# AEIC' 93

AL-AZHAR ENGINEERING THIRD
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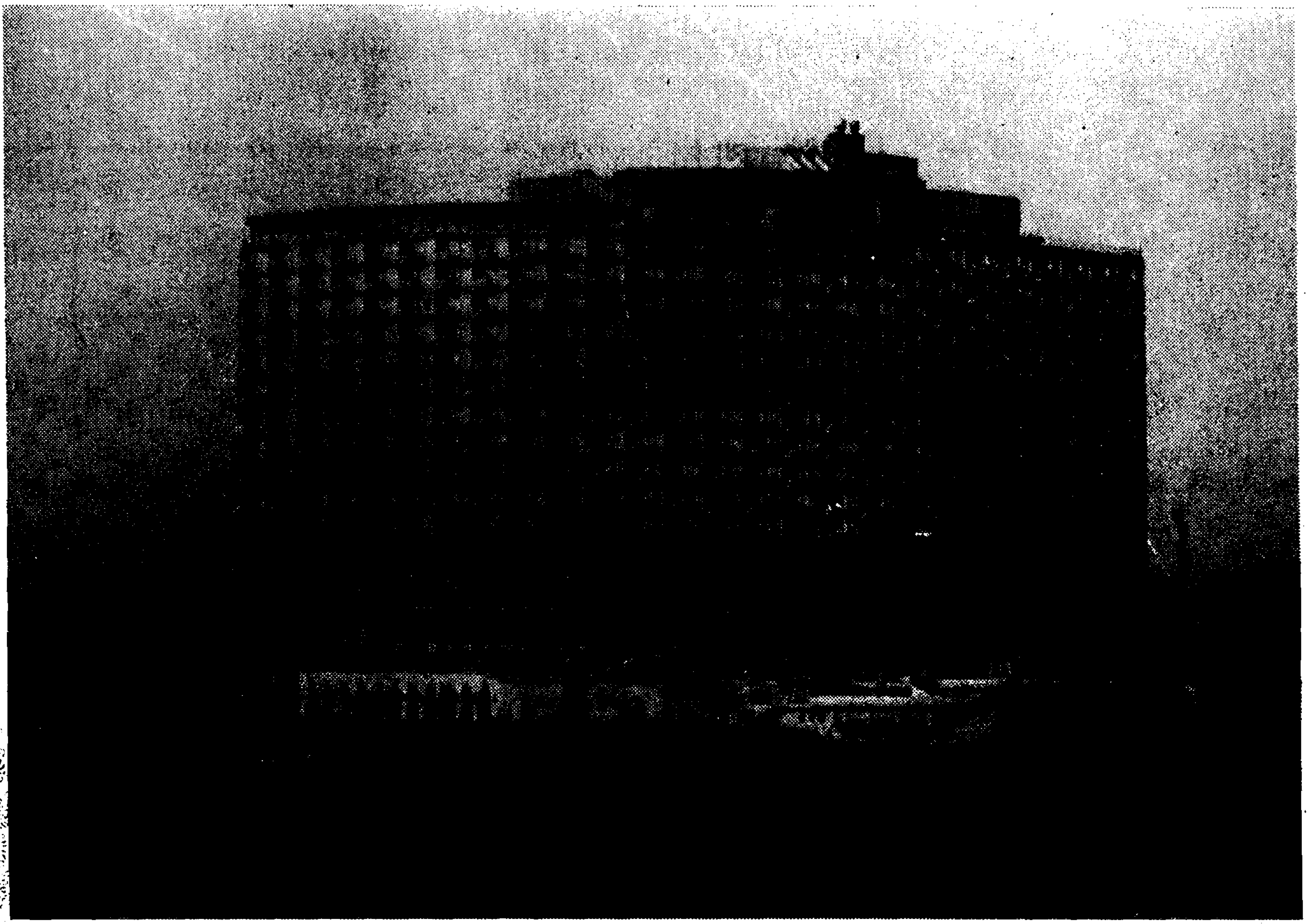

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# EXPERT SYSTEMS IN TRANSPORTATION:
# USEFULNESS AND APPLICABILITY

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**ABSTRACT**

The main focus of this paper lies in reviewing the Expert Systems (ESs) technology and evaluating the strengths and the weaknesses of applying ESs to solving transportation problems. This evaluation helps in gaining an appreciation of how ESs can contribute to the field of transportation.

