone Map) containing the combination of resource-related sensitivities and hazard-related risks that can be expected for each location in the study area. Figures 3.2a and 3.2b are examples of the "Environmental Zone Map" and its accompanying legend manually prepared within the framework of the Lagos Master Plan effort.

3.4.2 Identification of Interactions between Development Implications and Environmental Resources/Hazards

The second stage of developing the model is the identification of interactions between development implications and the environmental resources and hazards within the study area. This process involves the creation of an interaction matrix that will provide a basis for the site-specific environmental compatibility assessment and the identification of conflicts between development and environment.

As illustrated in Figure 3.1, construction of the Development-Environment Interaction Matrix consists of three steps:

1) Preparation of a list of all environmental constraints found within the area of concern,

2) Preparation of a list of all development implications and sensitivities,

3) Impact identification and evaluation – analysis of the development implications/sensitivities in respect of their potential conflicts with each of the environmental constraint factors.

While the list of environmental constraints (resources/hazards) within the area of concern can be extracted form the Environmental Zone composite layer, identifying the development implications and sensitivities requires the definition of development actions along with their possible impacts on the environment and vice versa.

As illustrated in Figure 3.1, definition of development actions and related potential environmental implications/sensitivities can be treated at a site-independent level and thus with generic data that can be compiled *a priori* in order to provide input for the construction of the Development-Environment Interaction Matrix. For this purpose, the information system as suggested by UNEP/UNCHS (Habitat), uses a "Simple Impact Identification Checklist" approach. In this approach, development actions are pre-defined and grouped into general (urban and non-urban) land-use classes. The classification principle is based on the impact of the land-use options (development actions) on the environmental resources and hazards. The land-use implications are grouped into two categories:

1) *Impacts of development* (development implications that might affect environmental sensitivity);

2) *Sensitivities of Development* in respect to environmental hazards and resource shortages.

Figure 3.2c provides an example of such an Impact Identification Checklist manually prepared within the framework of the Lagos Metropolitan Area Master Plan.

The final and the most difficult step is the identification and evaluation of the interactions between development and environment. This step involves a cross-reference between the checklist of development implications/sensitivities with respect to their potential interactions (conflicts) with each environmental resource/hazard factor retrieved from the "Environmental Zone Map". The information for cross-referencing is provided in a matrix, where the columns contain the description of the environmental constraints (resource/hazard factors), while the rows contain the potential development implications/sensitivities.

An example of the Interaction Matrix prepared to support the assessment of compatibility between development and environment within the framework of the Lagos Metropolitan Area Master Plan is given in Figure 3.2c. It can be regarded as the site-independent overview of all potential development-environment conflicts that can be expected within the Lagos Metropolitan Area.

3.5 Development-Environment Conflicts Evaluation

The purpose of this section is to provide an example of a typical evaluation process to determine conflicts between development and environment. The example summarizes the forms and formats of the UNEP/UNCHS model and illustrates the evaluation approach and procedures as they where manually applied in the Lagos Metropolitan Area Master Plan. (J. Engen, UNEP/UNCHS (Habitat), 987). Once the components of the model are prepared ("Environmental Zone Map", Projects Impact Identification Checklists, Development-Environment-Interaction Matrix), the evaluation procedures can be formalized so that users (planners, development control staff, etc) can apply them with limited training.

Engen (UNEP/UNCHS (Habitat), 1987) uses the example of a municipality that wants to construct a new car battery plant on a site shown in Figure 3.2a. How would the development-environment compatibility assessment of this proposal work? First, the practitioner performing the assessment task would locate the project site on the "Environmental Zone Map", as illustrated in Figure 3.2a and identify the code of the zone within which the site falls (in this case, zone C.14). Using the legend of the "Environmental Zone Map", illustrated in figure 3.2b, the type of environmental constraints at the proposed site would be determined. In this example, the legend indicates that the site lies:

- Inside the catchment area critical for the municipality water supply;
- Inside an area with soils suitable for agriculture;
- Inside the air-shed from which the air masses of existing urbanized areas are being replaced;
- On older consolidated dunes
- In the area with moderate foundation constraints; and
- In the area that is seasonally flooded.

Next, the practitioner would use a checklist relating development actions (land use options) to a list of potential development implications, as illustrated in Figure 3.2c. For heavy industry (car battery plant) this checklist would indicate, that in terms of development implications that might affect environmental sensitivity, all items on the list are applicable. In terms of sensitivities to environmental hazards the checklist would indicate that the proposed development is (a) sensitive to flooding, (b) requires high foundation loads; and (c) requires extensive infrastructure.

Having identified the environmental constraints for the proposed site and the development implications/sensitivities for the proposed development, the practitioner would finally compare them to determine the potential conflicts. This procedure is based on the use of an interaction matrix. As illustrated in Figure 3.2d a variety of potential conflicts are flagged for review. Most important (large dot) in this case are the problems of emissions in the urban air-shed, a series of potential impacts on water supply sources arising from grading and reclamation during construction activities and potential problems arising from storm water runoff and waste disposal. Other issues deserving attention include flooding and potential foundation problems, as well as issues related to the provision of access to environmentally sensitive areas.

The ultimate result of this routine evaluation procedure would be a report containing a list of potential development-environment conflicts that can be expected for the proposed development at the selected site. It would provide a basis for the introduction of environmental concerns at the very early stage of project planning in order for them to be studied.

The conceptual approach to environmental evaluation and the organization of the model's components illustrated in the example above served as a starting point in the preparation of the prototype of a Knowledge based GIS (KBGIS) developed in this research.

Figure 3.2 *An example of a typical development-environment conflict anticipation session*

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Figure 3.2a
An example of the manually prepared "Environmental Zone Map" (identifying for each location within the area concerned all critical resources/hazards issues)

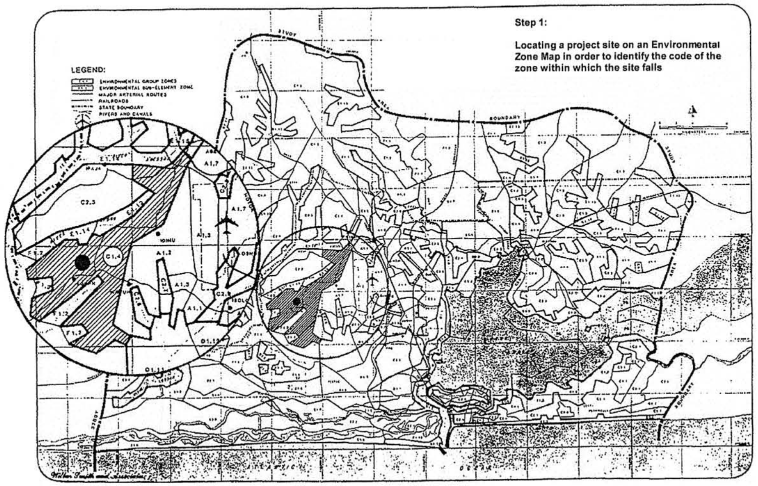


Figure 3.2b
Legend of Environmental Zone Map showing incidence of constraints (resource-related sensitivities and hazard-related risks) in each environmental zone

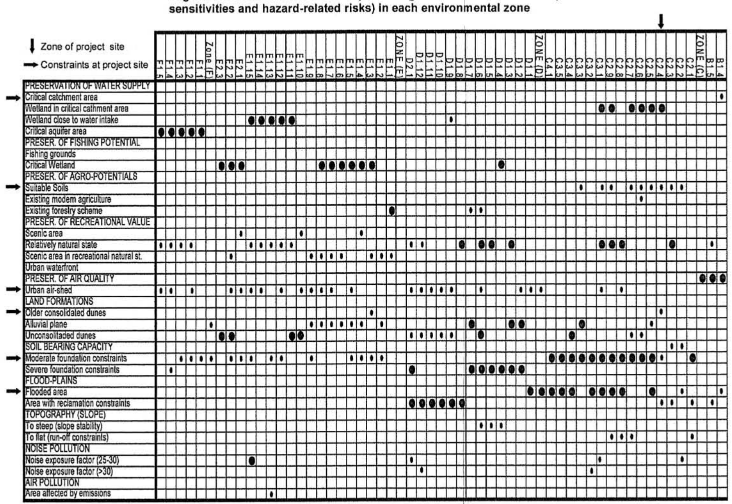


Figure 3.2c
An example of the manually prepared checklist relating development actions (land use options) to their potential development implications

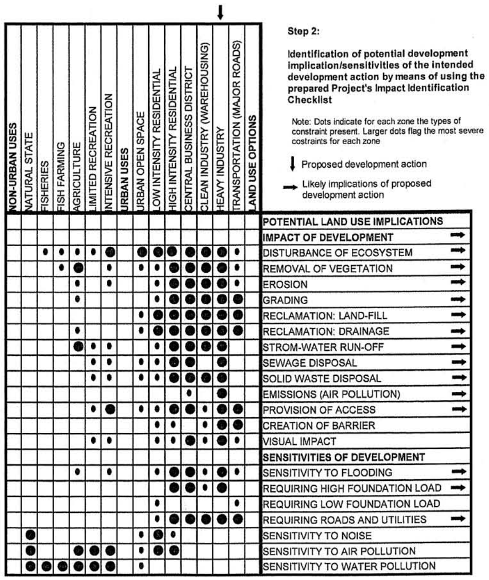
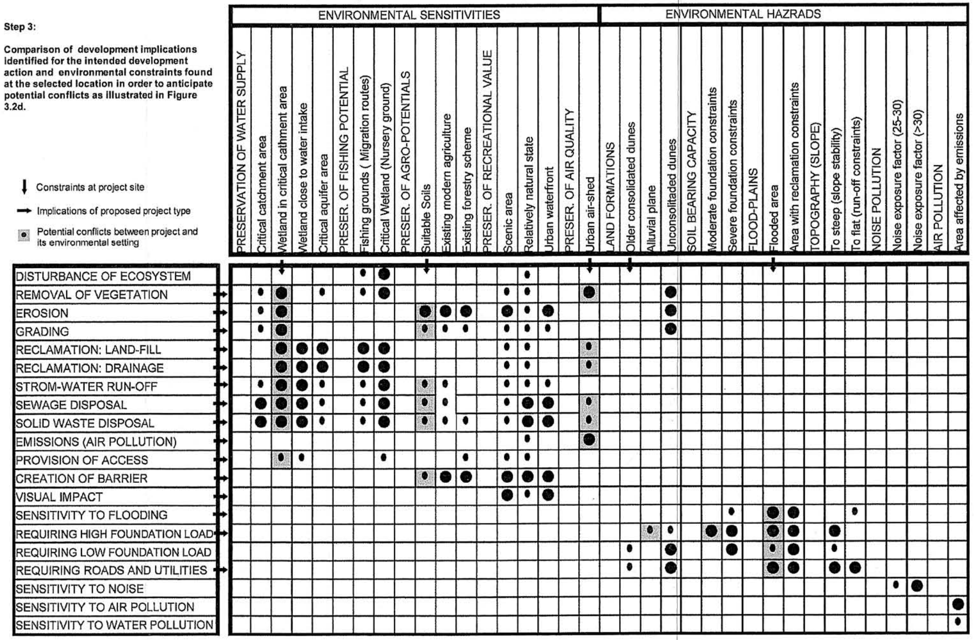


Figure 3.2d An example of the manually constructed interaction matrix indicating environmental constraints and their potential conflicts with development implications



Source: Eigen, J. "Land Suitability and Physical Constraints to Urban Development, Master Plan for Metropolitan Lagos, (Lagos, Nigeria: LSG/UNCHS/UNDP/WSA),1988

CHAPTER 4

THE KBGIS DEVELOPMENT

4.1 Introduction

As mentioned earlier, this research aims to develop a prototype problem specific knowledge-based GIS (KBGIS) for the evaluation of compatibility between development activities and their physical environmental settings. This was done by reconfiguring an existing model (see previous chapter) with the purpose to present a practical example of using GIS in automating semi-structured decision making tasks and, more importantly, to illustrate the usefulness of incorporating elements of knowledge-based techniques in enhancing "the level of intelligence" of current GIS. The model was ideal for this research project because it applies to a problem domain that would benefit substantially from both GIS and KBS.

In the context of the assessment procedure, GIS is regarded as a superior tool to support the collection, presentation, analysis, reclassification and retrieval of environmental data from a spatial database, i.e. environmental zone map. On the other hand, it is regarded as an inferior tool for analysing relationships between development and environment and identifying concerns (potential conflicts) in environmental compatibility assessment and impact prediction. Since these tasks, can obviously not be interpreted without the intervention of experts, the inferiority of GIS in supporting the model, is re-solved by incorporating (embedding) the elements of an expert (or knowledge based) system in a GIS. Its perceived role in the model's implementation is to act as an interactive front end to GIS with the ability to provide:

1) An easily accessible repository of domain knowledge (facts and expert opinions) concerning various project development implications/sensitivities (Impact Identification Checklist);
2) A set of generic rules for assessing their potential conflicts with environmental resources/hazards factors (Development-Environment Interaction Matrix)
3) Reasoning capabilities similar to those of experts (inference mechanism) for identifying, grading and presenting concerns (potential conflicts) in the process of site-specific environmental compatibility assessment and development-environment impact prediction.

This chapter explains the strategy used in this research to develop the prototype KBGIS system. It is divided into two parts. The first part describes the components of the model, namely the Environmental Zone map, the Project Impact Identification Checklist and the Development-Environment Interaction Matrix from the point of view of their organization, types and formats.

The second part explains the GIS - KBS integration (interfacing) strategy. It starts with a brief illustration of the prototype KBGIS system structure, along with a description of its components and functions. It then continues with an overall view of the system's modules and capabilities. Emphasis is placed to the procedures of the system operation.

4.2 Components of the Model

The steps to develop the components of the model using manual procedures were briefly explained in the previous chapter. This section illustrates how the model can be constructed and organised within a computerised KBGIS environment. It starts with an explanation of how an Environmental Zone Map can be established by using a GIS. Emphasis is placed on issues concerning database preparation and organisation to support the zoning task. This task is currently detached from the KBGIS environment, which means that it needs to be executed independently before setting up the system. The following section briefly explains the approach to the construction of the Project Impact Identification Checklist and Development-Environment Interaction Matrix.

4.2.1 GIS Approach to Environmental Zoning and Construction of Environmental Zone Maps

As mentioned in chapter 3, environmental zoning is a task that aims at providing input to the definition of a composite Environmental Zone Map by means of combining a comprehensive set of environmental factors. It can, fundamentally, be thought of as a mapping method (one problem-one map) that provides the option of overlaying the problems one over the other in order to delineate zones that feature homogeneous sensitivity levels to external initiatives.

In a manual processing technique, this task is accomplished by transparent overlays of environmental factor maps coordinated in terms of scale, coverage and reference grid. In practice, however, due to the large number of maps usually required, this process was usually scaled down because it was a tedious, non-flexible and time consuming process.

In order to overcome the constraints of the manual method, this research project proposes a strategy based on the use of GIS to automate environmental zoning tasks. Figure 4.1 illustrates this approach.

Because environmental zoning relies on a relatively large amount of data the correct choice and quality of data is more important than the tools used for handling and analysing the data. There is a widespread agreement that in the establishment of any information system, the end performance of the system is greatly affected by the organization of its database. In the case of a GIS database, this is even more important due to the spatial component of the data. Consequently, data input without proper organisation is usually not efficient. This issue justifies the use of a GIS database to support environmental zoning. As Figure 4.1 illustrates, database design involves two phases, namely a conceptual and a physical design.

The conceptual database design includes several mutually related activities including:

1) Identification of data requirements, collection and categorization of available data and evaluation of their usefulness for the task.
2) Formulation and ranking of environmental objectives according to their significance in supporting environmental zoning for the area concerned (Prioritisation of data sets required for environmental zoning tasks).
3) Determination of the final scope and contents of the GIS database (identification of layers, logical database organization, formal data structure, standards and tolerances, database documentation etc.)

This phase is considered important as it aims at providing the answer to the question of which environmental data and attributes should be included and how to organize them to enhance database performance.

The physical database design, starts immediately after or parallel to its conceptual design and includes the following:

1) Preparation of the base map to ensure appropriate registering and spatial referencing of data layers;
2) Thematic map manuscripts preparation along with identification of the master and component templates. Their purpose is to ensure that coincident component features of the various thematic data layers involved in construction of a GIS database are coordinate-coincident. (Spatial data normalization)
3) Map automation, which includes: (a) acquisition of layers through digitising, digital data conversion, processing of satellite images, generation from numerical data, scanning and raster-vector conversion; (b) establishment of topology, attribute code assignment and verification and quality control (positional and attribute accuracy, logical consistency and completeness).
4) Final database creation and the preparation of an Environmental Zone Map to be used by the prototype KBGIS.

Some practical issues concerning the database construction and implementation are discussed in chapter 5.

