KNOWLEDGE-BASED SYSTEMS AND DECISION SUPPORT SYSTEMS IN TRANSPORTATION PLANNING: WITH REFERENCE TO RAPIDLY DEVELOPING COUNTRIES

Saad AL-MUBAIYEDH
Assistant Prof.of City & Regional Planning
King Fahd University of Pet. & Minerals
Dhahran, Saudi Arabia

Andre de PALMA
Assistant Prof. of Civil Eng.
Northwestern University
Evanston, Il, U.S.A.

1. INTRODUCTION

This study will investigate the potential advantages of using Knowledge-Based Systems (or Expert Systems) and Decision Support Systems in the urban transportation planning process in rapidly developing countries.

The urban transportation planning (UTP) process is essentially a decision making process which can be viewed as consisting of four major stages: (1) problem identification and definition, (2) debate and policy formulation, (3) implementation, and (4) evaluation and feedback (Meyer et al., 1984) Like any other decision making process, UTP falls along a continuum that ranges from highly unstructured to highly structured decisions. According to Turban (1988) structured processes "refer to routine and repetitive problems for which standard solutions exist", and unstructured processes are "complex problems for which there are no cut-and-dried solutions". A good example of unstructured process in UTP is problem diagnosis. Network (or trip) assignment, on the other hand, is a good representative of structured processes in UTP.

Usually the unstructured and semi-structured aspects of the UTP process require one to deal with many objectives which are derived from multiple and contradictory goals. In most cases, optimization techniques for solving these types of problems are not available, so the solution techniques that are employed require a considerable amount of judgement on the part of the planner.

It is, mainly, the nature and complexity of the UTP process that has driven planners to exploit computers to the greatest degree possible. Planners in Western nations have been using computers to assist them in complex and repetitive tasks in planning for the last three decades. The early use of computers in the UTP process was limited to those aspects of the process that are well structured. During the 1960's, most of the emphasis was on the development and use of large-scale transportation and land use models (Brail, 1987). But, because of the inherently complex and non-transparent nature of the computerized planning models, the question has been raised as to whether the computer or the planner has the ultimate control over the planning process.

This last point, besides the fact that most planning issues are either semi-structured or unstructured, has resulted in a call for more interaction between computers and planners during the planning process. The augmentation of the creative capabilities, intuition, and judgment of the human analyst with the computational and storage powers of the computers has always been the ultimate goal of many people in the planning profession.

The first step toward achieving this goal was the use of interactive computer graphics in late 1970's in planning applications (Rieple, 1978). These techniques have been developed to allow the planner to visually and graphically monitor the computations of the models and to directly control their functions. Now these techniques have become an essential part of many UTP studies.

Recent developments in the field of applied Artificial Intelligence, and more specifically, in the field of Knowledge-Based Systems (KBS), and in the field of Decision Support Systems (DSS) provide an excellent chance to achieve the previously mentioned goal. These systems allow more interaction between the computer and the planner and have the ability to deal with the semi-structured and unstructured aspects of the planning process. Another importance of KBS lies in their ability to make use of one of the scarcest resources, namely, talent and experience of key members in an organization (or in a specific domain). Less expert members of an organization can benefit from this expert's knowledge captured in the system.

After their successful applications in different related fields, investigating the potential use of DSS and KBS in urban transportation planning seems natural.

The first part of this research will be concerned with the identification of major transportation planning issues in rapidly developing countries, then, another analysis will be undertaken to assess what aspects of these issues lend themselves to Knowledge-Based System\Decision Support System development. This will be done by means of a case study for Riyadh, the capital of Saudi Arabia.

The purpose of this research is twofold. First, to conceptually design a computer system that is intended to be used in long range transportation planning and policy analysis for Riyadh, Saudi Arabia, a city in a rapidly developing country. And second, to build a research prototype knowledge-based system which is one component of the overall computer system mentioned above. This knowledge-based system is to be utilized in projecting the input data needed for the travel forecasting models.