**KEYWORDS**

Transportation Planning, Road Planning, Traffic Engineering, Highway Engineering, Traffic Safety, Expert Systems, Knowledge-Based Systems.

## INTRODUCTION

"An ES is a computer program that represents and reasons with knowledge of some specialist subject with a view to solving problems or giving guidance. Such a system may completely fulfil a function that normally requires human expertise or it may play the role of an assistant to a human decision maker. It simulates human reasoning about a problem domain i.e. emulating an expert's problem-solving abilities, rather than simulating the domain itself", [1].

ESs, sometimes referred to as knowledge-based ESs, have been successfully applied to a range of problems in different areas. However, relatively little use of ESs have been made in the field of transportation. "ESs are an emerging technology, but one that may, in years to come, revolutionise professional activities in many areas of transportation engineering. Some predictions suggest that the impact of this technology may be similar to that of the computer itself in the last several decades", [2]. ESs enhance human decision-making power by allowing professionals to make decisions quicker and more accurately. In addition, they act as tools that can assist, advise and train people with less levels of skill and experience.

In contrast with conventional problem solving techniques that utilise algorithmic or statistical techniques, an ES attempts to solve a problem by applying coded experts' rules of thumb and judgements to a symbolic representation of knowledge about the problem domain. There exist two main approaches for developing an ES. The first known as the cognitive advisory approach. This is a rule based approach that gives advice depending on a set of predetermined list of conclusions. The second known as the synthetic problem solving approach. This generate solutions not previously considered based on available data and knowledge, thus improving and adding to the experts' knowledge. According to [3] "so many of the problems that transportation professionals face require specialised knowledge, skill, experience, and judgement for determination of solution strategies, the authors believe that, in general, the potential appears high for knowledge based ESs to become useful tools for practising transportation planners and engineers".

The utility of the ESs technology as regards its appropriateness and suitability for application to transportation problems is evaluated in this paper. A review of some of the studies that applied ES to different transport-related issues is presented. It is not the intention of this paper to review specific studies in detail. Rather it is directed towards unfolding, in a general context, the main characteristics of studies that applied the ESs technology to solving transportation problems. This is meant to demonstrate the applicability of ESs in handling a wide range of transport-related issues. In addition, it is hoped that this review can guide future research intending to use ESs to tackle specific transport areas.

## STRUCTURAL COMPONENTS OF AN ES

An ES consists mainly of two components, namely the knowledge base and the inference engine, see Fig. 1.

### Knowledge Base

A knowledge base is a reservoir area used for storing human as well as other types of knowledge about a particular domain problem. This includes knowledge about when/how to know that there is a problem? where is it? what should be done to solve it? how to go about achieving this solution? when is the time to implement this solution? who should undertake the solution to the problem? and various other pieces of knowledge. Knowledge can take several forms such as expertise, rules, facts, concepts, intuitions, judgement, ..etc.

## Inference Engine

An inference engine, sometimes referred to as the reasoning mechanism, acts as a shell that protects, controls and accesses the knowledge base. It can provide deduction and/or induction powers that can make conclusions using stored knowledge. In addition to performing reasoning over representations of human knowledge, an inference engine can do numerical calculations and/or data retrieval. Three main methods for reasoning exist, namely forward chaining, backward chaining, or a combination of both. Using forward chaining, the reasoning is deductive i.e. it starts with the data and moves towards the conclusions. It is employed whenever data is abundant and highly available. On the other hand, in backward chaining the reasoning is inductive i.e. attempts are made to work back through the rules from the conclusions to their preceding causes. It is mostly used when data is difficult to obtain.

## DEVELOPMENT OF AN ES

The procedure involved in constructing an ES is displayed in Fig. 1. The process involved in the development of an ES should be looked upon as a means for inducing an understanding as well as learning and accumulating knowledge about a problem domain.