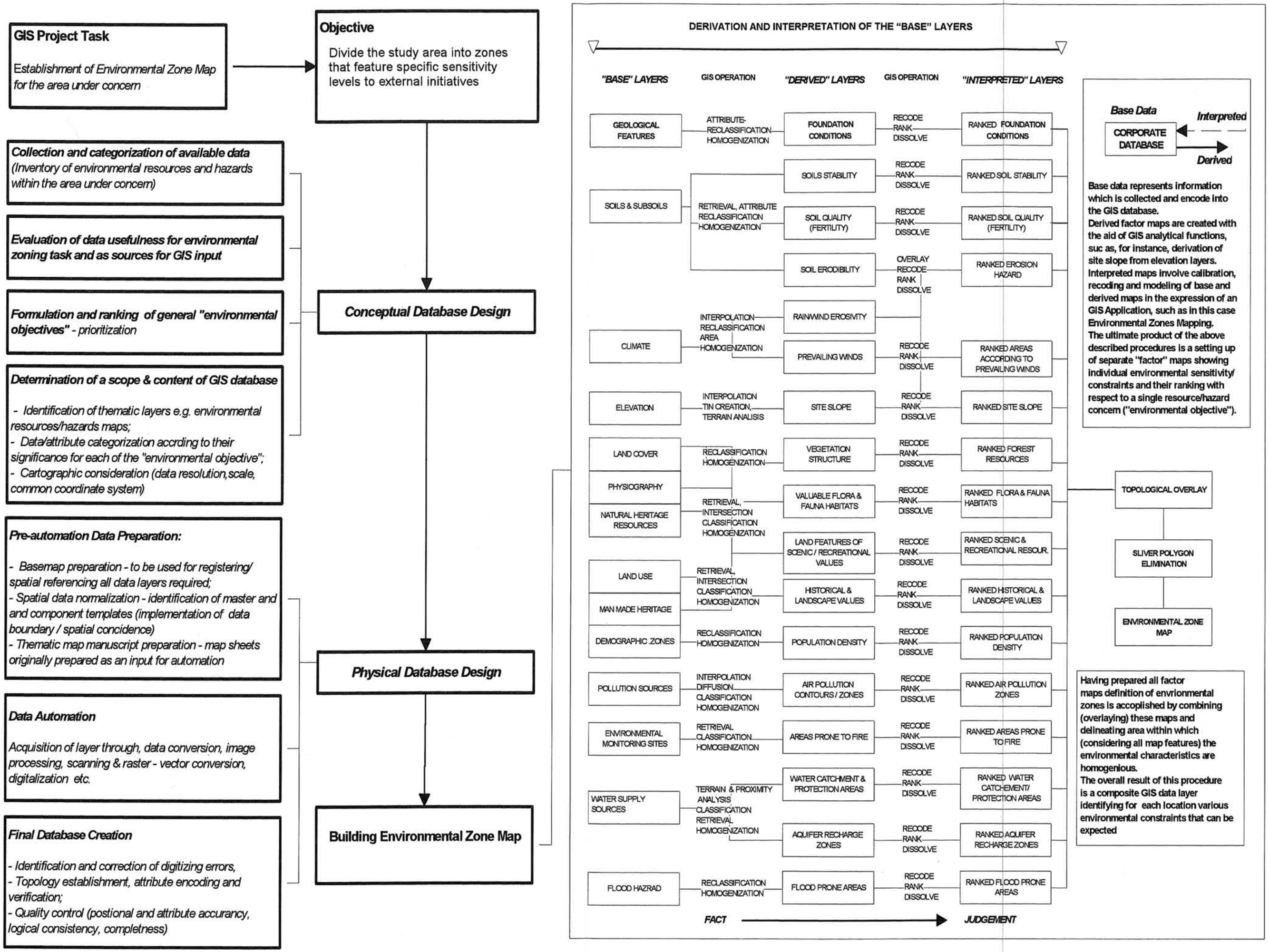
4.2.2 Summary of a GIS Data Organisation and Generation of an Environmental Zone Map

A typical GIS for environmental zoning can be seen as an inventory-related database created to provide a realistic and comprehensive environmental profile of the study area. It may contain various environmental data sets organized into layers that are mutually referenced to a common co-ordinate system. Each layer contains data grouped by thematic coherence starting from geology, groundwater potential, and proceeding upward through soil types, land cover types, topography, aquifer boundaries, environmental hazards features, etc. To this, agricultural, forest and water supply sources, and the man-made impacts to the environment such as existing land use, recreation and natural heritage resources are added.

These layers are composed of basic map features (points, line, polygons) showing boundaries and distribution of a single resource/hazard factor and associated descriptive attributes serving to identify and/or categorize map features.

Separation of a GIS database into a number of layers can be understood as a thematic approach to representing the environmental profile of the study area. This database organization is considered appropriate in supporting environmental zoning. Firstly, it leaves open the possibility of manipulating and combining different thematically associated data (layers) only when they are needed. Secondly, it eliminates risks of burdening the resulting composite layer (Environmental Zone Map) with superfluous data.

Figure 4.1 Flow diagram of typical steps involved in the construction of an Environmental Zone Map



An overview of the typical content of a GIS database for environmental zoning, and its layer separation is provided in Figure 4.1. The layers in the GIS database are normally categorized into two groups:

1) Primary ("base") layers and

2) Secondary ("derived" and/or "interpreted") layers:

This categorization essentially resembles the whole process of environmental zoning. The primary data layers represent spatial and related attribute data that are captured and encoded into the GIS database by means of digitising analogue thematic maps or through other methods (digital data conversion, processing of satellite images, generation from numerical data, scanning and raster-vector conversion etc.). Often these layers cannot be used in their original form to support the environmental zoning task. For example, an original soils layer and related attributes classification must be translated into levels of bearing-capacity in order to identify foundation constraints, into levels of fertility to identify agricultural potential, etc. Furthermore, original spatial data sets only provide data on potential (such as elevation points or contours) while the environmental zoning task requires its interpretation and categorisation (e.g. the slope of terrain ranked with respect to different levels of sensitivity to external initiatives). In addition, to solve the problem of graphic interpretation of the accessibility to roads, the primary layer using lines to show the existing road network must be transformed into a polygon layer showing levels of accessibility (distance buffers). Also, in order to identify the runoff coefficient for assessing and categorising the risk of flooding, data on soils need to be combined with topographical and climate information and translated into levels of permeation.

In accordance with the aforementioned examples, it is apparent that the original data sets must very often be processed and interpreted to become relevant for the environmental zoning task. This, within a GIS environment, is accomplished by means of generating new data sets with the aid of the various spatial analysis and modelling tools of GIS (spatial data retrieval, re-coding, aggregation, attributes calculation and re-classification, etc.). These new data sets, as illustrated in Figures 4.1 and 4.2 could be the results required for environmental zoning task ("interpreted layers") or they could constitute input to further analysis and interpretation ("derived layers"). In either case, the new data sets need not be stored physically because they can be generated rapidly when required with the GIS tools.

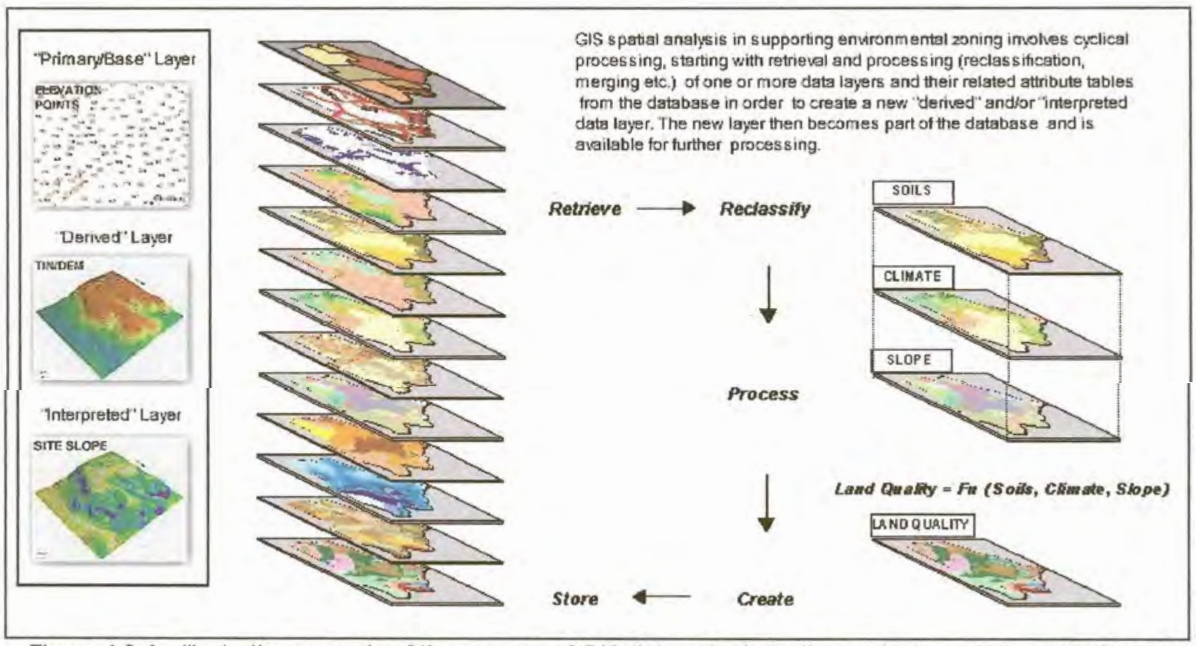


Figure 4.2 An Illustrative example of the process of GIS data sets derivation and interpretation with the aid of GIS analytical and modelling functions

The ultimate goal of the above mentioned procedures is to set up the separate ("interpreted") factor maps (layers), dividing the study area into zones featuring a specific type and level of sensitivity in respect of a single resource/hazard concern. Once the factor maps (layers) are adequately prepared, it is possible to proceed with the final step in the environmental zoning task. It involves the construction of an "Environmental Zone map" seeking to aggregate these factor maps and accordingly delineate areas within which the environmental characteristics are homogenous. As illustrated in Figure 4.1 this is achieved by using GIS topology overlay procedures allowing the creation of a new layer from intersections of the existing factor layers.

As briefly summarized above, the final result of the whole environmental zoning task is the creation of a composite GIS layer ("Environmental Zone Map") containing a combination of map features and associated descriptive attributes of all original input (factor) layers. Its perceived role within the prototype KBGIS implementation is:

1) To provide a basis for the identification of site-specific environmental constraints (resource-related sensitivities and hazard-related risks) that can be expected within the area of concern, and
2) To serve as data source (environmental input) for the construction of the Development-Environment Interaction Matrix.

Currently the prototype KBGIS only supports a vector data structure. This means that the Environmental Zone composite layer should be created and then stored within the system's database in vector data format with polygon topology. This data structure seeks to preserve exact boundaries of environmental (geographic) features, thus maximizing the accuracy of spatial presentation. Discussion concerning the selection of the GIS data structure to support environmental zoning is provided in chapter 5.

4.3 Approach to the Organization of the Project Impact Identification Checklist and Development-Environment Interaction Matrix within the Prototype KBGIS Environment

The Project Impact Identification Checklist and Development-Environment Interaction Matrix are the other two fundamental components of the prototype KBGIS. While the Environmental Zone Map must be constructed independently and made available before setting up the system, the establishment and maintenance of these two components are completely reliant on the KBGIS toolbox. The following section illustrates how this research project resolved the issue of their type and format within the prototype KBGIS.

4.3.1 Project Impact Identification Checklist

The role of the Project Impact Identification Checklist within the system implementation environment is to provide the means for:

1) Definition of development actions, and
2) Determination of how the development actions will influence the environment and/or how they could be affected by the environmental hazards and resource shortages.

For this purpose the system, as illustrated in Figure 4.3, uses a Simple Impact Identification Checklist approach. It is considered practical and suitable for several reasons. Firstly, it is not complex in terms of data and resource requirements. As such, it is regarded as an appropriate, low-cost method in providing inputs for the evaluation procedure supported by the system.

This approach, furthermore, allows development of a standard, site-independent checklist that can be defined in advance and then used as a template for identification of the project's development implications/sensitivities. As illustrated in Figure 4.3, it uses a tabular presentation format in which columns hold information about projects (development actions) while rows provide a generic and extendable list of potential development implications/sensitivities. This simple checklist approach can be best described as a tool that acts like a "prompt" to the user. He/she is allowed to identify, through use of a "tick-to-confirm-this" method, the likelihood and even significance of the impacts for the particular development action. This checklist approach provides a way of systematically ensuring that all likely implications of the relevant development action are considered.

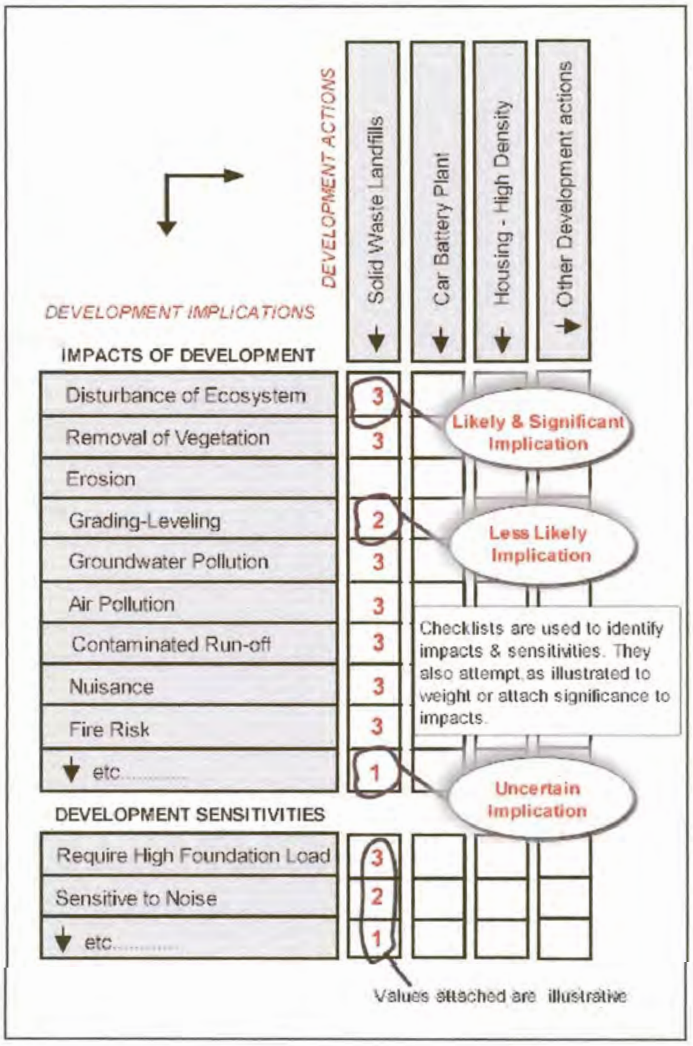


Figure 4.3 An illustrative example of a Simple Impact Identification Checklist used in this research for identification of development actions and their implications likely to have significant effects on the environment

4.3.2 Development-Environment Interaction Matrix

Development-Environment Interaction Matrix is the cornerstone of the prototype KBGIS. Its task is to provide a site-independent overview of all the potential "development implications-environmental constraints" conflicts that can be expected within a study area. As illustrated in chapter 3, the construction of such an overview involves cross-referencing the list of compiled development implications/sensitivities in respect of their potential interactions with each environmental resource/ hazard factor retrieved from the "Environmental Zone Map".

For this purpose the prototype KBGIS system uses the approach that closely resembles a simple Interaction Matrix method. The approach is considered appropriate and practical. It uses a tabular presentation format in which columns hold description of each individual environmental resource/hazard factor found within the area of concern, while rows contain a generic list of potential development implications/sensitivities. The matrix allows the user to identify direct "development implications-environmental constraints" interactions using the aforementioned "tick-to-confirm-this" method. Where there is no interaction the relevant matrix box is left empty. An example of the simple Interaction Matrix approach applied within the prototype KBGIS environment is given in Figure 4.4.