2. KNOWLEDGE-BASED SYSTEMS & DECISION SUPPORT SYSTEMS

One of the most significant achievements in the area of applied artificial intelligence (AI) during the last decade has been the development of Knowledge-Based Expert Systems (KBES), or expert systems for short.

Knowledge-Based Expert Systems are interactive computer programs that use expert knowledge and inference procedures to solve problems, in a specific domain, that are sufficiently complex as to require significant human expertise for their solutions (Waterman, 1986).

KBES are more appropriate for use in solving semi-structured or unstructured problems, i.e., problems for which a numerical model does not exist. The transportation planning field, like many other multidisiplinary areas, is full of ill-structured problems in which social, political, economic, and technical considerations are involved (Yeh et. al, 1986).

There are number of reviews of the potential applications of KBES in transportation planning and engineering. Examples of these reviews include, Takallou (1985), Yeh et al. (1986), Bonsall and Kirby (1986), Ritchie and Harris (1987), and Szwed (1988). Most of these reviews have identified the different areas within transportation which are considered suitable candidates for KBES development. Some of these reviews have reinforced the conclusion that KBES development in transportation have centered on the more traditional areas of highway and traffic engineering rather than the broader multidiciplinary areas of planning and system management and control, despite the fact that these areas are suitable candidates for KBES development.

During the last five years or so there has been a rush to build KBES in different areas within the transportation field. Examples of KBES applications in transportation include traffic engineering (Chang, 1987), transportation noise decision making (e.g., CHINA, Cohn et al., 1986), network design and analysis (e.g., EXPERT-UFOS, Tung and Schneider, 1987, and Taylor, 1990), railroad maintenance (Martland et al. 1990), urban transportation decision making (e.g., STREET SMART, Ritchie and Yeh, 1987), and advanced traffic management (Ritchie, 1990). Without going into details about these systems, most of the above mentioned studies have concluded that the utilization of KBES permits achievement of performance levels that are superior to the current state of practice in their respective areas.

Decision support systems (DSS), on the other hand, are interactive computer-based systems that help decision makers utilize data and models to solve semi-structured or unstructured problems.

Several authors, e.g.,Turban (1988) and Ford (1985), have discussed the relationship between KBS and DSS and have outlined some of the benefits that can be gained from integrating them together

KBS/DSS integrated systems are being developed and implemented at an increasing rate. in different fields, such as, manufacturing, marketing, engineering, and financial services

3. TRANSPORTATION PLANNING ISSUES IN RAPIDLY DEVELOPING COUNTRIES

The enormous increase in oil revenues in the mid 1970's (e.g., Saudi Arabia received about $ 1,214 million from oil in 1970, and about $84,000 million in 1980) helped in creating a sub-group of the developing countries that can be called 'wealthy' or 'rapidly' developing countries (RDC). The term RDC is used here to refer to oil-rich countries such as Saudi Arabia, Kuwait, U.A.E, and Qatar.

Nowadays, RDC differ notably from both developed and the majority of developed countries with respect to the factors that influence transportation planning. For example, as compared to the majority of developing countries, RDC have higher financial resources, better transportation infrastructures, and higher vehicle ownership. And, as compared to developed countries, RDC have inferior technical resources, instable growth rates, lower level planning controls, and different social and cultural values.

Major transportation planning issues in RDC can be summarized in the following points (AL-Mubaiyedh, 1991):

i. Future uncertainty: the major source of future uncertainty in RDC is the instability of growth rates. This instability will increase the difficulty of projecting the input variables needed for the travel forecasting models. This issue is not as serious in the developed world; while in the majority of developing countries there are other major sources of future uncertainty (e.g., lack of infrastructure).

ii. Availability of technical resources (skills): like the majority of developing countries, RDC still lack a sufficiency of qualified professionals. The importance of training local planners has been emphasized in the literature.

iii. Social and cultural values: transportation planning methodologies used in RDC, which were originally developed in Western countries, need to be adapted to take into account the difference in social and cultural values between RDC and Western countries.