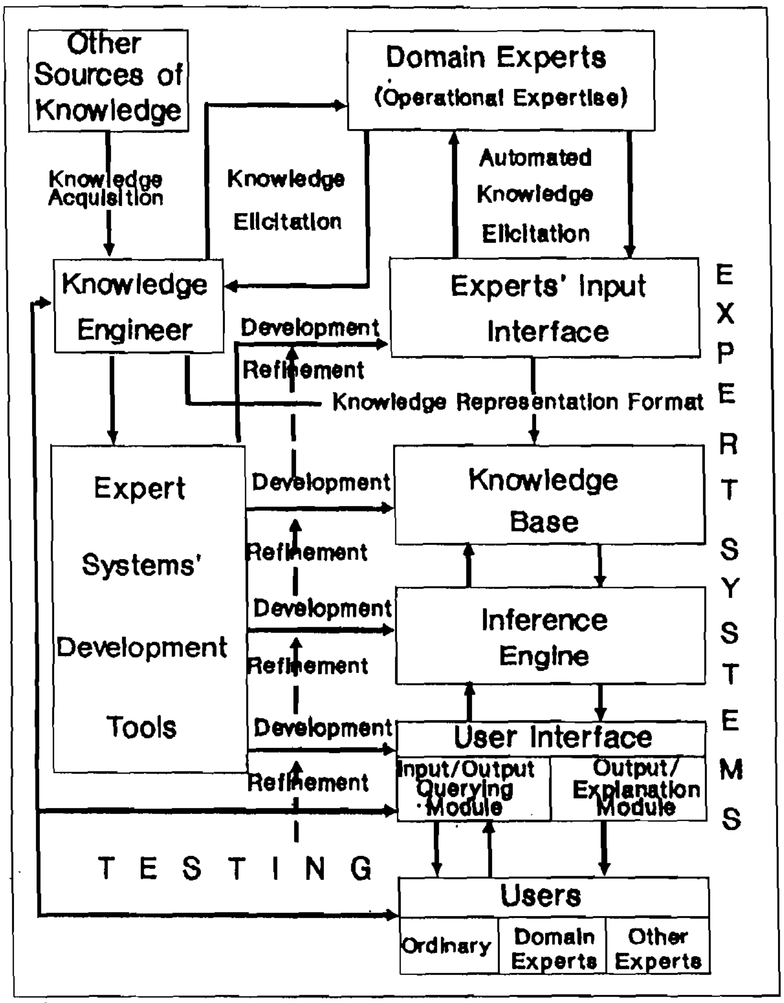


Fig. 1: Development of an Expert System

The process starts by a knowledge engineer, sometimes referred to as an ES builder, establishing a clear and crisp definition of the problem in hand. He/She has to identify what are the specific questions that an ES is attempting to answer, and consequentially the objectives and purposes of the ES tool. Another important aspect is to identify the users who are expected to use the tool. "These are crucial steps that can often dictate the general characteristics, the context, and the dimension demarcation, of the model (tool) to be developed. They involve establishing the purpose, the scope, the boundary (the breadth), and the level of detail (depth), of the model (tool)", [4]. The following subsections present a discussion, in some detail, of each of the components and activities that contribute towards the development of an ES.

## Knowledge Elicitation

The process of acquiring knowledge directly from experts is known as knowledge elicitation. This is a feedback process that involves communication between the knowledge engineer on one side and the domain expert(s) on the other. There exist two levels of knowledge elicitation. The first is the individual level which can be conducted using one or several of the following methods.

1. Clinical interviews (structured or unstructured) with experts with the purpose of obtaining their mental judgements regarding the problem domain i.e. capturing the experts' operational expertise. This can be documented using a pen and a paper or a small tape recorder.
2. Nominal and judgmental questionnaires. These include choice, ranking and rating questions used to determine individual choices, preferences and attitudes. Examples of these are the revealed preference, the stated preference and the attitudinal survey questionnaires.
3. Task/Observation analysis i.e. by shadowing experts while practising their operational expertise.
4. Requesting from experts to write a report on their expertise.
5. Directly from experts e.g. in lectures, tutorials, demonstrations, ..etc.

The second level of extracting knowledge and information from domain experts is the group level. Some of the techniques that can be used to solicit information from a group of experts include: cognitive techniques such as Delphi, brain storming, group meetings, discussions, structured workshops, ..etc.

## Experts' Input Interface

A relatively recent development in the field of knowledge elicitation is the development and introduction of computer based experts' input interfaces. These are designed to automate the process of capturing knowledge and information from experts. These are intended to replace the knowledge engineer in his/her task regarding elicitation of knowledge from experts as well as to facilitate the extraction of knowledge from several experts in a relatively short time, thus using their time efficiently. Once developed, it is regarded as one of the components, with the knowledge base and the inference engine, that constitute an ES.