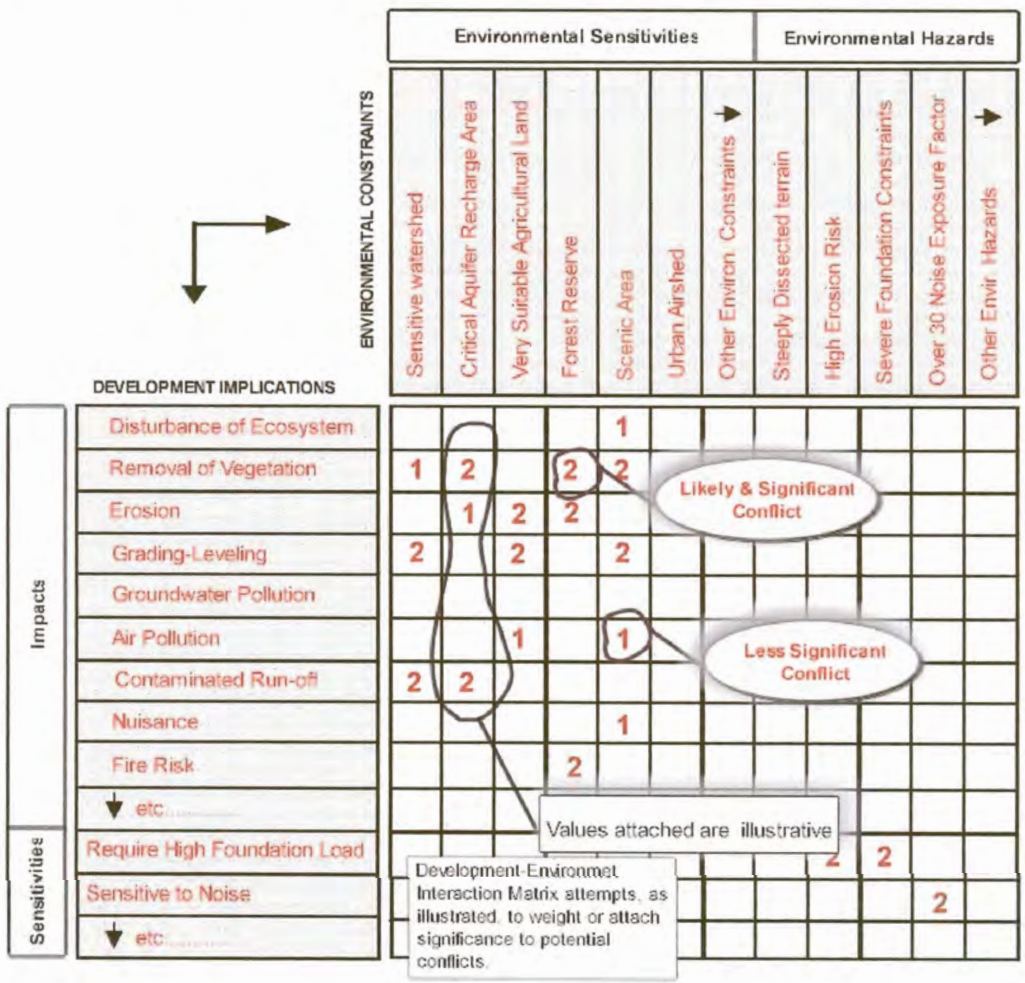


Figure 4.4 *An Illustrative Example of the simple Interaction Matrix approach used by the prototype KBGIS for identification of development-environment interactions (potential conflicts) within an area concerned*

4.4 The prototype KBGIS Architecture

This section describes the strategy applied in this research to develop the prototype KBGIS. It is focused on issues concerning the architectural basis of the integration between GIS and KBS.

4.4.1 Integration Approach

In the deliberation of the integration approach, it is appropriate to start the section with an overview of the basic KBGIS functions. They can briefly be described as a set of computer assisted procedures with abilities to:

1) Store and offer an easily accessible repository of domain knowledge concerning various development actions (Project Impact Identification Checklist) along with a set of generic rules for assessing their potential conflicts with environmental resources/hazards (Development-Environment Interaction Matrix);
2) Provide automated procedures (reasoning capabilities) for identifying concerns in site-specific development-environment compatibility assessment;
3) Facilitate spatial data visualisation, query and retrieval by the users not trained in GIS;
4) Display information concerning development-environment impacts in the language familiar to the user.

In order to provide an environment in which users are able to access the above functions it was necessary to combine the basic functionality of GIS with elements of knowledge based techniques. As indicated in chapter 2, there are different levels of integrating GIS and KBS. This research developed an example of a GIS-KBS integration in which the elements of knowledge-based techniques are actually one of the functions available inside the GIS. The idea for the system design was to put the data, the model and the decision analysis (reasoning) process all together into a GIS environment and within one single application with shared communication routines and a common interface.

The software used for the prototype KBGIS development is ArcView desktop GIS developed by ESRI (Environmental System Research Institute, Inc.). It features a user-friendly working environment and provides users with the fundamental functions for analysis, visualization and integration of spatial data and related attributes. Data storage, query and retrieval capabilities in ArcView give the prototype KBGIS a convenient method for a location-based inventory that is required by the system in the process of identifying the site-specific environmental constraints.

A major feature of ArcView that took an important role in the GIS-KBS integration is its Avenue macro language. It provides ArcView with the ability to extend its functions directly through programming and customisation routines. Three tools available within ArcView were employed in the prototype KBGIS system development. Firstly, ArcView's customisation routines were used to develop the common window and icon-based menus. Secondly, ArcView's Dialog Designer extension was used to develop various forms and dialogues required by the system for interactive data and knowledge acquisition. Finally, Avenue programming served to link dialogues, forms and menus and to isolate the user from the technicalities of the computer and the model. It was also used to develop the problem processor (inference mechanism) for identifying, grading and reporting concerns in the process of development-environment impact prediction.

The Environmental Zone composite layer along with related attribute tables constitutes the core of the system's spatial database. It is brought into the system and stored as an ArcView shapefile. The Project Impact Identification Checklist and Development-Environment Interaction Matrix represent the system's knowledge bases. Both of them can be understood as collections of domain specific information. They are organized within the system as internal Dbase files capable of replicating their conceptual forms illustrated in the pervious section.

The *analysis and query module* is the system's key module. It is developed within the "View" subsystem of ArcView, which provides tools for display, selection and retrieval of information from the system's GIS and ArcView's knowledge databases. All the generic spatial and database search and retrieval functions needed by the model are available to the user along with the new ones developed with the aid of the Avenue macro language and embedded within the same interface.

The core of this module is the *problem processor (inference engine)* composed of:

1) *Query and scenario manager* – capable to interact with the user in order to get basic input or additional information required by the evaluation model;
2) *Working memory* - hidden from the user and used to store input data and the intermediate results of the evaluation;
3) *Analysis and evaluation or reasoning mechanism* - capable to direct the search through GIS and knowledge databases in order to draw conclusions, identify and grade development-environment concerns (potential conflicts) from a set of expertise (facts) about the problem at hand.
4) *Justifier* - used to store assumptions underlying the system's reasoning process.

The role of the *display and report generator* is to report the evaluation results in a language familiar to the user. It is an essentially sub-module of the aforementioned analysis and query module and contains several point-and-click button-based options embedded into the main interface. The key options provided by this sub-module are:

1) A list of environmental constraints (resource related sensitivities, hazard related risks) found at selected locations;
2) A list of pre-defined development implications and sensitivities to environmental hazards for the selected development action (project);
3) A list of environmental concerns (potential conflicts) that can be expected for the proposed development action at the selected site.

4.4.3 The System Modes and Capabilities

The prototype KBGIS presented in this research has been created to function as a fully integrated GIS-KBS DSS aiming to replicate a specific domain of expertise. It was designed to include all of the necessary functions required for developing and running the system.

What made this possible is the separation of the system's database management module retaining specific knowledge on a problem domain, and its query and analysis module containing mechanism (inference engine) for applying that knowledge. As illustrated in Figure 4.5 this feature could be interpreted as a "plug-in" architecture. It is characterized by editing functions for entering required GIS and knowledge databases that are coded separately from the system's analysis and evaluation mechanism (inference engine). It furthermore permits the existing spatial and knowledge databases to be detached from the system and new databases containing different sets of data and knowledge to be inserted into it.

The "plug in" architecture contributes to scalability of the system making it open and capable to reproduce a specific domain of expertise it is designed for without a need to rewrite any portion of the computer program. In accordance with this, the prototype KBGIS developed in this research can be regarded as an application specific and GIS-enabled Expert System Shell. It consists of two basic modes:

1) Development (Knowledge Acquisition) mode and

2) Consultation (Running) mode.

The system's "Mode and GUI Manager" controls these two modes. It is a start-up program designed to verify and validate the status of the system in terms of the existence and consistency of all its components (GIS and Knowledge databases) required by the consultation mode. The output of this program, as illustrated in Figure 4.6, is the "Main Start-up GUI". Being in dialogue form, it provides appropriate explanation and button-based menu options critical for the effective use of the system.

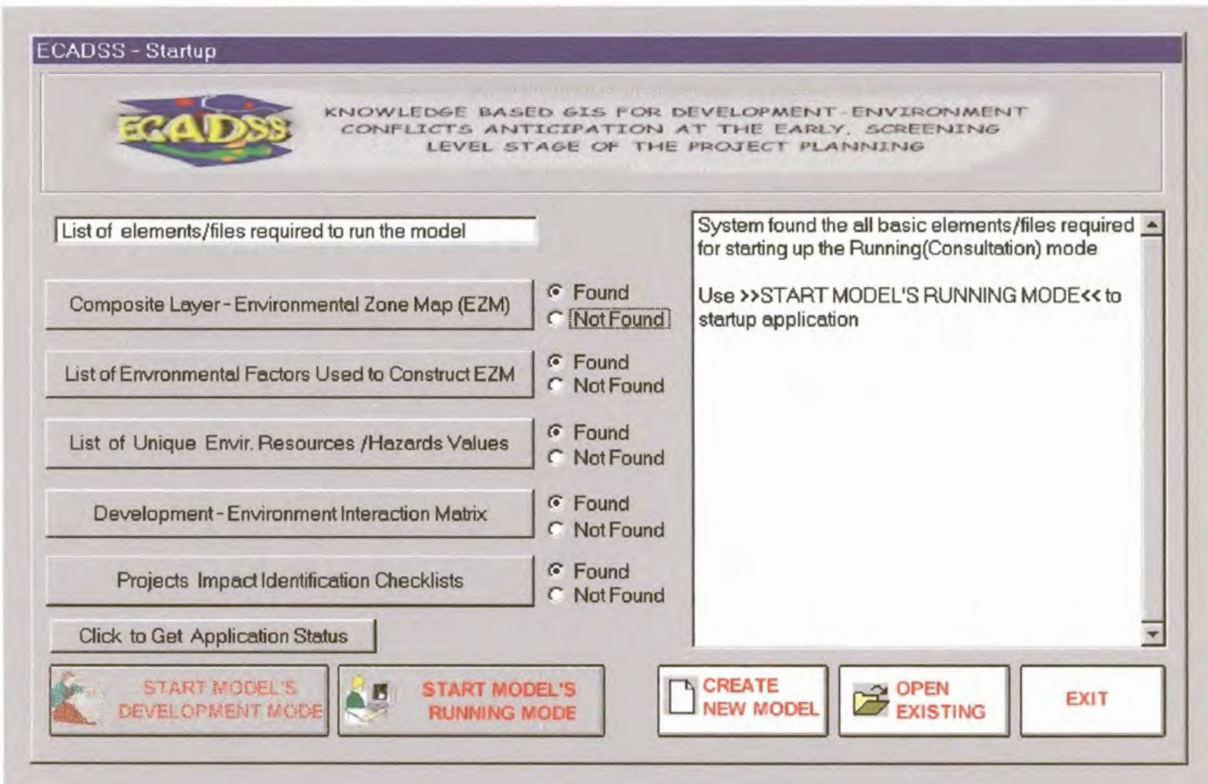


Figure 4.6 The KBGIS Start-up GUI

When the mode manager detects that some of the components (GIS and knowledge databases) are missing or not yet defined, it will act appropriately by:

1) Disabling the menu option that starts the consultation mode;

2) Enabling option that opens the development (knowledge acquisition) mode along with the relevant GUI;

3) Providing information on what is missing and what should be done before enabling the consultation mode.

If the mode manager verifies and validates the existence and consistency of all components (databases) required it will enable the consultation mode option along with its relevant GUI.

The following section provides a more in-depth explanation of the aforementioned functions and capabilities.

4.5 The KBGIS Data and Knowledge Acquisition Mode

As already indicated, the prototype KBGIS is designed as an open system that can be used to anticipate development-environment conflicts at various levels (urban, regional) and for different areas. To make this possible, the system provides tools for capturing environmental data and "domain" knowledge and organising it in area-specific data and knowledge bases.

The capturing of data and domain knowledge into the prototype KBGIS relies on its Knowledge Acquisition Unit. It is a collection of several tools designed to interact with the expert in order to acquire all the components (i.e. data and domain knowledge) relevant for the consultation mode. As illustrated in Figure 4.7, they are embedded in an appropriate Knowledge Acquisition (and now KA) Interface in various formats of interactive dialogues and form-filling schemes. These forms and dialogues tend to emulate a "paper and pen" environment in which the user enters required information into dialogue fields shown on the screen, or selects options from the list boxes and menus built into the system. This has earlier been referred to as an intuitive (directly apprehended) knowledge acquisition method capable of leveraging large amounts of knowledge (Gruber & Cohen, 1988).

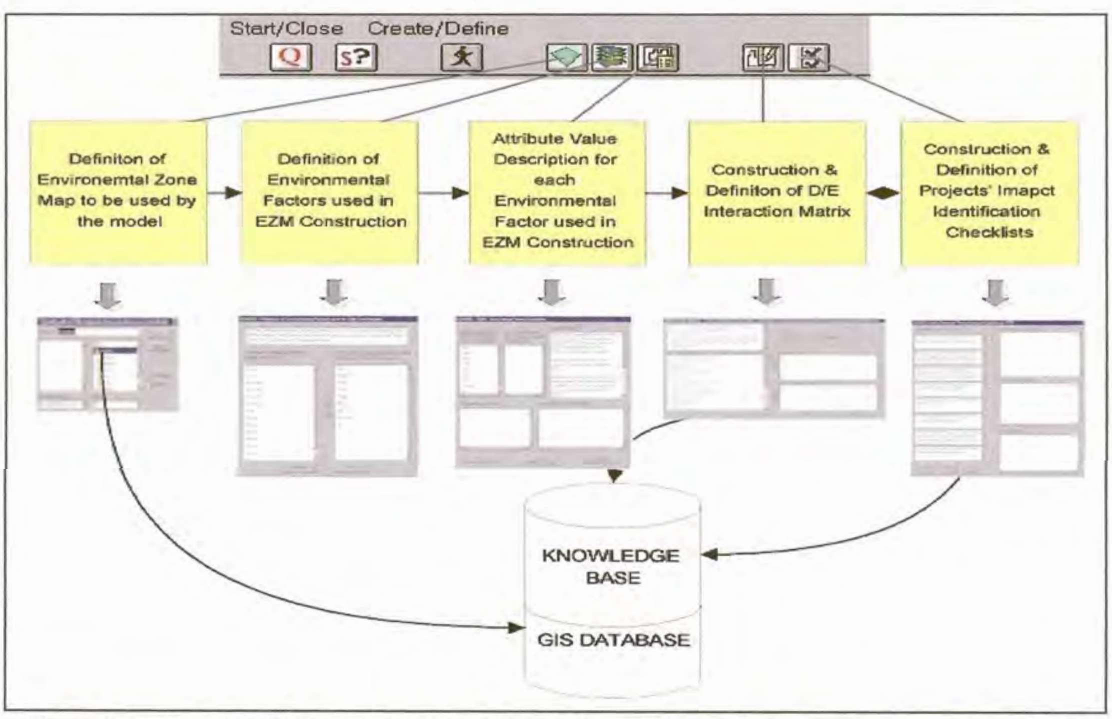


Figure 4.7 The KBGIS Knowledge Acquisition GUI and the steps involved in a typical data and knowledge acquisition session supported by the system

4.5.1 Acquisition of GIS Data

(1) GIS Data Source selection

The first step in a typical data and knowledge acquisition session is the selection of the Environmental Zone composite layer (EZM) that will be used for the identification of site-specific environmental resource/hazard constraints within an area of concern. As already indicated, this composite layer should be prepared before setting up the KA session. From the design point of view, an option for the selection of the EZM composite layer is provided in a File Dialogue form. It is essentially a modified ArcView Source Dialogue window enabling the user to browse and return the selected data source from a file system. As illustrated in Figure 4.8, the user is prompted to simply point-and-click on the existing data source (EZM composite layer) that he/she wants to use.

Figure 4.8 The KBGIS Data Source dialogue window for selection of the Environmental Zone composite layer

As soon as the user selects the EZM composite layer, the system fires up internal procedures of checking the format of the data source, its topology and the logical consistency. After that the system, if necessary, converts the selected EZM composite layer into the ArcView format (shapefile), and stores it in the database of the system for further processing. A feedback report is provided notifying the user about problems encountered during the data source validation process.

(2) Definition of Environmental Factors and their unique attribute values

After selection of the EZM composite layer the user is asked to indicate all individual environmental resource/hazard factors that were used in the EZM construction (such as slope stability, soil quality, etc.). These factors are contained in the associated EZM Polygon Attribute Table. For this purpose the user is provided with a simple point-and-click interactive dialogue whose left part, as illustrated in Figure 4.9, lists all item names contained in the EZM's Polygon Attribute Table. The user is then requested to select the items that represent environmental resource/hazard factors.