4. THE PROPOSED COMPUTER SYSTEM

The proposed system is intended to be used by a regional planning agency (Arriyadh Development Authority, ADA). ADA is similar, in terms of its functions, to metropolitan planning organizations (MPO) in the U.S.A.

The proposed computer system incorporates some features from KBS and DSS. In the literature, such a system is called an intelligent DSS, an integral DSS/KBS, or an integral KBS/DSS. The focus of the proposed system is on strategic/ long range transportation planning and policy analysis (10 years or more into the future). The main function of strategic planning is to identify issues that are likely to become critical in the future, to identify data and analysis techniques to deal with these issues, and to analyze alternative courses of actions (Stuart, 1983).

For these reasons, the products of strategic/ long range planning will depend more on *the creativity of the planner* in recognizing problems and devising options to test them, than on the specific techniques used in the analysis (Schultz, et al., 1983). These properties of strategic planning make some of its aspects *potential candidates* for KBS/DSS development.

Major transportation planning issues in RDC, mentioned in section 3, will be taken in consideration in the design of the proposed system after assessing the aspects of these issues that lend themselves to KBS\DSS development.

4.1. Architecture of the System:

It is important to notice here that the major features of the proposed system complement what is already available at ADA. At present time, ADA has a powerful transportation planning software package known as EMME/2 and some other traffic operations software. The utilization of these software is, somehow, limited to the *structured* aspects of the process. By integrating these software (in certain ways) with other specific KBS, both *structured and unstructured* aspects of the whole planning process can be dealt with by using the computer.

The proposed system, as shown in **figure 1**, is basically a DSS which incorporates more than one KBS that can be triggered at any point of time. The different components of the system are: data base, model base and analytical tools, user interface, and knowledge-based system (which consists of four different KBS). The way in which each component can be accessed and used will be illustrated in section (4.2). But for now, each component of the proposed system is discussed in some detail below:

USER INTERFACE: this module introduces the system to the user. It is expected to contain a brief discussion about the nature and the function of each component of the system. It will also help to guide the user through the overall process. Through the user interface, the user can access all other components of the system.

DATA BASE: the data base should contain all data relevant for strategic planning analysis. Recently, ADA has built a new data base, from several types of surveys and inventories. Data available in this data base include socioeconomic and other land use and travel related data.

The existing data base can be organized in several smaller data bases, each of which can be used for a specific purpose. These data bases can be accessed through the user interface or directly from any other component of the system (e.g., from a KBS).

MODEL BASE AND ANALYTICAL TOOLS: this component of the system is expected to contain all the required models and analytical tools. Examples of these are, DemProj (a population projection computer program), RTRPGEN and TRPGEN (computer programs to apply the trip generation process), EMME/2 (traffic assignment and graphics), SAS (Statistical Analysis System), and others.
KNOWLEDGE-BASE MODULE: this module can be accessed at different stages of the process. Four different routines of the process, in which KBS can be potentially supportive, are identified. These are diagnosis (KBS1), forecasting of input variables (KBS2), travel forecasting (KBS3), and search and screen (KBS4) (each will be explained in more detail later on in this section). These knowledge-based systems differ in their relative importance and the support they offer to the user.

Some of the common characteristics among the above mentioned four routines that make them *potential candidates* for KBS development are :

1. For each of these routines, algorithmic solutions are impractical because of the complex social, economic, and political components.
2. Each of these routines (tasks) requires some kinds of symbol manipulation and heuristic solutions.
3. The knowledge and expertise needed to perform each of these tasks (routines) is not limited to the pure technical component of knowledge only, but it also requires a collection of judgment, intuition, rules-of-thumb, experience and other expertise in that particular area.
4. There exist people, "experts", from whom some of the specific knowledge needed for each phase can be acquired. But the number of these "experts" is few and the majority of them are foreigners. Therefore, it will be very beneficial for ADA (or similar organizations) to have the expertise of these people documented in a KBS. This will allow the user of the proposed system (ADA) to utilize such expertise even after these people leave the agency.