## Knowledge Acquisition

The process of obtaining knowledge from sources other than experts is known as knowledge acquisition. This is a unidirectional process i.e. the knowledge engineer extracting information from the various available sources of knowledge. The following is a list of some of the sources of information and procedures that knowledge engineers can use in carrying out their knowledge acquisition exercise.

1. Personal observations and direct individual experience of the knowledge engineers.
2. Literature search and content analysis.
3. Descriptive and formal (theoretical) knowledge.
4. Other existing models, facts, evidences, accepted theories, assumptions and hypothesis.
5. Existing Data.

## Knowledge Representation

The acquired and the elicited knowledge are structured in the knowledge base using a knowledge representation format. Knowledge representation entails the explicit expression, organisation, structural mapping, and transfer of available information to a certain format. This could be a set of rules, facts, trees, frames, classes, scripts, semantic networks, causal models or objects, ..etc. This task is undertaken either by the knowledge engineer or is automated through the experts' input interface.

## Users' Interface Modules

When constructing an ES, efforts should be made towards developing a tool that is easy and simple to operate. This entails designing a front-end user interface, considered as one of the components, with the knowledge base, the inference engine and the experts' input interface, that constitute an ES. The user interface incorporates two modules, namely an input/output module and an output/explanation module.

The input/output module is meant to facilitate a user-friendly dialogue. It represents an on line dialogue, and a real time interaction, between the computer and the users. Its meant to support the users in their choice of available options as well as in their entering of input specifications required by the ES. It should be comprehendible and self-explanatory so that input data will be entered correctly. In general, its main purpose can be described as allowing users, with a minimum level of computer experience, to have a relatively easy access to using the ES.

An ES must be capable of providing answers/solutions to the problem in hand. It should be also capable of explaining and justifying these solutions/recommendations so as to convince the user that its reasoning is in fact correct. The role of the output/explanatory interface module is to provide users of an ES with answers to the questions specified through the input/output module as well as to demonstrate how and why these answers were reached. Output of an ES can take several forms such as statements, notes, graphic displays. Explanatory output is mainly in the form of interpretation and justification remarks.

Users of an ES can be classified into ordinary users, experts involved in contributing their knowledge to build the knowledge base i.e. domain experts), and other experts. These initially use the system to test and verify the knowledge and the reasoning of the system. Their comments are taken into consideration by the knowledge engineer in his/her refinement of the system.

Once the ES has been refined it can be mainly used by the ordinary users who have limited expertise with the problem domain and is using the system mainly for advisory, consultancy or training purposes. The system is also used by the experts to enhance their knowledge and expertise and to support their decision-making process.

## Tools For Developing An ES

Knowledge engineers employ a set of computer tools for developing the four main components of an ES, namely the experts' input interface, the knowledge base, the inference engine and the users' interface modules. Tools for developing an ES can be classified into three categories. The first is the conventional high level programming languages such as BASIC, COBOL, FORTRAN, PASCAL, C. The second is the special purpose languages, known as the artificial intelligence programming languages, such as LISP, PROLOG. The third is the ESs' Shells such as EXSYS, ART, OPS5, DUCK, NEXPERT, OBJECT, S.1, KES, KEE, LEVEL5, INSIGHT2, M.1, RUNNER, GEPSE, SMECI, SNARK2, AIDA, SEL+ .. etc. Having selected the tools to be used in developing an ES, these are used for programming and coding the system into an executable computer program. The software is then debugged, and the logic of the programm verified. ESs' shells substantially reduces the time and effort involved in the construction (programming, testing, refinement) of an ES. However, the ESs developers are frequently constrained by the limited capabilities of shells. For more sophisticated and detailed problems it is advisable to use high level or artificial intelligence programming languages depending on the available computer expertise. These provide powerful and flexible programming medias.

## Tasks Of The Knowledge Engineer

Developers of ESs are known as the knowledge engineers. Tasks of the knowledge engineers can be stated as follows.

1. Elicitation of operational expertise from domain experts.
2. Acquisition of knowledge from other available sources of information.
3. Utilising selected ESs' development tools to build the experts' input interface, the knowledge base, the inference engine and the user interface.
4. Testing the ES by personally using it as well as getting feedback comments and remarks from users of the system.
5. Refining the ES. This can include refinement of the experts' input interface, the knowledge base, the inference engine or the user interface or a combination of these components.

## USEFULNESS OF ESs TO TRANSPORTATION PROBLEMS

Drawn from the literature the following advantages can be attributed to using ESs in solving transportation problems.