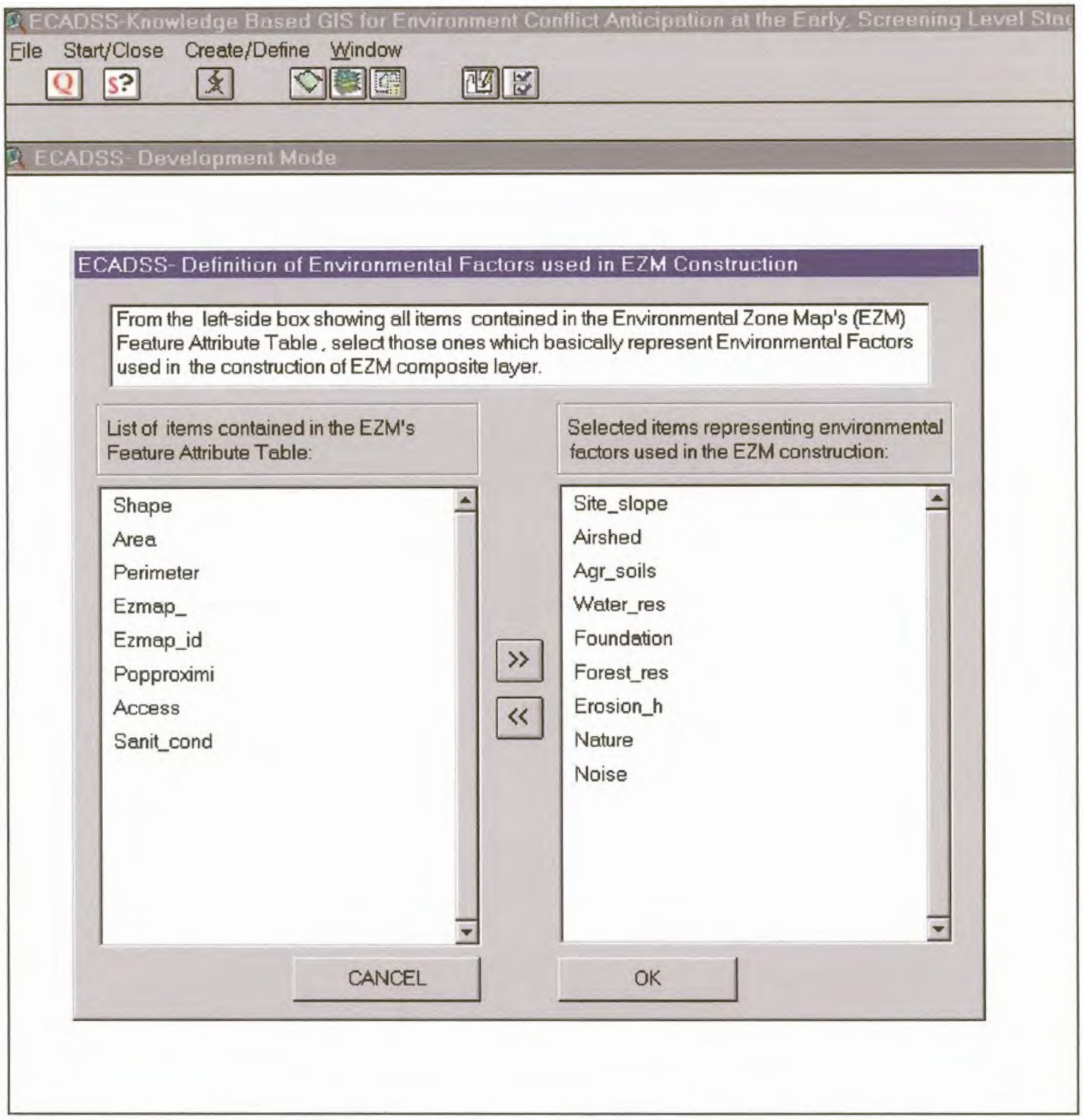


Figure 4.9 The KBGIS interactive dialogue for the selection of environmental resource/hazard factors to be used by the system for identification of environmental constraints within a study area

After identifying all relevant environmental factors, the system automatically starts searching through the EZM polygon attribute table in order to extract the combination of unique attribute values for each of the selected factors. The user is then requested to verify their attribute value descriptions in terms of how explicable they portray the individual resource/hazard concerns. It has been explained in section 4.2 of this chapter that the EZM composite layer is based on the aggregation (overlay) of individual "factor" layers. Each of these layers portrays unique environmental resource/hazard attributes (such as slope stability, soil quality, susceptibility to erosion etc.) and its variation (ranking) by the level of environmental constraint it may pose to external initiatives. Sometimes, however these attribute rankings contained in the attribute table are simply coded as integers or string abbreviations and therefore may not be easily understandable in terms of the environmental concerns they portray. Lets for example consider an attribute value classification (ranking) of an individual factor layer such as the slope of the terrain. Very often the attribute classification for this factor is expressed in a form of slope percentage categories such as 0-0.5%, 0.5-10%; 10-20%; 20-30%; >30%. This attribute classification is meaningless from the prototype KBGIS point of view since it does not describe the specific resource/hazard concern in a language familiar to users. This especially refers to the users who are not in a position to understand the meaning of the aforementioned attribute categories in terms of the environmental constraints they pose to various external initiatives. Therefore, instead of 0-0.5% or >30%, the site slope attribute categorization and description expressed in a form such as "To flat (run off constraint)" or "Steeply dissected terrain" is considered more appropriate from both, the user and the proposed system point of view.

For this purpose the system provides an interactive, dialogue form whose upper left part, as illustrated in Figure 4.10, presents the list of the previously selected environmental factors to be used for identification of environmental constraints. The user is prompted to point-and-click on each environmental factor (item) in order to get its unique attribute value descriptions contained in the EZM attribute table. The user is then requested to re-define each of these value descriptions in order to provide the new ones that will portray the relevant resource/hazard concerns more effectively. (Examples: high erosion risk, severe foundation constraints, naturally flooded area, scenic area, very suitable agricultural land, hilly terrain, no significance, etc.).

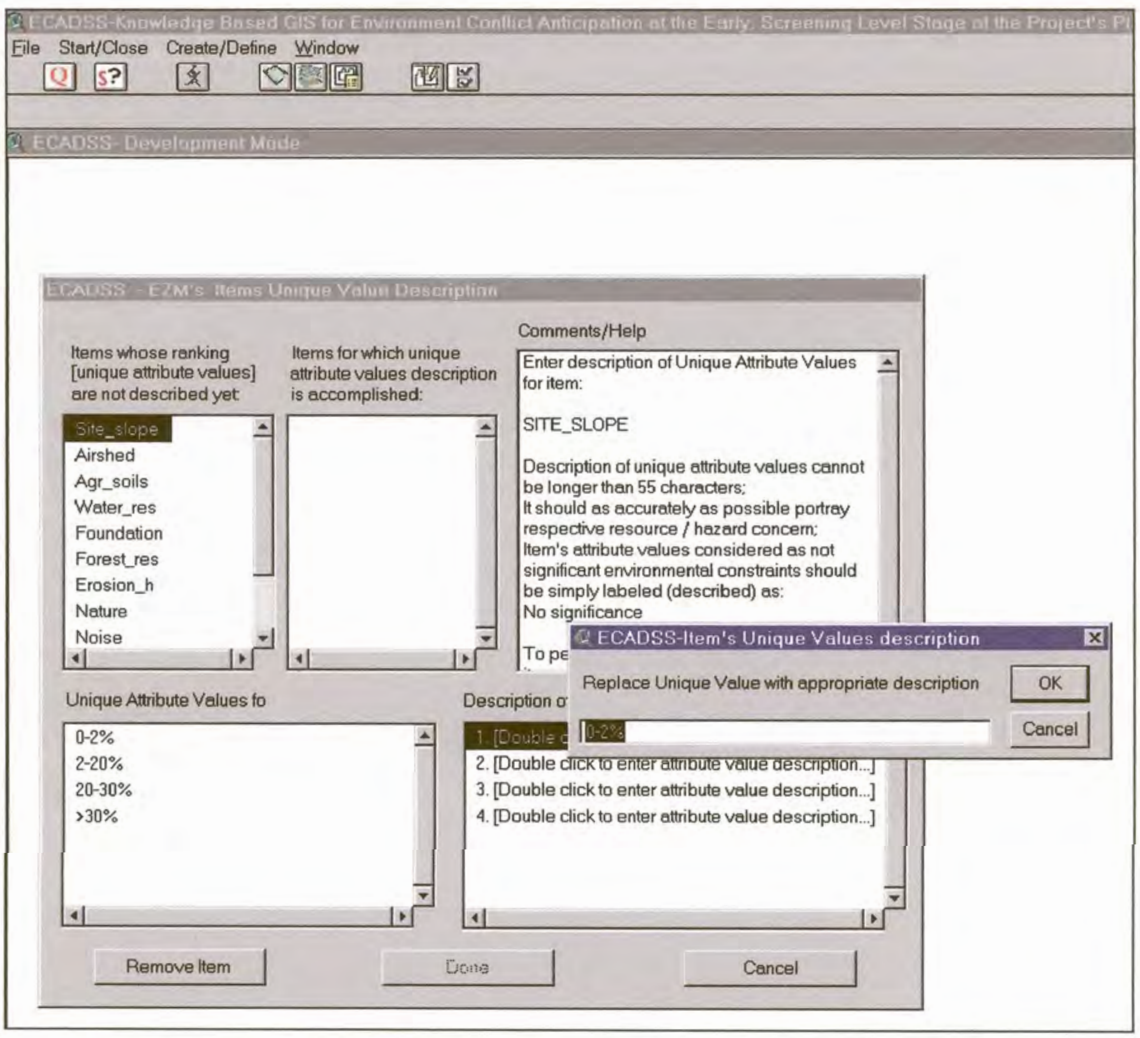


Figure 4.10 The KBGIS interactive dialogue designed to support viewing and typing in descriptions of unique attribute values for each environmental factor selected from the EZM attribute table

The unique attribute value descriptions for each of the selected environmental factors will become a part of the KBGIS knowledge base. They will be used by the system for:

1) Presentation of the site-specific environmental constraints in a language familiar to the user, and
2) As data source (environmental input) for the construction of the system's D/E Interaction Matrix.

4.5.2 Acquisition of Knowledge within the Prototype KBGIS Implementation Environment

The final steps in a typical data and knowledge acquisition session of the proposed KBGIS are the construction of the Development-Environment Interaction Matrix (D/E Interaction Matrix) and definition of the Project Impact Identification Checklist (PII Checklist)

(1) D/E Interaction Matrix

D/E Interaction Matrix is the foundation of the prototype KBGIS with the task to provide a set of development-environment relations required for grading and assessing potential conflicts between site-specific environmental constraints and the project's development implications.

As illustrated in section 4.3.2 of this chapter, its construction involves cross-referencing a list of development implications/sensitivities with the previously selected environmental factors and their values. This procedure requires a strong element of human expertise and judgement about the array of possible development implications-environmental constraint interactions, especially in the situation where such identification attempts to attach significance to each of the identified interactions.

The judgmental process on the likely development-environment interactions and on their significance is achieved within the prototype KBGIS through the use of a so-called automated expert-driven knowledge-acquisition method. It allows the expert to construct a D/E Interaction Matrix without assistance of the knowledge engineer. Furthermore, it is based on an interactive dialogue form capable of:

1) Capturing the expert's opinion about the array of possible interactions between the aforementioned problem entities, and then
2) Automatically populating the related Interaction Matrix and knowledge base required by the consultation mode.

Figure 4.11 illustrates the form-filling dialogue implemented by the knowledge acquisition mode of the prototype KBGIS. It interacts with the user by generating a list of development implications / sensitivities, which need to be cross-referenced with each environmental factor (resource/hazard concern). The user is requested to select the development implications that according to his/her opinion might cause conflict with the environmental factor shown in the upper-right corner of the relevant dialogue. This procedure is repeated for all environmental factors identified by the data acquisition procedures explained above.

As already indicated, the knowledge acquisition method implemented by the system allows the user to attach weights (significance) to each of the identified potential development-environment interaction. However, the level of sophistication is rather shallow, but still in line with the basic goal of the prototype KBGIS system - that is to support screening and diagnostic process in site suitability assessment and environmental impact prediction. An important aspect of such a process is to identify environmental concerns at the earlier stage of project planning. It would then encourage detailed investigation if found necessary.

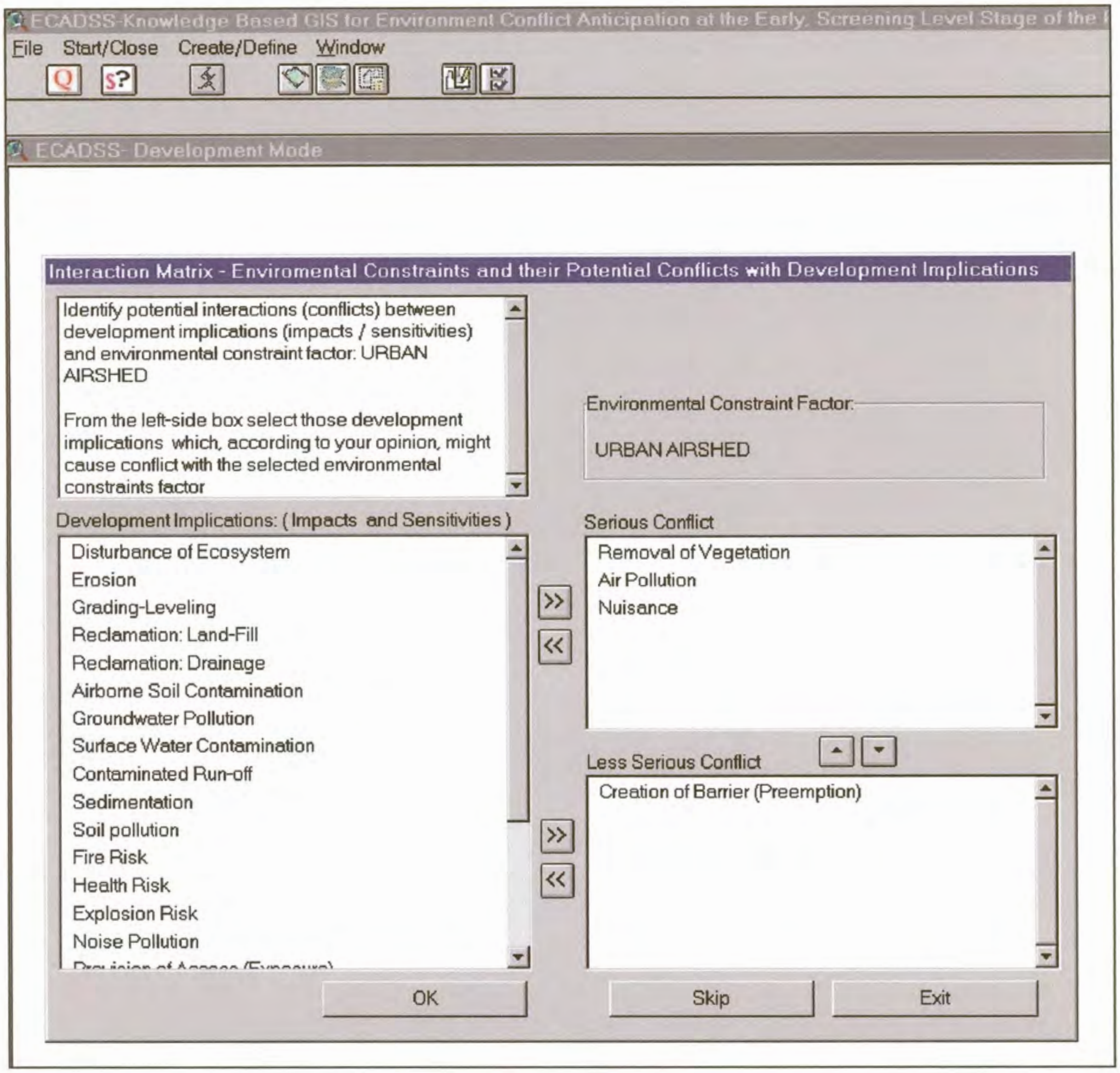


Figure 4.11 The KBGIS form-filling dialogue designed to support construction of Development/Environment Interaction Matrix

(2) Definition of the Project Impact Identification Checklist

Definition of a project impact identification checklist (and now PII Checklist) involves assembling a knowledge base that will contain the list of development actions (projects) along with their implications likely to have significant effects on the environment (impact of development) and vice versa (development sensitivities).

This step is optional in a typical knowledge acquisition session supported by the prototype KBGIS. This is mostly due to the fact that during model construction the user cannot anticipate all development activities that could be proposed. Therefore, definition of PII Checklists and assembling the relevant knowledge base is available in both modes of the KBGIS (the development and the consultation mode). This contributes to the system's flexibility since the user can add a new PII checklist without the need to repeat the whole process of assembling the relevant knowledge base.

Apart from being used by the system's inference engine for the identification of site–specific development-environmental conflicts, the PII Checklist knowledge base also plays a role as a provider of the compiled list of development implications/sensitivities required for the construction of the D/E Interaction Matrix. Therefore, one can conclude that if it is not defined a priori, it could disqualify the D/E Interaction Matrix construction. To overcome this problem the system maintains an internal (generic) list of development implications/sensitivities that could be utilized to provide inputs required for the construction of D/E interaction Matrix. This list is automatically updated with the new development implications/sensitivities attached to a project impact identification checklist during its definition and/or refinement.

The process of assembling the PII Checklist knowledge base is achieved within the prototype KBGIS through the implementation of a number of interactive dialogues. They are designed to assist and lead the user through the construction of each PII checklist. For this purpose a common list of basic screening questions (see Box III) along with the related development implications/sensitivities has been pre-defined and built into the system.

Box III

Checklist of Screening Questions designed as an aid for assessing the likelihood of the project's implications that might affect environmental sensitivity

1) Does the project involve any land disturbance or site clearance, or extensive earthworks or underground works?
2) Does the project generate emissions to air (odours, blowing litter, airborne pathogens, dust emission, toxic fumes, gaseous and particulate emissions) from fuel combustion, production processes, materials handling, disposal of waste through burning in the open air and other sources?
3) Does the project involve/or generate disposal of considerably large volumes of solid wastes or sewage, industrial effluent and/or contaminated wastewater discharge?
4) Does the project involve the storage, handling, use or production of toxic and hazardous substances?
5) Does the project include the use of pesticides, herbicides or fertilizers or other chemicals?
6) Does the project release noise and vibration into environment (including blasting, piling etc.)?
7) Does the project require/involve the construction of roads, ancillary utilities and/or construction of significant structures (buildings, production halls, warehouses, protection walls etc.)?
8) Are there any other project related factors that might affect environment and which are not mentioned above?