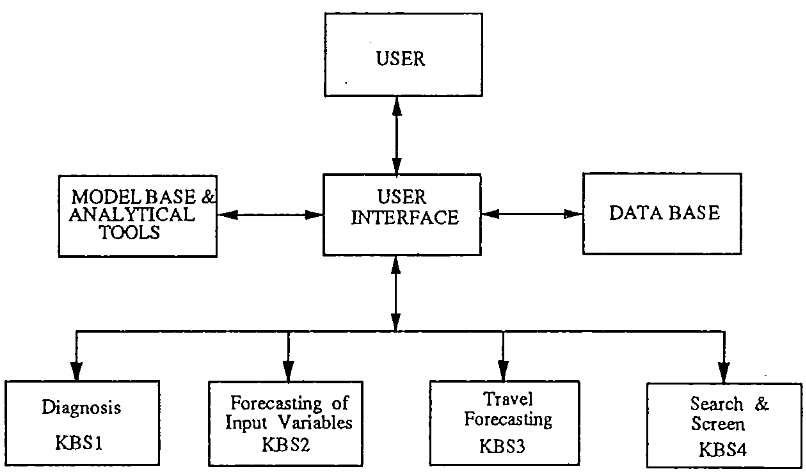

Figure 1: Architecture of the Proposed System

4.1.1. Function of the Knowledge-Based System Component

The function of each of the four KBS is explained below:

Diagnosis (KBS1):

The function of a KBS in this case will be to help the user in getting a better understanding of the problem context. As was discussed earlier, one of the main functions of strategic planning is to identify issues that are likely to become critical in the future.

The consequences of any policy issue that the user wishes to consider may not all be clear in the beginning. For each policy issue to be analyzed, this KBS is expected to provide some background about this issue, and some guidance as to how to use the remaining KBS so that all the consequences of that issue are identified

Forecasting of Input Variables (KBS2):

As pointed out in section 3, the issue of instability of growth rates in RDC (Riyadh as an example) makes the forecasting of input variables in these countries more complicated than it is in developed countries.

The function of this KBS is to assist transportation planners at ADA to forecast/ project all the socioeconomic variables needed to apply the first element of the travel forecasting model, namely, the (regional) trip generation process. More precisely, the goal of this KBS will be the forecasting/ projecting of the input data items required to run RTRPGEN; this is the computer program used by ADA to apply the regional trip production model.

These input data items are usually forecasted/ projected by people from outside the Transportation Division, like, demographers, land use planners, and urban economists. In such circumstances, a KBS will even be more appreciated by transportation planners. Moreover, the knowledge and expertise needed for forecasting input variables in Riyadh includes specific technical knowledge, judgment, familiarity with the study area, etc. This will make this task a good candidate for KBS development.

Travel Forecasting (KBS3):

A general travel forecasting model for Arriyadh has already been developed as part of the Riyadh Transportation Study (RTS). The *focus* of this KBS3 will be on how to apply the existing modelling system to the policy issue being considered (e.g., impact of future growth, impact of an increase in women's participation in the labour force, etc.). The following quote from one of the reports of RTS will help to explain the need for this KBS: "The travel modeling system has been designed to be flexible in order to satisfy the ADA's diverse transportation analysis needs, and to match the capabilities provided by EMME/2. .... the provision of this flexibility in travel modelling has a liability associated with the analysis options outlined above: a considerable amount of user expertise will be required to efficiently apply the models and properly analyze the results" (ADA, Undated).

Search and Screen (KBS4):

This KBS will support the user in screening the solutions generated in the preceding stage. It is more concerned with eliminating what is infeasible than with determining what is appropriate. KBS4 will be utilized after the future travel demand (for any specific study area, or the whole region) has been estimated. But due to the nature of the process (uncertainty, policy issues to be considered, etc.) there are likely to be many different "scenarios" of expected future ravel demand. Starting with these forecasts or "scenarios", the user then tries to come up with different designs for each scenario, making the number of possible solutions very high.