1. An ES facilitates the accumulation and presentation of knowledge in a systematic discernable fashion. Knowledge related to a particular transport application area is encoded in a standard format.
2. ESs help in saving and sustaining knowledge and experience (know how, know when, know where, know why) known to be a scarce resource in the transport field.
3. The knowledge base of an ES could be easily modified. Modifications include knowledge being adapted, updated and enriched as changes occur. This can be attributed to the knowledge base being separated from the inference engine.
4. Through ESs the knowledge and operational expertise of an established expert in a particular transport domain can be emulated, hence providing a degree of performance and competence that could be only achieved by experts.
5. Portability of ESs means that experts' knowledge could be accessible to other people at various levels of skills, and at other times and places.
6. ESs can handle transport problems of complex nature. These need a substantial amount of human expertise. Using ESs technology allows the possibility of several experts merging their knowledge to cover a broad range of potentialities.
7. In solving transport problems many activities are required. These include: consultancy/assistance, advisory, training, expertise enhancement, planning/scheduling, forecasting, design, management, control, monitoring, interpretation, diagnosis, repair. All of which are amenable to ESs application.
8. An ES mimics the operational expertise of several experts with the advantage of utilising the computer high speed operation, its big memory capacity and its ability to deal with a lot more knowledge than what a single human expert can handle at one time.
9. ESs could be developed to facilitate the use of sophisticated transport programmes as well as to guide inexperienced users towards the interpretation of the results of these programmes and hence reaching conclusions.
10. Possibility of interfacing an ES with other software tools means that the ES could perform computations on data available from databases or could execute transport programmes, thus obtaining results necessary to provide conclusions.
11. ESs can contribute to increasing the efficiency and effectiveness of transport training and education. They help in shortening the time of the learning curve associated with gaining human expertise. People are capable of attaining expert levels of performance given technical assistance from an ES program. In addition ESs help in supporting and enhancing the decision making capabilities.
12. ESs assist in alleviating the pressure on the limited transport expertise that exist in developing countries. Experts previously tied down to handling routine problems could be relieved from these tasks hence having more time

to dedicate their efforts to perform more critical and/or creative tasks.

13. In an increasingly competitive environment, companies, through developing ESs, can now analyse problems and respond to new situations much faster than their competitors. ESs can lead to major savings resulting from reducing the time that it takes to perform some important assignments.
14. An ES will always provide a consistent output. It applies the same knowledge and reasoning process to every case i.e. the same knowledge is reusable in an invariable manner.
15. Most ESs exhibit high performance characteristics such as speed, reliability, reusability, ease of maintenance, transparency and productivity. They are designed in a manner that is thought to offer usefulness and flexibility to users. A knowledge engineer always strives to include various alternative options and choices so as to make the ES as flexible as possible, thus catering for the needs of different users. Flexibility in building ESs has the advantage of making them adaptable to different conditions and situations, thereby increasing the life span through which ESs can be used without requiring major modifications.

## LIMITATIONS OF ESs

While the ESs technology has its limitations, the motivations for pursuing it for solving transport problems are overwhelming. The following represents some of the limitations encountered in applying ESs technology to solving transport problems.

1. Developing an ES is highly dependable on the cooperation and seriousness of experts. A situation that is sometimes difficult to achieve as experts can be reluctant to cooperate. Experts may be over-protective from fear of losing job or status.
2. Knowledge may be over-learned and hence difficult to elicit.
3. There is always a degree of uncertainty in experts' judgements. In other words there is always a need to establish confidence levels for pieces of knowledge elicited from experts.
4. A knowledge base obtained from several experts may lack consistency.
5. It is relatively expensive to develop an ES. There is a scarcity in the number of knowledge engineers. ESs development tools are costly. Time resources consumed in developing and maintaining an ES is very high both in terms of the involved experts' as well as the knowledge engineers' time.
6. ESs can sometimes be sophisticated to the extent of computational intractability.
7. Examining and validating the reasoning mechanism and the relational structure of the knowledge is a difficult task that is frequently ignored.
8. There is always a danger of ordinary users depending totally on the output of ESs in making their decisions. ESs are meant to support and enhance the decision-making process rather than to act as a replacement for experts.

## WHEN TO USE ESs TECHNOLOGY

If the right ESs applications are chosen, these systems provide paybacks that are much higher than the paybacks one expects from conventional computer systems. These allow transport companies to solve strategic problems that could not have been automated in the past, making them more efficient and profitable.