As illustrated in figure 4.12 this list is embedded into the main, question-like dialogue designed to support the PII checklist construction. Its task is to ensure that the most relevant project-related factors and their associated implications on the environment are considered. At the same time, its purpose is to maintain a level of knowledge required and supported by the prototype KBGIS. Answering the questions provided by the dialogue is not meant to require studies or investigations. On the contrary, the user of the dialogue is expected to base his/her answers on existing information or knowledge he/she possesses about the project whose Impact Identification Checklist is being defined. Recognizing that there may be issues not included in the common list of project-related screening questions, an option is provided within the relevant checklists' construction dialogue for further questions that might be added.

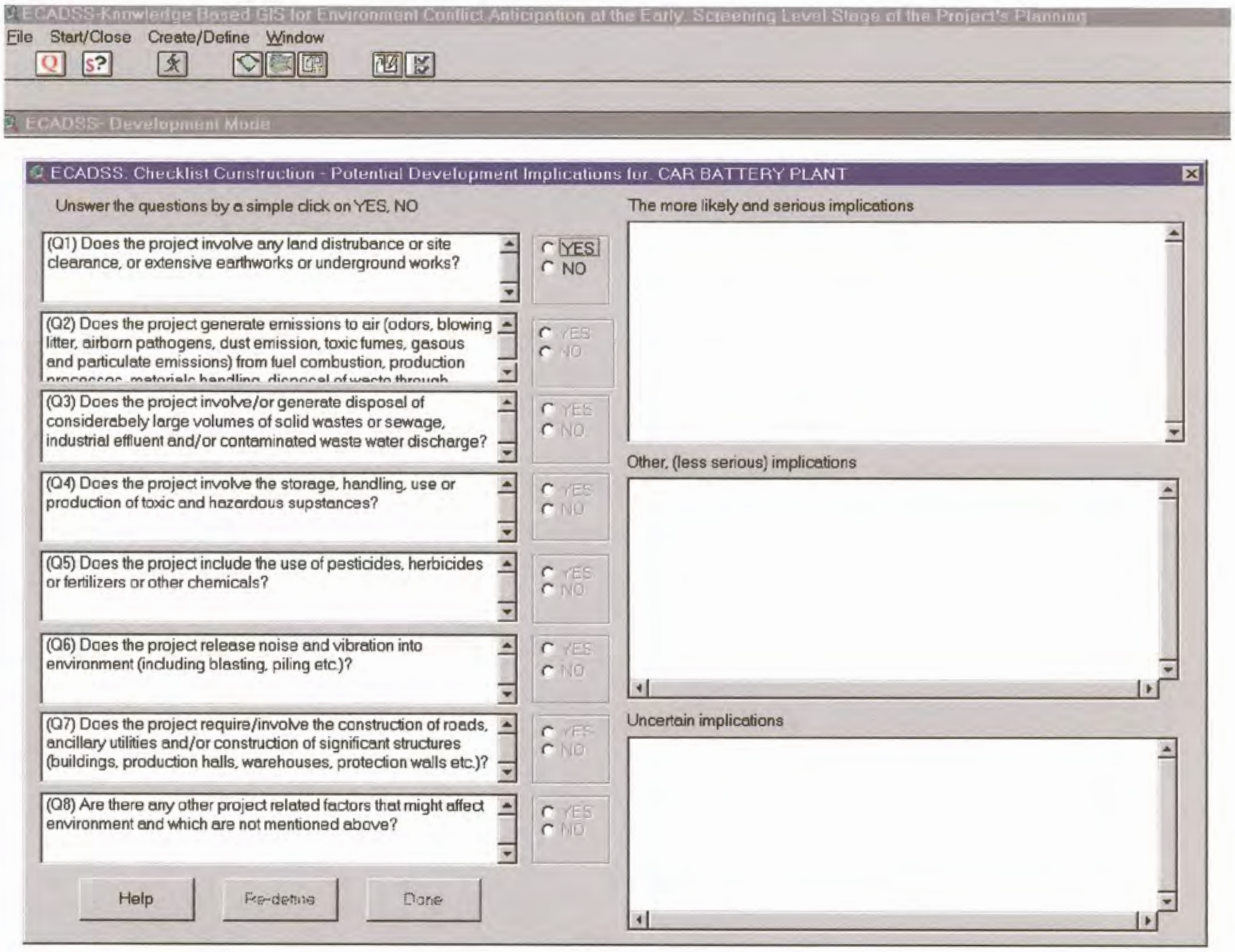


Figure 4.12 The KBGIS question-like dialogue designed to support construction of the Project Impact Identification Checklist

A "YES" answer on each of the questions provided by the main checklist construction dialogue, triggers another dialogue that contains the list of potential development implications associated with the related question. To give an example, if the user answers positively on the question of whether the project under consideration involves any site clearance, a dialogue containing the list of the related potential implications that might affect the environment will show up. As illustrated in Figure 4.13, the user is then requested to assess the likelihood and significance of each implication from the point of view of the project being considered. The user is also allowed to add other development implications not provided by the dialogue, but perceived as applicable for the relevant screening question.

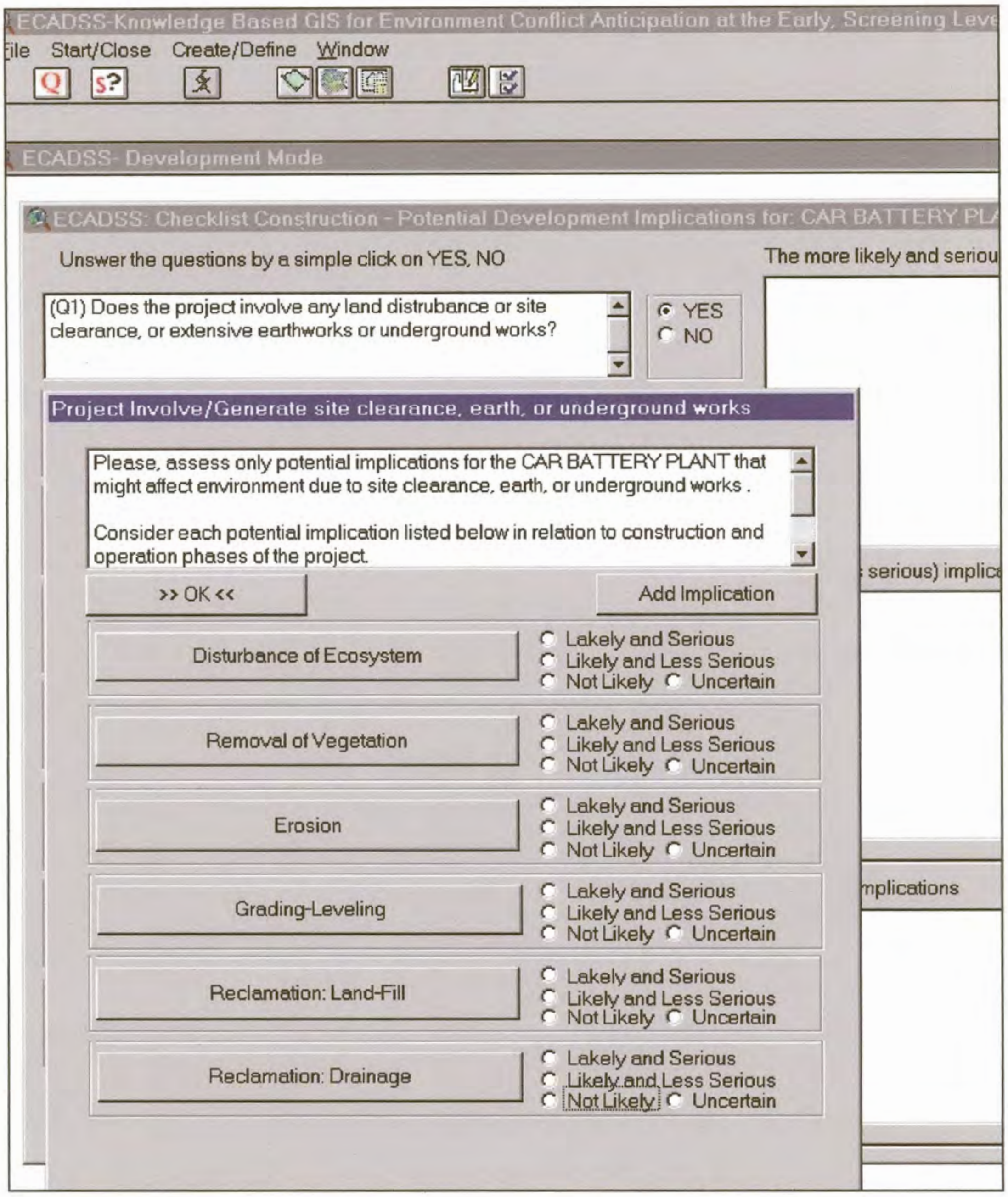


Figure 4.13 The KBGIS point-and-click dialogue for assessing the likelihood and significance of the project's implications associated with the related screening question

As soon as the question's relevant development implications for the project are assessed, the system automatically appends their likelihood and significance to the project impact identification checklist. This checklist is then displayed within the main checklist construction dialogue allowing the user to review or re-define it (see Figure 4.14). The whole procedure is repeated until the last question is answered and related development implications are assessed.

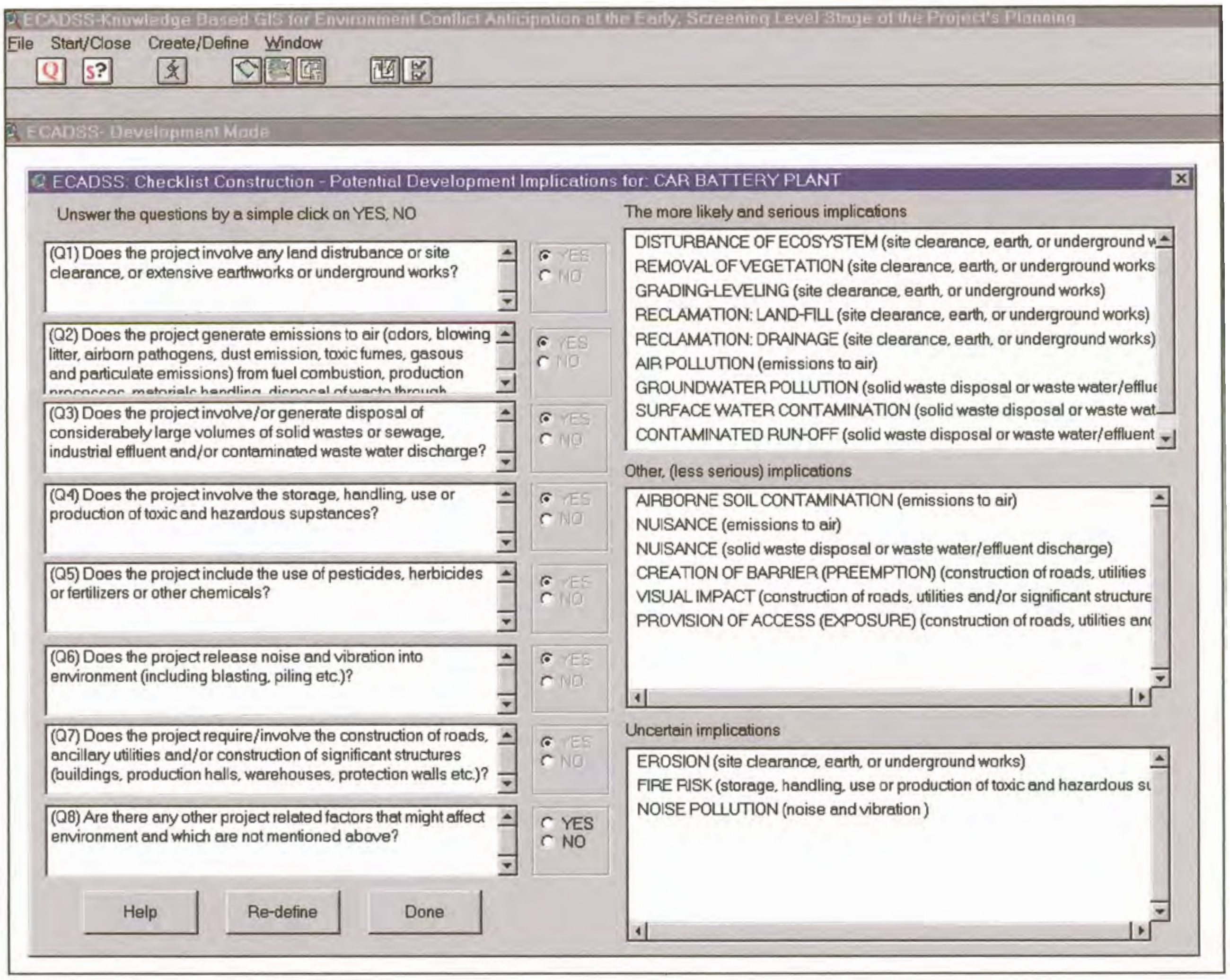


Figure 4.14 An Example of the project Impact Identification Checklist displayed in the main construction dialogue for the purpose of being reviewed and re-defined, if required

The final step involved in the construction of the PII checklist for the project under consideration refers to the assessment of its development sensitivities. For this purpose the user is provided with the simple point-and-click interactive dialogue whose left part, as illustrated in Figure 4.15, offers the list of generic (system compiled) development sensitivities. The user is then requested to select or append those that are considered to be of significance for the project. The system then automatically appends the identified development sensitivities to the impact identification checklist of the project, and finally inserts it into the relevant knowledge base.

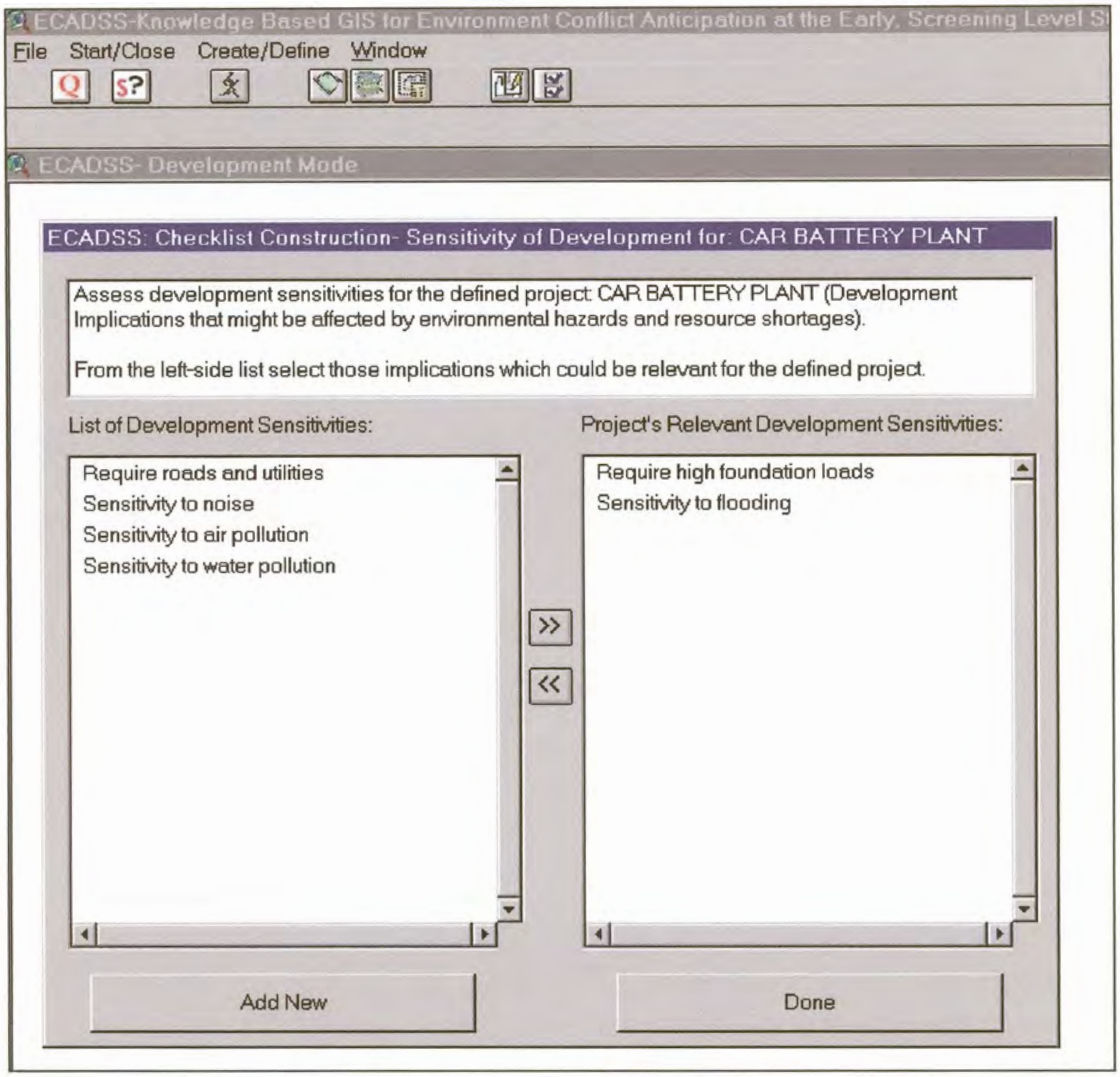


Figure 4.15 The KBGIS interactive, point-and-click dialogue for assessment of the project's development sensitivities

4.5.3 Knowledge Representation within the prototype KBGIS Environment

Several different approaches to knowledge representation within knowledge-based systems (KBS) have been developed over the last few decades. Among them, the production or declarative rules (IF premise THEN conclusion) seems to be the most commonly used, especially by the KBS designed to support location problem-solving tasks. This research is different since it implements the type of knowledge representation that is based on a so-called "domain (truth) table", rather then on production rules. The reasons for this are mostly related to the fact that knowledge required by the system can lead to the construction of a large number of "IF-THEN" rules. This in turn might create problems for both, the knowledge base search and the knowledge base maintenance. Because of this the domain (true) table approach is considered to be more appropriate and provides for a much easier knowledge presentation scheme. By this approach, knowledge is represented and organized in a spreadsheet (tabular) format. It uses columns and rows to develop lists of the problem domain entities and to assign their interactions by utilizing modified Boolean (true and false) values (see Figure 4.16). This type of domain (true) table is furthermore easy to understand and what is even more important it can be developed and manipulated within the knowledge management environment of the KBGIS in a simple Dbase file format.