4.2. Integrating the Proposed System Within The Transportation Planning Process

A major concern associated with designing any particular computer application is the acceptability of the final product by the intended user(s). Even though much effort is invested into designing a computer application system, there is a chance that the system may be misused or totally unused.

A requirement for designing an effective (acceptable) computer system is to have an explicit model of the user's decision making process before hand (Manheim et. al, 1987) Unfortunately, many of the existing expert system applications in planning and transportation (almost all of them are stand-alone systems) seem to ignore this essential issue.

Given that the proposed system will be utilized by a regional planning organization for strategic/ long range transportation planning, the proposed system in this research is based, in some general terms, on the work of Mintzberg et al. (1976) in which they suggested a basic framework (model) that describes unstructured, strategic decision processes.

According to Mintzberg et al., the process is divided into three phases: identification, development, and selection. These three phases are described in terms of seven central routines: recognition, diagnosis, design, search, screen, evaluation, and authorization.

Once a general framework of the decision making process of the user has been identified, the next step is to show how the proposed system can be integrated within that process.

Figure 2 illustrates how the system is integrated within the transportation planning process. The two major phases in the process are the travel forecasting phase (Phase I) and the design phase (Phase II).

It is very important to mention here that the relationships between the different components (routines) of the process are more complicated than they appear in figure 2. Some of the links that connects different routines of the process are not shown in figure 2. For instance, a direct link between the "DESIGN" routine and KBS2 (Forecasting of Input Variables), although exists, is not shown in the figure. Similarly, direct connections between KBS1, KBS2, and KBS3 are not presented in the system.

Figure 2 is meant to be a *simplification* of the real transportation planning process. As the proposed system matures important connections between the different routines are expected to become more apparent.

The dotted line in figure 2 is intended to refer to the connection between the two major phases of the process (Travel Forecasting, and Design), or in other words, to the cyclical nature of the process.

Next section will summarize the experience gained from the construction of a research prototype of one of the proposed KBS, namely, the Forecasting of Input VAriables Knowledge-Based System , henceforth, FIVAKBS.

5. FORECASTING OF INPUT VARIABLES KNOWLEDGE-BASED SYSTEM (FIVAKBS)

FIVAKBS is a knowledge-based system that demonstrates how KBS can be utilized in forecasting the socio-economic data needed to apply the ADA's regional trip production model. This KBS was referred to as KBS2 in chapter 4.