1. The total amount of time which an expert or a group of experts has spent in accumulating his/its skills and expertise is considerable.
2. Scarcity of living experts who can deal with the specific problem domain or experts approaching retirement.
3. Obtaining solutions for the problem domain is highly expensive. This could be attributed to the scarcity of experts hence being too busy and costly.
4. Sheer size of knowledge required to deal with a problem domain. An ES provides an efficient and extensive use of ample knowledge.
5. Problem domain is characterised by being dynamic in its nature. Therefore requiring different pieces of knowledge to react appropriately to different situations. In effect, demanding programs that tailor their own behaviour to address the problem at hand.
6. The problem in hand should not be too simple such that it is a waste of resources to develop an ES for. On the other hand, it should not be so complex that an ES would be just too difficult to build and maintain.
7. ESs could be very applicable in cases of ill-structured problems where algorithmic solutions do not exist or can only provide restricted capabilities for solving these ill-defined problems.
8. In cases of imperfect data, it might be appropriate to develop ESs. An ES solves problems by heuristic or approximate methods. A heuristic is essentially a rule of thumb which encodes a piece of knowledge about how to solve a problem. ESs can benefit from heuristics (generated by either man or machine) in providing acceptable solutions to hard problems.
9. Developing ESs for recurring problems is very useful in assisting users to deal with these problems without having to repeatedly refer to experts.
10. The existence of a big potential of users that can render the development of an ES worthy. Alternatively the type of problem domain cannot endure the possibility of a faulty human expert advice.
11. An ES is very appropriate for problems that are detailed but crisply defined.

## APPLICABILITY OF ESs IN TRANSPORTATION STUDIES

An extensive review, covering 34 of the relevant studies that developed ESs to different transport-related issues, is presented. The information extracted from this review is presented in a tabular form (see Table 1). The main headings of the Table are:

(1) the reference of the study i.e name of the first author and date of publication;
(2) the general area of transportation with which the ES is concerned;
(3) name of the developed ES;
(4) name of country/area where ES was developed i.e. place from where experts involved in the knowledge elicitation process were drawn;
(5) the type of output that the ES produces i.e. the functional performance. This include functions such as assistance, consultancy, advisory, training, expertise enhancement, planning/scheduling, forecasting, design, management, control, monitoring, interpretation, diagnosis;
(6) the development tools used in constructing the ES;
(7) type of reasoning;
(8) the purpose and objectives of the ES.

The diversity of the transport topics addressed by the studies reviewed in this paper demonstrates that ESs is a well suited technology to cater for the needs of several problems in transportation. "To identify new applications and research needs, consultations with appropriate experts and a more careful and complete review of domain-dependent problems are required. Such work should be followed by development and evaluation of new prototype ESs. This would improve the ability to assess the feasibility and true potential of such systems in transportation planning and engineering.", [3].

## CONCLUSION

The utility of the ESs technology as regards its appropriateness and suitability for application to transportation problems was evaluated in this paper. The paper started by introducing the main structural components of an ES. It then went on to describe the process followed in the development of an ES.

The usefulness and limitations of applying ESs to transportation problems were thoroughly discussed. This was followed by laying down several situations that could render ESs to be highly useful and desirable for application.

The paper concluded with a review of studies that applied ESs to transportation problems. In general, ESs technology has been widely applied in other disciplines. In transport it is steadily gaining momentum in the midst of the conventional approaches. A very important function of the ESs technology is to develop tools that can act as credible supports to the problem solving and decision-making processes. ESs that are carefully and diligently programmed act as intelligent amplifiers that can filter the mental models of users. These are not in any sense meant to replace experts or even to inhibit their consultation role, rather they are developed to help and support them in better achieving their tasks. ESs can offer a lot in terms of better planning and solving transport related problems.