PROJECTS IMPACT IDENTIFICATION DOMAIN (TRUTH) TABLE

Implication/Sensitivities \ Development Actions	P1	P2	P3	Px
IM1	0	3	1	2
IM2	1	0	0	1
IM3	2	2	0	0
IMx	3	2	2	0

0 → False (No such Implication)
1 → True (Uncertain)
2 → True (Less likely)
3 → True (Likely & Serious)

D/E INTERACTION MATRIX DOMAIN (TRUTH) TABLE

Environmental Constraints \ Implication/Sensitivities	IM1	IM2	IM3	IMx
EC1	0	1	0	2
EC2	1	1	0	0
EC3	0	1	0	0
ECx	0	2	1	0

0 → False (No Interaction)
1 → True (Less Significant Conflict)
2 → True (Likely & Significant Conflict)

Figure 4.16 Illustrative example of the knowledge representation approach implemented within the prototype KBGIS

In this research the domain (true) table knowledge presentation scheme was used for developing both of the knowledge bases (Project Impact Identification Checklist, and Development/ Environment Interaction Matrix). By themselves they do anything apart from being searched and interpreted by the problem processor (inference engine) during the process of the site-specific environmental impact prediction and site compatibility assessment. Therefore, they can be thought of as a sort of meta-database stored and manipulated within the prototype KBGIS in a type of internal Dbase file.

4.6 The KBGIS Consultation Mode

The KBGIS consultation mode aims at providing the environment that is capable of supporting the identification of the site-specific development-environment concerns at the early, screening level stage of project planning. It is the core of the system and composed of the following two basic parts:

1) _The ArcView desktop GIS data manipulation and mapping tools -_ *used for* storage, visualization, selection and retrieval of spatially referenced data;
2) _The problem-specific knowledge based reasoning system_ (KBS) - developed with the aid of Avenue programming language and embedded into ArcView GIS environment. It consists of the *Knowledge meta-databases* and *the KBGIS inference engine* (problem processor).

The GIS part, within this mode, is conceived as a slave to KBS. As mentioned above, its function is to provide the means for displaying, managing, analysing and retrieving environmental data from a spatial database ("what" and "where") and to pass them to the inference engine of the system for further analysis. The perceived role of the KBS, on the other hand, is to overcome the inferiority of GIS in analysing relations ("why") by furnishing the system with domain knowledge as well as with the search mechanism and reasoning capabilities for identifying development-environment concerns in a language familiar to users.

From the functional point of view, the KBGIS consultation mode is nothing else but a collection of tools each serving a related set of functions that are controlled either by the user or the system itself. They are embedded into a common graphical user interface (GUI). From the users perspective the GUI operates mostly as a window or icon-based graphic menu. It is designed to guide the user quickly and easily through the consultation session. Simply by "pointing-and clicking" the user can invoke appropriate options from the GUI to perform as many or as few changes during the evaluation session in order too see the results immediately.

From the system design point of view, the GUI provided by the consultation mode is essentially a generic ArcView GUI that is associated with its "View" subsystem and designed to provide a means for displaying, exploring, querying and analysing geographic data and their attributes. Those original tools from the GUI that are regarded as not vital for the consultation mode have been disabled and replaced by the new ones required by the system and developed with the aid of the Avenue macro language. As illustrated in Figure 4.17, the new tools embedded into the generic ArcView GUI are:

1) The KBGIS query and scenario manager toolbox;
2) The KBGIS analysis and evaluation toolbox;
3) The KBGIS inference engine justifier tools;
4) The KBGIS knowledge refinement toolbox.

The first three toolboxes are essential parts of the proposed consultation mode. They basically represent the system's control and reasoning (inference) mechanism, which is the brain of the whole system.

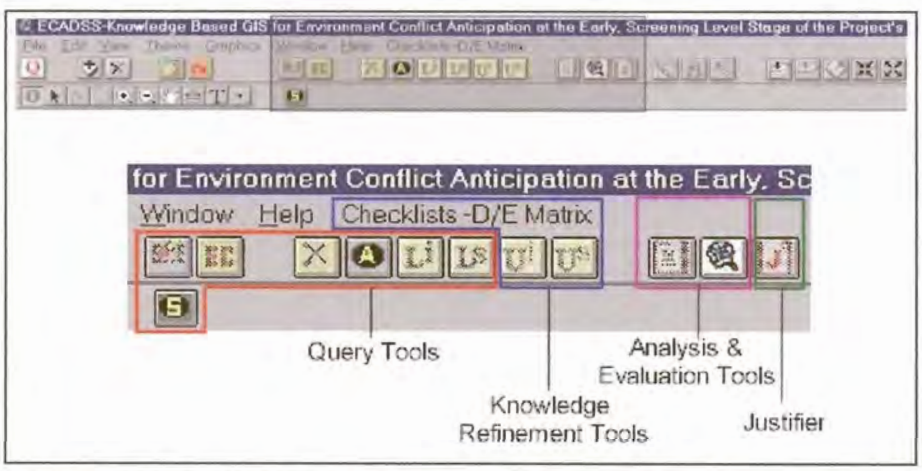


Figure 4.17 The KBGIS consultation mode toolbox developed with the aid of Avenue macro language and embedded into the ArcView GUI

The purpose of the *"Query and Scenario Manager toolbox"* is twofold, namely: (1) to interact with the user in order to get input information, and (2) to forward them to the working memory which is hidden from the user and controlled by the system itself.

The purpose of the KBGIS "Analysis and Evaluation toolbox" is to provide reasoning mechanisms capable to direct (based on input data) the search through the system's GIS and knowledge databases and to draw conclusions about the problem at hand. In essence it represents the KBGIS inference engine which is also controlled by the system for the benefit of isolating users from the "what next and how to do" type of tasks. The inference engine is composed of two components: (a) the scenario analysis, and (b) the evaluation mechanism (interpreter). The former has the purpose of interacting with the system's working memory in order to acquire input data provided by the user and to enable the system's scenario evaluation tools that are requested. The latter basically represents the computer algorithm that controls and carries out the reasoning process in order to generate final results for the problem at hand in a form of expert advice.

There is only one scenario currently supported by the analysis and evaluation toolbox. As illustrated in 4.18, it refers to the assessment and listing of the potential development-environment conflicts that can be expected if the proposed development action and its tentative location are known. Additionally another scenario might be added to the system with the task to identify the most and least suitable sites. This scenario can be useful in the situation where the user specifies only the intended development action (project) without its tentative location.

The purpose of the KBGIS *"Inference Engine Justifier tools"* is to provide a variety of displays that allow the user to examine the reasoning process in order to refine it, if necessary, by means of updating or even changing the underlying assumptions.

Finally, *the KBGIS "Knowledge Refinement toolbox"* embedded into the consultation mode GUI acts as a standalone unit separated from the system's inference mechanism. It was primarily designed to allow the user to modify and update the knowledge bases and to add new information (knowledge) about the domain even when using the consultation mode.

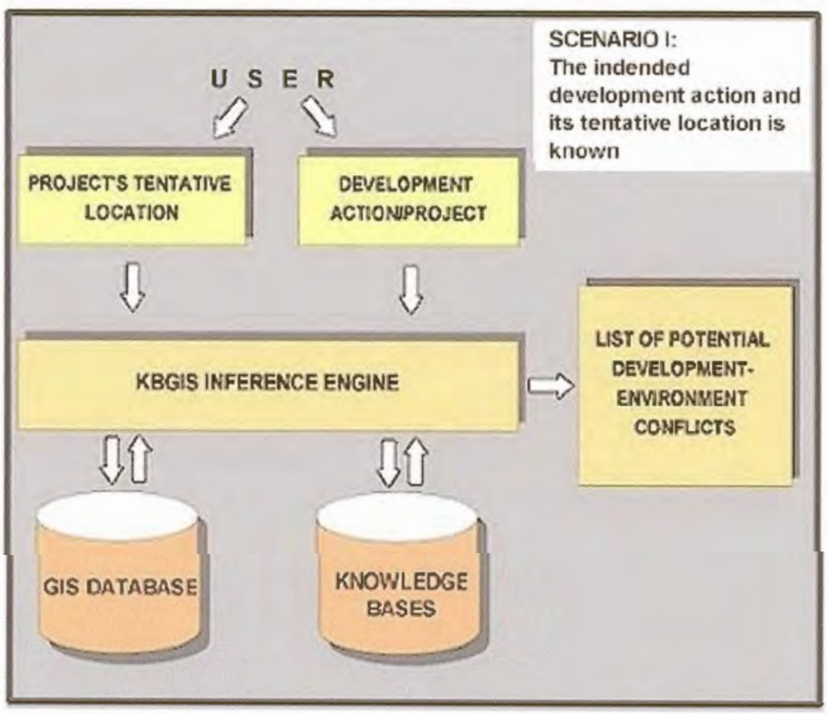


Figure 4.18 Analysis and evaluation scenario that is supported by the prototype KBGIS

4.7 The KBGIS Inference Mechanism: How it works

This section illustrates the basic steps of a typical consultation session as supported by the prototype KBGIS along with the reasoning procedure that tries to reach conclusions at the end of the consultation stage.

1) The first step of a typical consultation session supported by the system includes interaction with the user for the purpose of the input data acquisition. This interaction is controlled through the GUI, which provides two icon-based controls (Figure 4.19). They allow the user to simply point-and-click in order to invoke interactive data input procedures for the two basic types of information required by the system:

   1.1. Specification of the intended project (development action), and

   1.2. Selection of its tentative location.

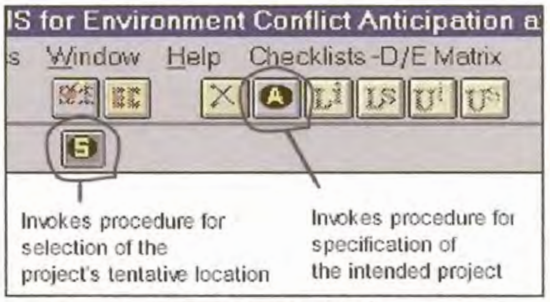


Figure 4.19 The KBGIS data input controls

Specification of the intended project is accomplished through the interactive dialogue facility. It provides the user with the list of all projects (development activities) whose Impact Identification Checklists are already defined and stored within the relevant knowledge base. (See Figure 4.20)

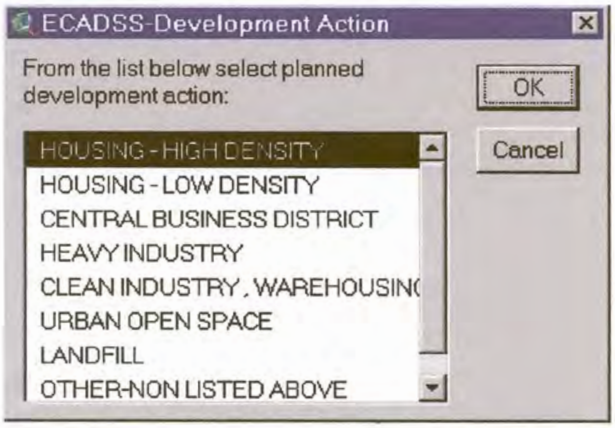


Figure 4.20 An Example of the interactive dialogue designed to support selection of the intended project

As soon as the project (development action) is identified, the system automatically takes over the control by passing on information to its working memory. The working memory furthermore forwards information to the inference engine, which automatically fires up the search through the relevant knowledge database in order to extract the project's impact identification checklist and its pre-defined development sensitivities. It then enables the controls from the GUI that allow the user to re-view the project's impact identification checklist and its development sensitivities. (See Figure 4.21)

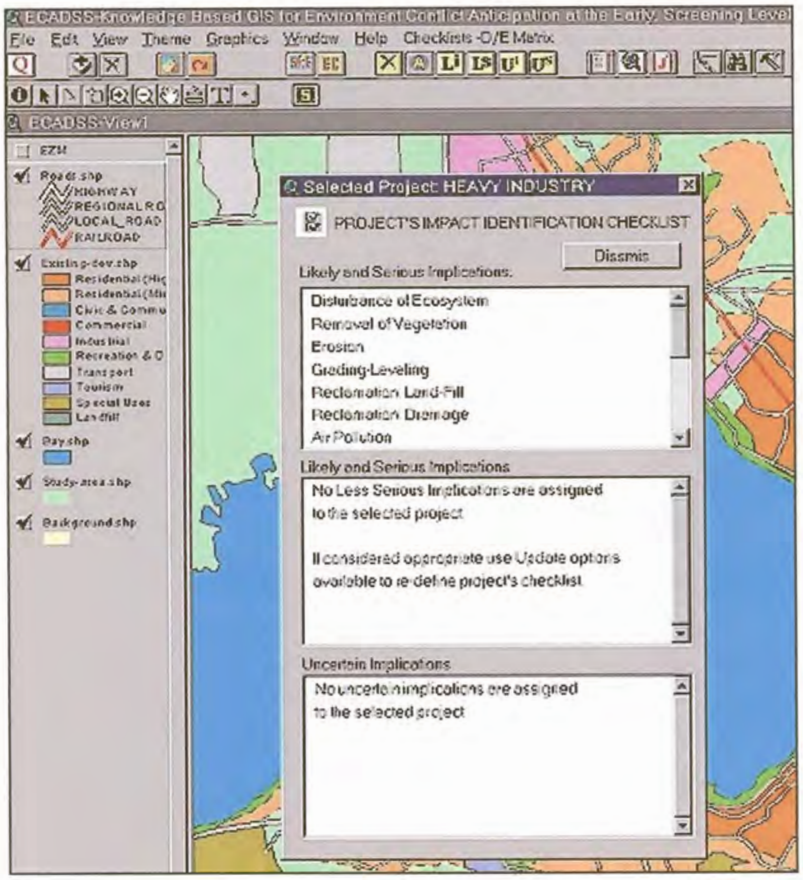


Figure 4.21 The Screen snapshot illustrating the KBGIS's ability to extract the Impact Identification Checklist of the selected project from the knowledge database and allow the user the review it

If the user cannot locate the intended project or, at least its counterparts from the relevant list provided by the system, he/she would be permitted to define the project impact identification checklist and then append it to the existing knowledge base. This is achieved with the aid of the knowledge refinement toolbox (see section 4.8)

The selection of the project's tentative location is accomplished through the icon-based tool button. When invoked, it firstly activates the graphic window containing the visual presentation of the study area and then prompts the user to move the cursor and pinpoint the project's desired location. For this purposes the user is provided with various generic GIS tools (zoom, pan, etc.) in order to locate the project's desired site as precisely as possible.

As soon as the desired location of the project is identified, the system again takes over control and passes on the users inputs to the working memory. Then, on the basis of the data forwarded from the working memory, the system's inference engine employs generic GIS search and data retrieval functions in order to acquire the environmental constraints at the proposed project site from the EZM composite layer. It then enables the control that allows the user to review the site-specific environmental constraints (see Figure 4.22).