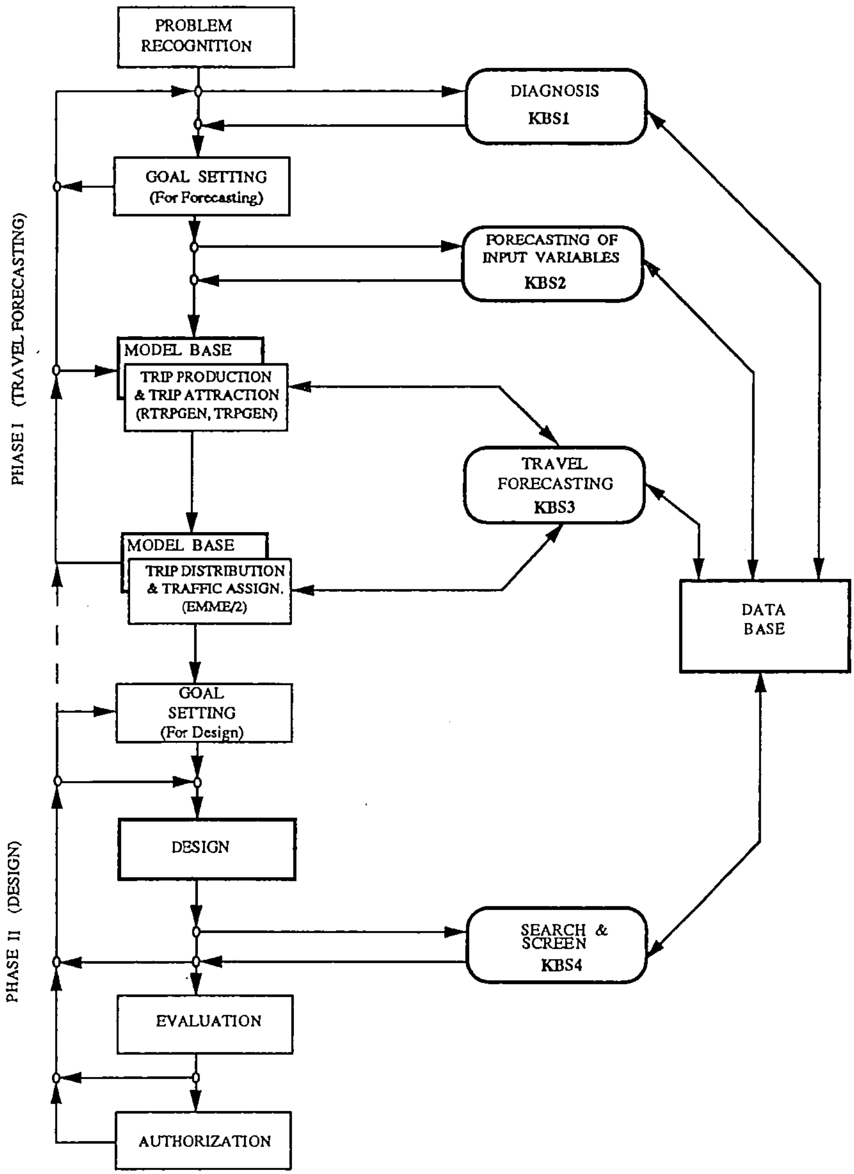

Figure 2: Integrating the Proposed System within the Transportation Planning Process

The goal of FIVAKBS is to forecast/ project the 15 input data items that are required to run RTRPGEN for the years 1996 and 2001 (10 and 15 years from the base year). These data items are: households by (i) Nationality (3), (ii) Household size (4), (iii) Structure type (2), (iv) Household type (2), and (v) Vehicle availability (4). These data are not yet available at ADA

The data and some of the knowledge used to construct this KBS were obtained from some working papers of the Riyadh Transportation Study , other reports about population projection in Riyadh, as well as meetings with specialists from ADA's Socio-economic Group and the Transportation Division. The major part of the knowledge base, though, is the authors' contribution based on theoretical and empirical research related to the projection of the required input data.

The present status of FIVAKBS can be called a *research prototype* system, which is defined as a system that displays credible performance on the entire problem but may be fragile due to incomplete testing and revision (Waterma, 1986). There are more than 200 rules in the present version of FIVAKBS. FIVAKBS was developed using a KBS development environment (shell) known as GURU (MDBS, 1989)

5.1. The Value of FIVAKBS

FIVAKBS will not only enable transportation planners to project the required input variables by themselves, but will also allow them to test several scenarios related to these input variables without going back to socio-economic variables forecasters each time; this is the real value of FIVAKBS.

According to the current planning and policy analysis practice at ADA, and probably at many other transportation organizations, the transportation division will ask other divisions for all or some of the future values of the input variables needed to run their travel forecasting models. Demographers, land use planners and others will respond with one set (or more) of the required input variables. Each set is based on certain assumptions regarding basic external factors affecting regional growth, such as, future fertility rate, economic conditions, and so on.

As it is now, transportation planners are not able (by themselves) to test scenarios related to those assumptions, in other words, they can only assess the impact of the policy issue of interest on travel demand but they can not assess the impact of that same policy issue on the very input data that they use to run their travel forecasting models.

By using FIVAKBS transportation planners will be able to assess the *full effect* of the policy issue being considered.