Table 1: Review of studies that applied Expert Systems technology to transportation problems

| Reference | General Area of Application | Name of Developed Expert System ES | Country/ Region of Applicat. | Type of Output | Develop-ment Tools | Type of Reasoning | Purpose/Objectives of Expert System (ES) |
|---|---|---|---|---|---|---|---|
| Yeh, 88a [3] | Review Paper: It describes the characteristics of knowledge-based expert systems (KBES) and suggests some applications that appear to have a high potential for development in the field of transportation planning & engineering These include: facility design, study design, planning methodology, disaster response planning, bus transit network planning, traffic congestion diagnosis, roadway safety diagnosis, hazardous material transportation, air traffic control, ground traffic signal timing control, dispatching & scheduling, transit vehicle maintenance, pavement rehabilitation | | | | | | |
| Lewis, 87 [5] | Review Paper: It discusses the objectives and role of transport in Canada & developing understanding of ES technologies and their relationship to the transport sector in general. Identified potential areas of application of ESs in transport include: vehicle crews, vehicle maintenance, external control of vehicles in transit, permanent way control and operation, terminal facility control and operation, operational planning and regulation | | | | | | |
| Faghri, 88 [6] | Review Paper: It examines the significance of the means of representing the knowledge base in the ESs, with special reference to transportation engineering | | | | | | |
| Ritchie, 88 [7] | Review Paper: It presents the results of a research project with the objective of preparing a plan for the development and implementation of a knowledge-based ESs project throughout the California Department of Transportation (Caltrans). A total of 45 candidate projects were identified and ranked by priority. | | | | | | |
| Ritchie, 87a [2] | Highway Engineering | SCEPTRE | U.S.A. | Assist | EXSYS | Backward Chaining | 1. To assist highway engineers in planning and developing cost-effective flexible pavement rehabilitation strategies at the project level. |
| Ritchie, 87b [8] | Highway Engineering | OVERDRIVE | U.S.A. | Advise Assist Design | | | 1. To assist local engineers in designing the structural thickness of asphalt concrete pavement overlays. |
| Hajek, 87 [9] | Highway Engineering | ROSE | Canada Ontario | Assist Plan | EXSYS | Backward Chaining | 1. To improve selection and planning of maintenance and rehabilitation (routing and sealing) actions for asphalt concrete pavements in cold areas. |
| McNeil, 87 [10] | Bridge Engineering | PAIRS | U.S.A. | Assist | GEPSE | Forward Chaining | 1. To establish the facility condition, evaluate the need for bridge painting, identify appropriate painting strategies, and cost the strategies. |
| Martland, 90 [11] | Railroads Engineering | REPOMAN | U.S.A. | Assist Advise Schedule | LISP | Forward & Backward Chaining | 1. To help in determining when to relay or replace rail, a process that is called rail scheduling. |
| Corby, 90 [12] Pugelli, 90 [13] | Highway Engineering | ERASMUS | France | Assist Diagnose | SMECI | Forward & Backward Chaining | 1. To assist the person responsible for maintenance at the time of diagnosing the problems of a road and the design of the repair works for a uniform section. |
| Makarachi, 1990 [14] | Highway Engineering | | U.K. | Advise Assist | TURBO PROLOG | Forward Chaining | 1. To guide and advise a naive user of the World Bank's Highway Design and Maintenance Model (HDM-III) through the data prepration process. |
| Wilkins, 91 [15] | Highway Engineering | | U.K. | Assist | PDC-PROLOG | Forward Chaining | 1. To use the predictive capabilities of HDM-III to calculate critical deterioration levels for each road/traffic combination in the maintenance management system BSM. |
| Hozayen, 92 [16] | Highway Engineering | DMMD | Canada | Assist Diagnose Design | INSIGHT 2 | Forward & Backward | 1. To act as a decision support throughout the different stages of the PMSE process that can quickly and reliably diagnose Marshall test results & recommend adjustments. |