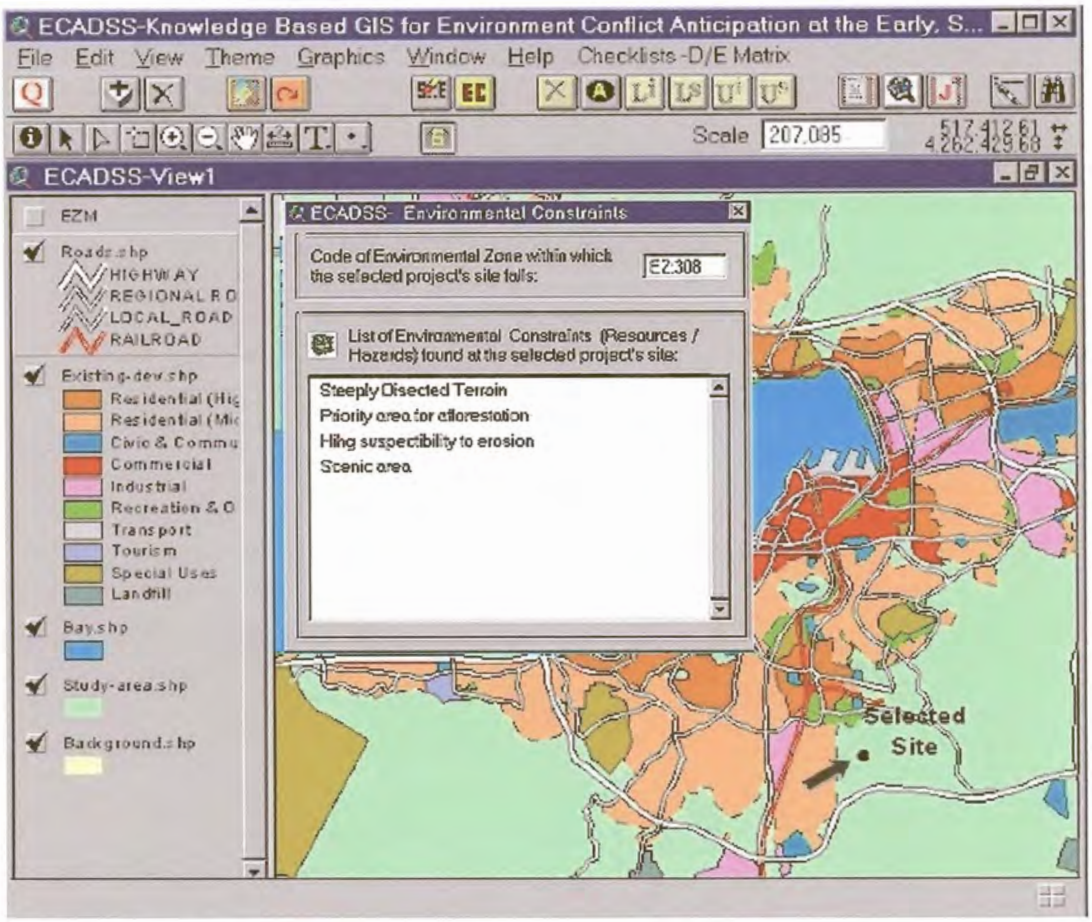


Figure 4.22 The screen snapshot illustrating the KBGIS ability to extract from its GIS database all environmental constraints found at the selected location

2) Once the system has obtained all the information from the user and the data and knowledge base it becomes "ready-to-reason" in order to reach the conclusions and to provide the expert advice for the problem at hand. For that purpose the user is provided with the icon-based GUI controls that allow him/her to simply point-and-click in order to invoke appropriate reasoning procedure (see Figure 4.23).

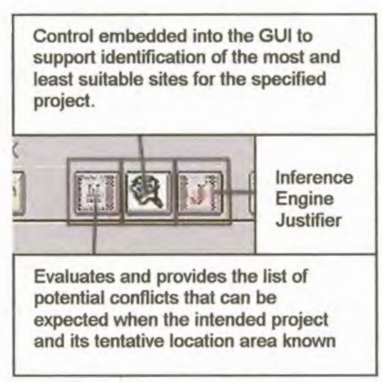


Figure 4.23 The KBGIS evaluation tools embedded into the system's GUI

The following is an explanation of a typical reasoning process currently supported by the prototype KBGIS. It refers to a situation where the system is required to evaluate and list potential conflicts with the proposed project and its tentative location known.

2.1 With the required user inputs (the proposed project and its location) stored into the working memory, the KBGIS inference engine (triggered by the user through GUI control) starts the reasoning process. Firstly, it searches through the Environmental Zone composite layer in order to extract environmental constraints (resources/hazards) found at the selected project's location and place them into the working memory as a part of the problem description.

2.2 Secondly, the inference engine also searches through the PII Checklist knowledge base in order to extract the list of development implications and sensitivities attached to the proposed project. The list is then forwarded to the working memory as a part of the problem description.

2.3 Once the site-specific environmental constraints and the project's development implications/ sensitivities are obtained from the GIS and knowledge databases and forwarded to the working memory, the system starts the reasoning (evaluation) process and draw conclusions (e.g. to provide a list of potential conflicts that might be expected for the proposed project at the selected location).

This process involves the application of procedural (inference) rules, usually called "pattern matching". It basically refers to an algorithm on how to search the system's D/E Interaction Matrix and infer conclusions on the basis of given facts (site-specific environmental constraints and the project's development implications) contained in the system's working memory. An example of a procedural rule, implemented by the proposed KBGIS inference engine is given below in its generic form:

***IF** development implication **AND** environmental constraints = **TRUE** (interacts)*

***THEN** infer (return) interaction value significance*

***ELSE** continue*

The inference engine provided by the prototype KBGIS uses a so-called forward chaining inference method. As illustrated in Figure 4.24, it operates by comparing the facts available in the working memory to the premises of the inference rule illustrated above. In other words, all site-specific environmental constraints found at the proposed project's location and forwarded to the working memory are compared with each of the project's development implications also stored in the working memory. The comparison is done by means of searching the available D/E Interaction Matrix and inferencing the interaction values between them. If the interaction (conflict) exists, the rule "fires" by extracting its attached significance and placing it in the working memory as a conclusion. (The conclusion is basically an expression of the seriousness of the potential conflict forwarded to the working memory in a language familiar to user).

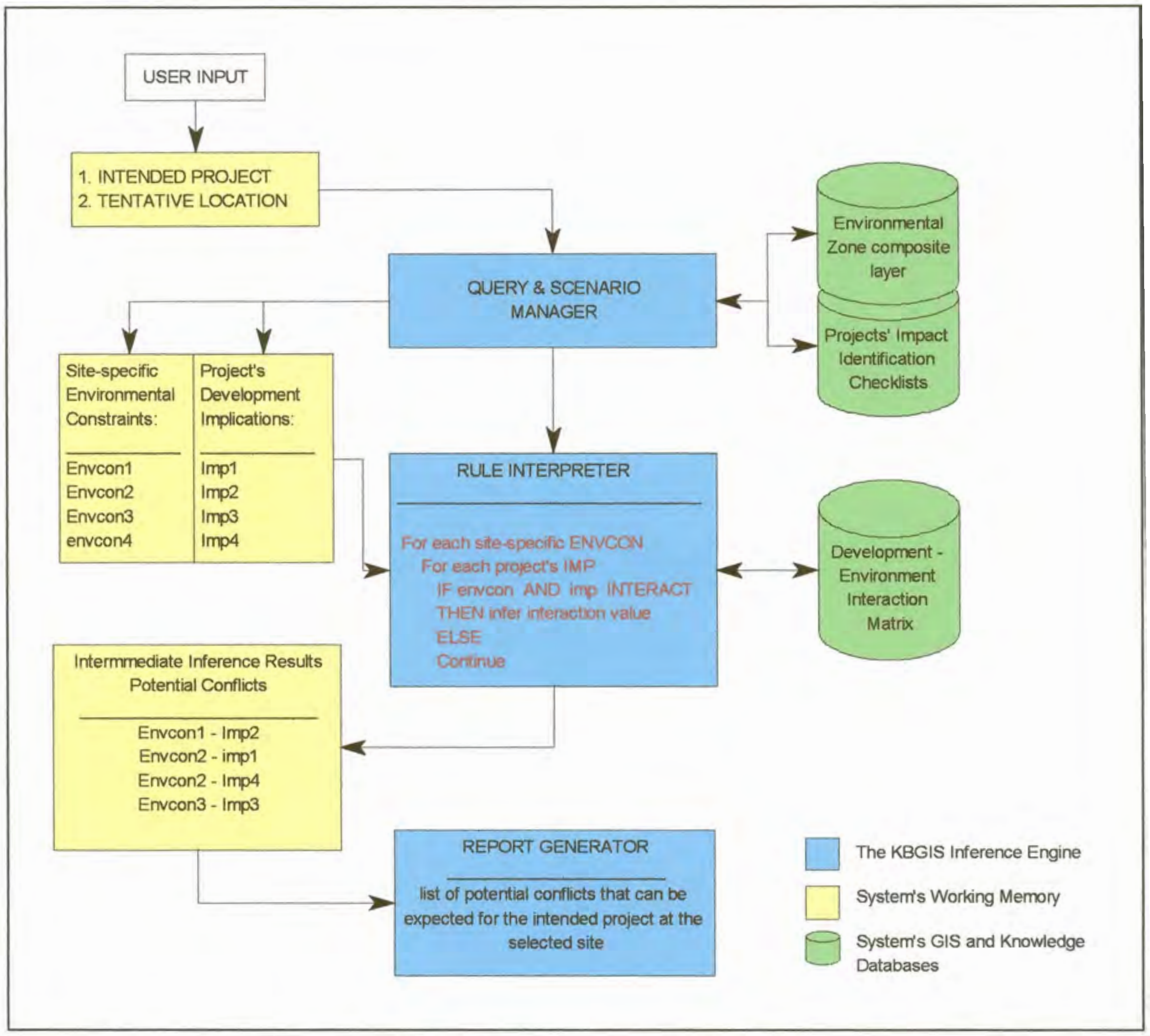


Figure 4.24 Schematic representation of the reasoning process currently supported by the prototype KBGIS

2.4 Finally, once the system has inferenced the existence and significance of all the interactions between site-specific environmental constraints and the project's development implications, it generates the report. This is done by extracting the intermediate inference conclusions stored in the working memory and then ranking them on the basis of their significance. At least two lists can be generated containing different levels of seriousness of the inferred conflicts that can be expected for the proposed project at the selected location. As illustrated in Figure 4.25, these lists are automatically shown to the user at the end of the consultation.

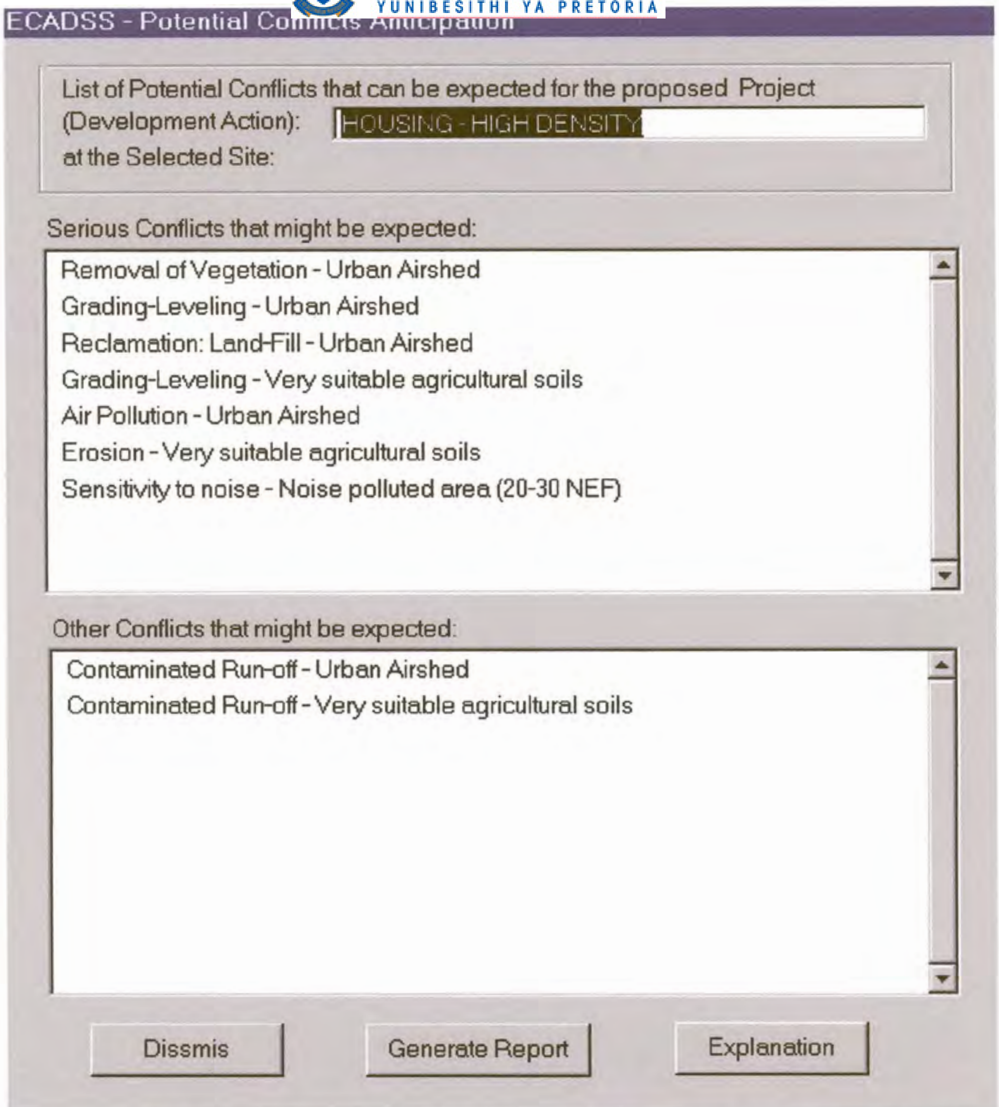


Figure 4.25 An example of the system's inference conclusions provided in a language familiar to the user

2.5 Parallel to the inference conclusions described above, the system also keeps track of the whole consultation session by means of recording each and every line of the reasoning process. The results are stored in a temporary file controlled by the system and updated whenever the user restarts the consultation session. Its purpose is to allow both the user and the system's builder to observe, clarify and, if necessary, enhance the assumptions underlying the reasoning process. Interaction with the user for the sake of reviewing or even printing the above-mentioned file is accomplished through the GUI control that becomes available as soon as the consultation session ends. Figure 4.26 shows an example of such a file.

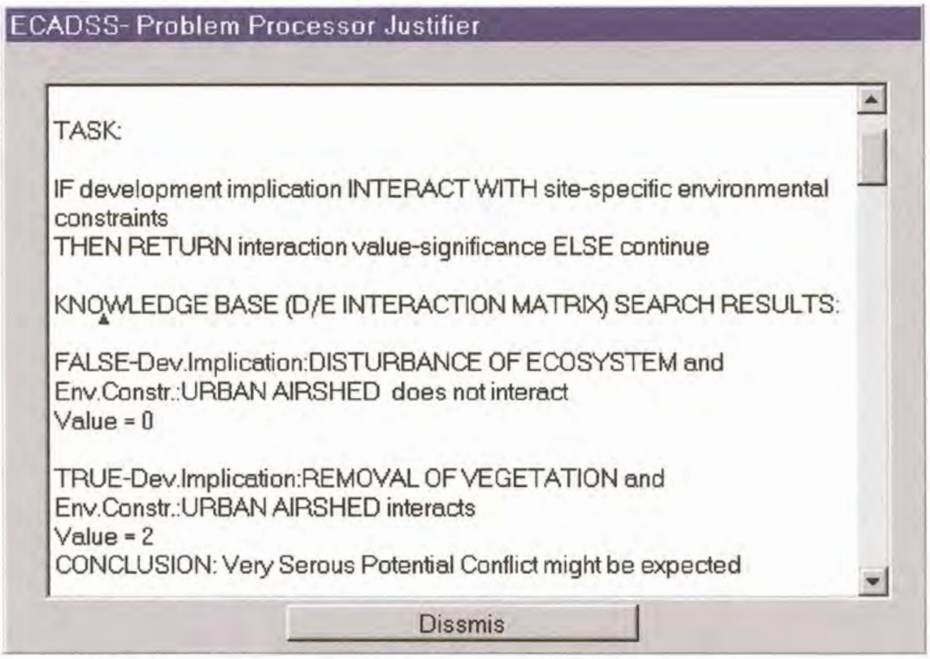


Figure 4.26 An example of a textual file generated by the system for the purpose of storing assumptions underlying its reasoning process

4.8 The KBGIS Knowledge Refinement toolbox

The KBGIS knowledge refinement toolbox acts as a standalone unit separated from the inference mechanism. Its purpose is to allow the user to not only modify and update the knowledge bases, but also to add new information (knowledge) about the domain even during the consultation mode. This ability contributes to the system's openness and ease of expansion without the need to repeat the whole knowledge acquisition process from scratch.

This ease of expanding, updating and modifying the knowledge bases makes the system open for rapid prototyping. In this process the user can construct the knowledge bases (PII checklist or even the D/E Interaction Matrix) as initial prototype solution. Expert can later improve the relevant knowledge bases by running the system, examining its reasoning process and changing the underlying assumptions. Another example is related to the process of inserting the project's impact identification checklist in the relevant knowledge base. As mentioned earlier the user cannot anticipate all development actions (projects) during the knowledge acquisition session. The knowledge refinement tools make this unnecessary by providing the user with the abilities to add new and even modify or delete the existing PII checklist during the system's consultation mode.

Figure 4.27 illustrates the knowledge refinement tools embedded into consultation mode interface in a format of the easy-to-use interactive dialogue.