At this stage, the accuracy of FIVAKBS results is not as important as what the system can do, and how it does it as compared to the current practice. But at later stages, and before the system becomes operational, different aspects of the knowledge base need to be validated. This is an important point in KBS development.

5.2. Scenario Forming and Testing Utilizing FIVAKBS

The five explanatory variables included in the ADA's regional trip production model can all be related to policy related options. For example, the households by nationality variable allows for the testing of policies that vary the composition of the expatriate work force, and the vehicle availability variable could be related to economic policies, and so on.

Once a policy issue is identified, a scenario can be formed by first using

FIVAKBS (with that policy issue in mind) to project the required input variables, and then using RTRPGEN to assess the impact on travel demand on the regional scale.

The potential advantages of using FIVAKBS, as compared to the current practice, have been so far demonstrated through two examples. But , since it will be difficult to discuss any of these two examples in details in this paper, we will briefly refer to the result of one of these examples.

The goal of that example was to assess the likely impact of increasing women's participation in the labour force on travel demand for the year 2001. In that example two scenarios have been compared to each other; the first simulates the current practice (at ADA) and the other utilizes FIVAKBS (and RTRPGEN). The results from that example have show that, without using FIVAKBS, daily total trips will be underestimated by about **13%**.

6. SUMMARY AND CONCLUSIONS

This study has dealt with two different areas of research. The first is the application of Knowledge-Based Systems and Decision Support Systems, and the other is transportation planning in rapidly developing countries.

After major transportation planning issues in RDC have been identified in section 3, a conceptual KBS\DSS computer system was designed and presented in section 4. This system is to be used by a regional planning agency--Arriyadh Development Authority (ADA). The focus of the system is on strategic\ long range transportation planning and policy analysis. Four different routines of the transportation planning process, in which KBS can be *potentially supportive*, have been identified. These are, diagnosis , forecasting of input variables, travel forecasting, and search and screen (see figure 1, page 5).

The operational development of the computer system proposed in this study is beyond the scope of any research of this type. The real challenge faced in this study was to be able to operationally develop one part of the overall computer system which, at the same time, can stand alone for testing and evaluation.

Among the four proposed KBS, the Forecasting of Input VAriables Knowledge-Based System (FIVAKBS) was the one that was operationally developed. This KBS implicitly deals with the issue of *instability in growth rates*. This issue, as relevant literature reveals, is a major source of *future uncertainty* in the UTP process in developing countries in general.

The speed at which scenarios can be developed by using FIVAKBS, and the ability to assess the *full effect* of the policy issue being considered are very promising and encouraging results. Moreover, all the analysis can be performed in an environment in which the user will be able to follow the process very clearly (explanation module).

Although the overall proposed computer system cannot be judged at this point, but based on the result of using FIVAKBS, it is expected that the benefits will even be greater when the other three KBS are operationally developed.

ACKNOWLEDGMENT: The authors would like to thank *King Fahd University of Petroleum & Minerals* for providing the computer software used in this research.

BIBLIOGRAPHY

AL-Mubaiyedh, Saad A., *Transportation Planning in Rapidly Developing Countries: Contributions from Knowledge-Based Systems and Decision Support Systems*, Unpublished Ph.D. Dissertation, Dept. of Civil Engineering., Northwestern University. 1991.

Andriole, S.J. (ed.), *Applications in Artificial Intelligence.* Princeton, N.J.: Petrocelli Books, 1985.

Arriyadh Development Authority (ADA), *Final technical report* . Riyadh Transportation Study Phase 2, Stage 1, Undated.

Bonsall P. and H. Kirby, The role of expert systems in transport. In Bonsall P. and Bell M. (eds.), *Information Technology Applications in Transport,* Utrecht, VNU Science Press, 1986.

Brail, R.K., *Microcomputers in Urban Planning.* New Brunswick, N.J.: Center for Urban Policy Research, Rutgers University, 1987.