Table 1: Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ritchie, 87c [17] | Transportation Planning | STREET-SMART | U.S.A. | Assist Advice | LISP | Forward & Backward | 1. To assist and advise users of the Streets of the City gaming simulation. |
| Janarthanan, 1988 [18] | Transportation Planning | TNOP-ADVISOR | U.S.A. | Assist Advise Design | RUNNER | Backward Chaining | 1. To assist in the development of high performance transit network designs. 2. To provide advice about how to modify designs to obtain improved performance. 3. To act as an aid to the designer who wishes to make more productive use of TNOP software. |
| Braun, 88 [19] | Transportation Planning | Research Approach | Brazil Rio de Janeiro | Assist | | | 1. To help in the decision making process involved in the completion of operational plans for recovering transportation service in cases of disruptions caused by emergency or contingency or joint plans. |
| Tyler, 89 [20] | Transportation Planning | | Brazil | Assist Design | | | 1. To produce a design for an appropriate high capacity bus priority system. |
| El-Araby, 92 [21] | Transportation Planning | NETSSA | U.S.A. | Assist Advise Plan | LISP | Forward Chaining | 1. To assist transportation planners and engineers in selecting micro computer packages for network-based transportation planning to satidfy their agencies needs and constraints. |
| Safwat, 93 [22] | Transportation Planning | SIAA | U.S.A. | Assist Advice | LISP/ Knowledge Pro | Forward & Backward | 1. To assist in addressing issues and questions that typically arise prior to and during conducting and reviewing traffic studies related to new & expanding developments. |
| Bryson, 87 [23] | Road Planning | Prototype ES | U.S.A. | Advise Design | M.1 | Forward Chaining | 1. To recommend geometric modifications to improve operation of signalised intersections. |
| Tung, 87 [24] | Road Planning | EXPERT-UFOS | U.S.A. | Assist Design | M.1 | Forward Chaining | 1. To solve the simple-mode (automobile), fixed demand, discrete, multicriteria, equilibrium transportation network design problem. |
| Yeh, 86b [25] | Traffic Engineering | HERCULES | U.S.A. | Advise | RUNNER | Backward Chaining | 1. To provide advice on appropriate post-disaster traffic control strategies for reducing congestion. |
| Zozaya, 87 [26] | Traffic Engineering | TRALI | U.S.A. | Assist Design | OPS5 | Forward Chaining | 1. To assist in designing the operation of a traffic signal for isolated intersections. |
| Chang, 87a [27] | Traffic Engineering | Prototype ES | U.S.A. | Assist | INSIGHT 2 | Forward & Backward | 1. To assist traffic engineers in selecting proper traffic-related software packages for optimum traffic analysis. |
| Chang, 87b [28] | Traffic Engineering | Three Prototype ESs | U.S.A. | Assist Design | PD PROLOG TURBO PROLOG INSIGHT 1 | Forward Chaining | 1. To recommend alternative left-turn phase selection process to optimise signal capacity and operational safety at signalised intersections. |
| Taylor, 90 [29] | Review Paper: It discusses the application of knowledge-based system (KBS) technology to the production of an ES to provide route guidance information for some groups of urban travellers. | | | | | | |
| Ritchie, 90 [30] | Review Paper: It suggests a novel artificial intelligence-based solution approach to the problem of providing operator decision support in integrated freeway and arterial traffic management systems, as part of a more general Intelligent Vehicle-Roadway System (IVRS). | | | | | | |
| Gray, 91 [31] | Traffic Engineering | Prototype ES | U.K. | Advise Inform | | | 1. To advise and inform operators at urban traffic centres on the treatment of recurrent congestion in their networks. |
| Scemama, 1991 [32] | Traffic Engineering | SAGE | France | Assist Train | SNARK2/ AIDA | Forward Chaining | 1. To provide the functions of automobile traffic surveillance and regulation aid. 2. To improve the knowledge of the operators and traffic engineers. |

Table 1: Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kirschfink, 1993a [33] | Traffic Engineering | KIDS | Germany Rhine/Main | Assist | C | | 1. To assist in the completion of the data-base for the traffic control system Rhine/Main. |
| Kirschfink, 1993b [34] | Traffic Engineering | KIMS | Germany North Rhine-Westphalia | Assist Manage Control | ES Shell | | 1. To enable traffic control centres to utilise the technical possibilities of traffic detection and traffic control in an optimal way. 2. To assist traffic authorities in North Rhine-Westphalia to manage the traffic and in particular the congestion problem. 3. To prevent or reduce traffic disturbances in North-Westphalia through timely information. |
| Chou, 93 [35] | Traffic Engineering | | U.S.A. | Assist | EXSYS | Backward Chaining | 1. To provide the designer with decision-making support about guidelines of guardrail installation |
| Theobald, 1988 [36] | Traffic Safety | | U.K. Strathclyde Essex Hertfordshire | Assist Advise | Beagle/ SD-RULES | Forward & Backward Chaining | 1. To search for relationships within the accident database to identify characteristics of road accidents that can be used to distinguish between different classes of accidents thus suggesting appropriate remedial measures |
| Ramache, 88 [37] | Traffic Safety | Prototype ES | U.K. Tyne & Wear | Assist | PROLOG | Forward Chaining | 1. To assist a traffic or a highway engineer when making decisions about the location of roadside objects (lighting columns, signposts, ..etc.) |

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