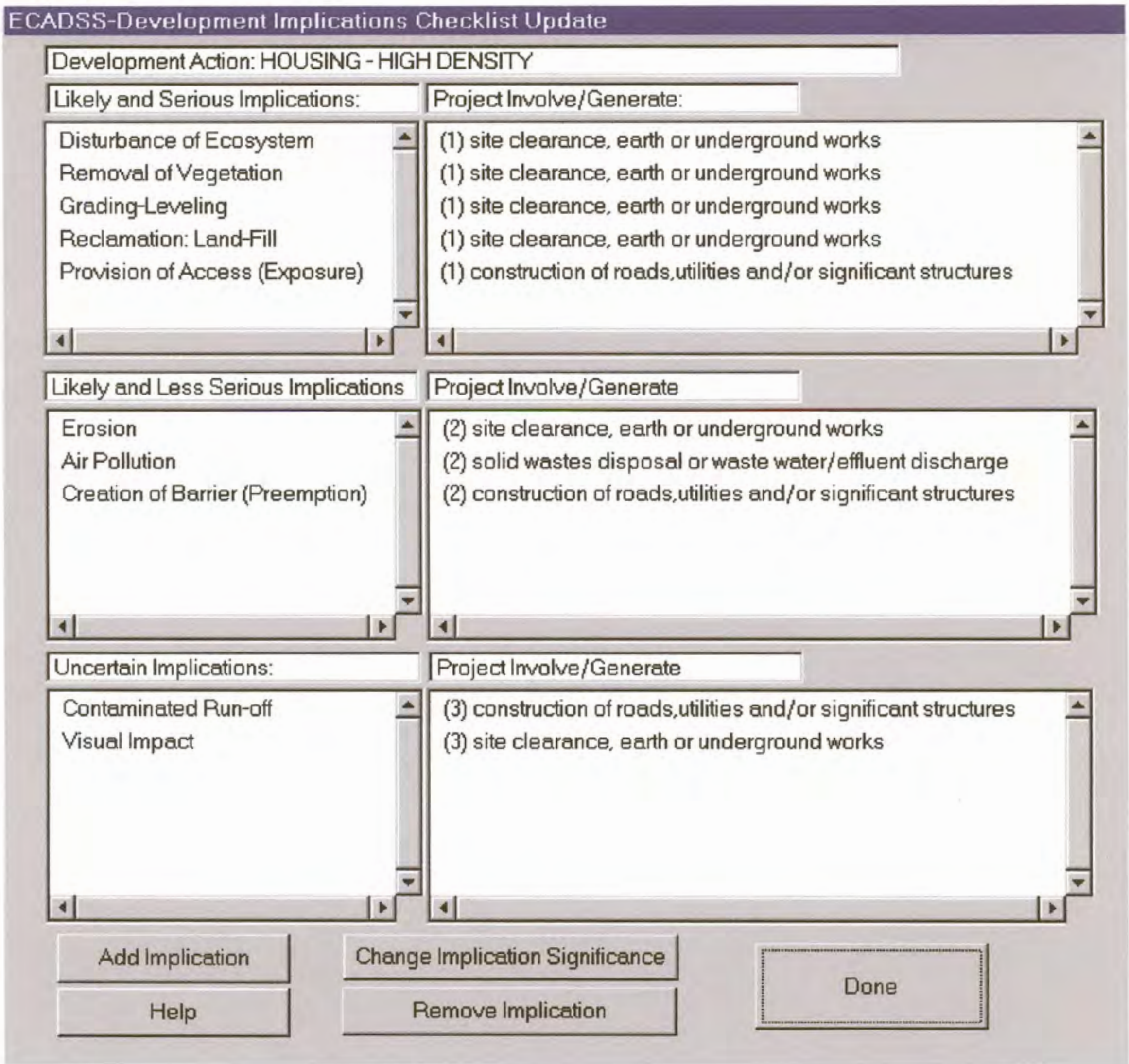


Figure 4.27 An example of the system's interactive dialogue designed to support the construction or modification of PII checklists

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Research Summary

The objective of this research was to examine how the usefulness and capabilities of a GIS in site suitability assessment and environmental impact prediction could be improved by incorporating (embedding) into a GIS the elements of an expert system. The following motivated the research:

(1) A GIS is seen as a convenient and well-structured information technology for handling large quantities of spatial data and related attributes. However, there is a widespread agreement that it does not provide sufficient capabilities needed to fully support complex spatial decision problems. The main reasons for this are:

- Inappropriate logical foundation which give no room for imprecision in information, human cognition, perception and thought process;
- Low level of intelligence in terms of possessing facilities for utilizing declarative and procedural knowledge;
- Lack of explicit analytical and modelling tools required to adequately explore the solution space of problem-specific and unstructured decision-making tasks.

In addition, the complexity of current GIS technology has generally showed a tendency to divert the process of spatial decision-making away from decision-makers into the hands of highly trained technological specialists and experts.

(2) Efforts to overcome these deficiencies of GIS by integrating them with decision support tools drawn from other disciplines have emerged as an important research area. However, they have not yet reached maturity since the majority of the Spatial Decision Support Systems are still in a research and development stage and the number of operational ones seems to be limited.

(3) The integration of GIS and knowledge-based systems (KBS) was found particularly interesting in site selection and environmental domains. Tasks in this spatial problem solving area are often unstructured requiring heuristics and other knowledge based techniques. This type of integration has become a substitute for purely knowledge driven expert systems because the latter proved to be to limited for a wide range of spatial problem solving tasks. This was mainly due to their inability to interact with spatial data, especially in cases where decision rules depend on geographical location.

Various logical ways of linking GIS and expert systems for spatial problem solving tasks have been identified. Of these, the most frequently used approach was the so-called loosely coupled GIS-KBS integration. Only a few attempts have been made to incorporate elements of knowledge-based techniques into GIS environment and to develop fully integrated spatially enabled Knowledge Based System.

To improve on the above issues, this study aimed to develop a practical approach for the integration of GIS and Knowledge Based Systems (KBS) to support site suitability assessment and environmental impact prediction. In an effort to meet the above requirements a prototype Knowledge-based GIS

(KBGIS) was developed that would be able to anticipate development-environment conflicts at an early stage of project planning.

This prototype KBGIS is based on the evaluation model developed by UNEP/UNCHS (habitat). It is essentially based on a checklist of problems and can be seen as a screening and diagnostic process for the identification of interactions between three sets of mutually related factors, namely location, development actions and environmental settings. The model involves the assignment of qualitative labels to site-specific development-environment conflicts based on the available data on the physical environment and the planned development action, as well as a set of generic rules (facts) for assessing and grading the likely consequences. This model has been used on several occasions as part of environmental planning and management routines to make urban and regional planning more responsive to environmental considerations.

These applications were however based on manual processing techniques. The objective of this research was to reconfigure this model into a KBGIS using automated techniques and computer technology. The conceptual approach and development of the various elements of the proposed system were discussed in chapter 4.

Generally, the whole research revolved around the idea to build an integrated set of computer-assisted procedures to produces a system that could be used as a "consultant" in the process of anticipating possible development-environment conflicts. To fulfil this task it was necessary to integrate the basic functionality of a GIS with elements of a Knowledge Based System.

Different levels of GIS-KBS integration have been suggested in the related literature. This research developed an example of the full GIS-KBS integration in which the elements of KBS techniques are actually one of the subroutines available within GIS.

The design of the prototype KBGIS places the model, data, domain knowledge, as well as the system's knowledge acquisition and reasoning mechanism together in a single GIS environment and within one single application with shared communication routines, common interface and data structure. The role of GIS within the system's implementation environment was to provide visualization tools, data and domain knowledge storage and management capabilities. It was also conceived as a slave to KBS with tasks of retrieving spatial and attribute data from the database ("where" and "what") and passing them to the system's reasoning mechanism (inference engine) for further analysis. The role of the KBS was to furnish the prototype system with easily accessible domain knowledge, as well as with the reasoning capabilities (inference mechanism) for identifying development-environment concerns in the language familiar to users. It was also conceived to act as an intelligent front end capable of controlling and guiding the communications between the user and the system.

5.2 Achievements of the Research

The application of the prototype KBGIS in an existing test area lends credibility to the results of this research. Some of the important achievements are as follows:

Firstly, the research proved that integrating different information technologies - in this case GIS and KBS - is a very useful approach to support screening and diagnostics tasks in site suitability assessment and environmental impact prediction. A further enhancement is the fact that the prototype KBGIS combines the functionality of "conventional" GIS with elements of KBS techniques.

The capabilities of the system to store facts and expert opinions (domain knowledge) and to emulate reasoning processes of experts seemed to have an important impact on the effectiveness and flexibility of the evaluation task in terms of:

1) Providing users with the high speed and reliable expert advice for the problems at hand, and
2) Eliminating the necessity of the involvement of a GIS expert and domain experts on development-environment impacts that would normally be required when using the "conventional" GIS techniques in generating different problem solving solutions.

The successful application of the prototype KBGIS system in a test area, has clearly illustrated:

1) How current GIS can be improved by linking GIS with a domain specific KBS capable of imitating expert reasoning processes in spatial problem solving situations.
2) How the limitations of the purely knowledge based system could be overcome by linking it with GIS tools.

Another achievement of this research, going beyond its basic objectives, was the design of the application specific and GIS-enabled expert system shell. Although fairly limited in scope and functions, it has proven to be capable not only to reproduce the specific domain of expertise it was designed for, but also to be adapted to other applications with a similar conceptual framework. This was made possible by implementing the so-called "plug-in" system architecture characterized by the separation of the system's "Knowledge Acquisition" and its "Consultation" mode.

Another noteworthy capability provided by the prototype KBGIS is the provision of an user-friendly and interactive graphical user interface (GUI) designed to control and guide the communication between the user and the system. The system's Knowledge Acquisition GUI is capable of emulating a so-called "paper and pen" environment and as such it bears a resemblance to an expert driven knowledge acquisition method in which the expert enters required information (facts) into dialogue fields and input boxes without assistance of a knowledge engineer. The KBGIS Consultation mode, on the other hand, operates as an icon-based graphic menu with the capabilities to:

1) Guide users easily through the consultation session;
2) Assist them in defining the problem and considering the possible outcomes; and
3) Allow them to examine the line of the reasoning process and refine it, if necessary.

These abilities make the system easy to implement, thus promoting its usability even by occasional users who usually demand a less complicated problem-solving environment.

The successful integration of the KBGIS modules and components into a single application within ArcView desktop GIS is yet another achievement of this research. It has revealed the possibility of using available customisation and programming utilities of desktop GIS to transform a conceptual knowledge model and include it as one of the analytical functions of a GIS.

5.3 Important Issues Relevant for Environmental Zoning and Construction of an Environmental Zone Map

During the development of the prototype KBGIS several issues related to the establishment of the GIS database for the Environmental Zone Map emerged. Two are elaborated with an intention to provide ideas for further research.

(1) Quality of Data to be used in the construction of an Environmental Zone Map

Based on the experience gained through the construction of the Environmental Zone Map for a test area, it appeared that the efficiency of GIS utilisation in supporting this task largely depends not only on correct choice, but also on quality of data.

As illustrated in the chapter 4, GIS databases required for environmental zoning would normally come from a variety of sources of analogue and digital data, each with its own characteristics, format, scale, positional and attribute accuracy. Accuracy of data is defined in terms of the magnitude of the difference between the value eventually reported and its true value. These differences are errors and they typically range from:

- Positional error in source material usually viewed as a discrepancy that might arise between the type of analogue or GIS data model and the nature of reality that it is seeking to capture;
- Errors in the attributes associated with spatial data.
- The impact of manipulation procedures e.g. digitising, logical consistency of data structure, overlay analyses, image processing etc.

Working with a combination of several different data layers from various sources will invariably result in error propagation. Consequently it would be naive to believe that an error free suitable and simple model could be devised under normal circumstances.

This issue is frequently out of the hands of practitioners involved in the construction of an Environmental Zone Map. From practical experience, it is apparent that either analogue or digital data sets often exist before the environmental zoning task is conceived and this task is usually designed to take advantage of what is available. Thus the issue here is not how the model represents reality (or ground truth) but rather how to understand and work with the existing data representation and uncertainty associated with the given data set (e.g. its confidence limits). Consequently, what a GIS database for environmental zoning seeks to accomplish is not a precise estimate of errors but some confidence that the error levels are not too high to doubt the validity of the results. This issue obviously needs an in-depth investigation since it influences the validity of KBGIS results.

(2) Formal Data Structure of an Environmental Zone Map

In the context of this research, the issue of data structure basically refers to a question of which one (raster or vector) would be better for the construction of an Environmental Zone Map. In practice there is no clear-cut preference and often both are combined to make use of their specific advantages.

For an Environmental Zone Map where it is important to maximize the accuracy of the spatial presentation of environmental features, the vector data structure seems to be more appropriate. On the other hand, the raster data structure has the advantage of being compatible with remotely sensed and other automated data capturing technologies, as well as its computational simplicity of spatial analysis and modelling. Furthermore, the vector data structure has richer data content, which basically means that a larger variety of database queries can be formulated. However, the overlay process within the vector domain can be time consuming and computationally intensive requiring the comparison of many line segments with many others for the purpose of detecting intersections and rebuilding the topologic and feature attribute tables. Sometimes, depending on the number and quality of data sets being aggregated, it can produce a cumbersome composite layer containing a large volume of very small polygons (not to mention slivers typical for the situation where input data sets with common boundaries do not geometrically coincide). On the other hand, the raster data structure provides a more flexible and efficient overlay capability, mostly due to a simpler data structure. However, this data structure has the problem of accuracy of spatial representation. It is well known that regularly spaced shapes rarely distinguish geographic phenomena. Therefore, grid cell in raster-based systems are usually classified as the most common attribute for the relevant cell. This leads to a problem of determining the proper resolution for particular data sets required for environmental zoning. If one selects too coarse a cell size then data may be fairly generalized and, therefore, less accurate. On the other hand, if the cell size is too fine then too many cells may be created resulting in a large data volume, slower processing time and greater request for storage space.

A brief comparison of the two main classes of data structure (vector and raster) sough to emphasize the fact that there are certain advantages and disadvantages associated with each data structure and the awareness of these advantages or disadvantages allows users to select the more appropriate one. It seems that the combination of the vector and raster data structures and their processing capabilities provides the greatest flexibility. However, this is not yet entirely achievable since there is still no GIS system capable of providing tools for integral vector-raster data sets aggregation that is required for the final construction of an Environmental Zone Map. In other words, GIS data must be, firstly transformed to either vector or raster format before they can be aggregated.

Although the research has not handled this issue explicitly it is my contention that future research efforts in enhancing the prototype KBGIS system should explore this theme in a detailed manner so that appropriate solutions for different environmental zoning requirements can be devised.

5.4 Directions for Further Research

As indicated above the prototype KBGIS developed in this research achieved a degree of effectiveness. It is however just a modest start or the first step towards a system with far more functions to support screening and diagnostic tasks in site suitability assessment and environmental impact prediction. Much work remains to be done especially in extending the system functionality and, subsequently improving its capabilities to assist all phases involved in development-environment impact evaluation and related decision-making processes.

The evaluation model applied in this research could be improved by adding an easily accessible repository of knowledge, which would:

1) Indicate the type and extent of mitigation measures that could be applied to overcome potential development - environment conflicts identified by the system for particular development actions at the selected location;

2) Provide recommendations for controlling identified potential conflicts, and for complying with the established standards and legislation.

This appears to be possible by constructing a knowledge browser containing a repository of the aforementioned mitigation measures and established standards or legislation. It would essentially represent a searchable hypertext system of help and explanatory text functions connected to the reasoning mechanism (inference engine).

Furthermore, research efforts should focus on the development of additional evaluation scenarios in order to improve and expand the current capabilities to support the model for site suitability assessment and environmental impact prediction. Two additional evaluation scenarios are considered important for the expansion of the system's capabilities. The first one is a scenario that would use the system's reasoning mechanism and its available GIS data and domain knowledge to assist users in the identification of the most suitable sites for an intended development action within an area of concern. The second could support the determination of development actions that are suitable or permitted at the particular location within a study area. Both scenarios are so-called "What if" types of analysis in order to assist users in the examination of the consequences of different planning proposals.

In addition, future research should also look at possibilities to add a set of computer-assisted procedures capable to automate the process of constructing the Environmental Zone Map. As indicated in chapter 4, this process is currently executed separately. Although GIS can facilitate the environmental zoning process it still remains difficult for a user to perform all the necessary data preparation and complex overlay procedures required for the construction of an Environmental Zone Map. Therefore, in order to make this task more user-friendly further research should focus on a strategy to automate overlay analysis. This will not be an easy task as it obviously aims at anticipating a number of possible options in order to keep the system sufficiently open to support different environmental zoning requirements.

Experience gained through this research reveals that improvements and extensions of the prototype KBGIS should be based on direct involvement of domain experts. It is their view of problems and experience that provides the necessary input in constructing the various domain databases.

The aforementioned especially refers to the provision of a valid and easily accessible repository of domain knowledge required for environmental evaluation tasks supported by the KBGIS. As explained in chapter 4, this domain knowledge is captured and stored in the form of:

1) Impact identification checklists for various development actions, and

2) Development-environment interaction matrix (as a basis for assessment of potential conflicts between the project's development implications and the site-specific environmental factors).

In many cases both the project impact identification checklist and development-environment interaction matrix can be incomplete in its coverage and miss important effects. In some cases they also try to cover such a wide range of implications and/or impacts that it is almost impossible to identify the key environmental concerns. In these cases they depend more on the background, expertise and experience of the people involved in its construction.

This research, although limited in scope, has clearly illustrated that desktop GIS could be efficiently used as an appropriate environment for the development of an intelligent GIS-based DSS capable of assisting unstructured spatial problem solving task.

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