Chang, E.C., Select traffic analysis software using expert systems, paper presented at the 66th annual meeting of the Transportation Research Board, Wash., D.C., 1987.

Cohn, L.F., Using expert systems for transportation noise decision making, *Transportation and Decision Making*, vol. 3, 1986, pp. 313-322.

Dimitrion, H.T. (ed.), *Transport planning for third world cities.* London: Routledge, 1990.

Ford, F.N., Decision support systems and expert systems: a comparision, *Information & Management*, vol. 8, 1985, pp. 21-26.

Kim, T.J., L.L. Wiggins, and J.R. Wirght (eds.), *Expert Systems: Applications to Urban Planning.* New York, N.Y: Springer-Verlag, 1990.

Manheim, M.L. and D. Isenberg, A theoritical model of human problem-solving and its use for designing decision support systems, paper presented at the 20th Hawaii International Conference on System Sciences, Jan. 1987.

Martland, C.D., S. McNeil, and J. Eshelby, Applications of expert systems in railroad maintenance: scheduling rail relays. *Transportation Research,* vol. 24A, no.l, Jan. 1990, pp. 39-52.

Meyer, M., and E. Miller, *Transportation Planning: A Decision-Oriented Approach.* New York: McGraw-Hill, 1984.

Micro Data Base Systems, *GURU Expert systems Management.* Version 2, July 1989.

Mintzberg, H., D. Raisanghi, and A. Theoret, The structure of 'unstructured' decision processes, *Administrative Science Quarterly* 21,1976, pp. 246-275.

Rieple, R. and C. Gehner, Interactive graphics in Europe: Three computer- aided transportation tools, *Computer Graphics*, vol. 1, no. 13, Dec. 1978, pp. 18-25.

Ritchie, S.G. and C. Yeh, A knowledge-based approach to improve urban transportation decision making. Working paper, ITS, Univ. of Calif., Irvine, 1987A.

Ritchie, S.G. and R.A Harris, Expert systems in transportaion engineering. In Maher M.L. (ed.), *Expert SYstems for Civil Enqineers*, New York: ASCE, 1987B.

Ritchie, S.G., A Knowledge-based decision support architecture for advanced traffic management. *Transportation Research,* vol. 24A, Jan. 1990, no.1, pp. 27-37.

Schultz, D., and F. Spielberg, Workshop on strategic planning, *Travel Analysis Methods for the 1980's,* TRB Special Report 201, 1983, pp. 11-16.

Stuart, D.G., State of the practic : travel analysis methods in long-range and strategic planning, *Travel Analysis Methods for the 1980's*, TRB Special Report 201, 1983, pp. 145-155.

Szwed N., Expert systems in traffic management. In Hadgraft R.G. and Young W. (eds.), *Knowledge-Based Svstems in Civil Enqineerinq*. Monash Univ., Melbourne: Dept.of Civil Eng., 1988.

Takallou H., Knowledge-based expert systems: what is happening in transportation engineering? *ITE Journal*, vol. 55, 1985, pp. 33-38.

Taylor, M., Knowledge-based systems for transport network analysis: a fifth generation prespective on transport network problem. *Transportation Research*, vol. 24A, no.l, Jan. 1990, pp.3-14.

Tung, S., and J.B. Schneider, Designing optimal transportation networks: an expert systems approach, Paper presented at the 66th annual meeting of the Transportation Research Board, Wash., D.C., 1987.

Turban, E. and P. R. Watkins, Integrating expert systems and decision support systems, DSS-85 Transactions, J. Elam (ed.), 1985, pp. 52-63.

Turban, E., *Decision Support and Expert Systems: Managerial Perspectives*. New York: Macmillan, 1988.

Waterman, D.A., *A Guide To Expert Systems*. Reading, Mass.: Addison-Wesley, 1986.

Yeh, C., S.G. Ritchie, and J.B. Schneider, Potential applications of knowledge-based expert systems in transportation planning and engineering, *Transportation Research Record 1076*, 1986, pp. 59-65.