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EXPERT SYSTEM IN ENGINEERING TRANSPORTATION: A REVIEW

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Abstract

This paper reviews expert systems applications in engineering transportation. The Expert System (ES) offers advantages over human experts such as accessibility, consistency, time constraints, stability, and efficiency. ES methodologies could be classified to rule-based systems, knowledge-based systems, neural systems, fuzzy ESs, and modelling in transportation. The necessity to develop an expert system that can help to control damage is reviewed in this article. It was demonstrated that the development directions for ES methodologies and implementations in transportation engineering such as flexible pavement, rigid pavement, mix design concrete traffic calming, pavement evaluation and rehabilitation, pavement maintenance, traffic light control, traffic accidents, highway geometric design is necessary. The aim of this article is to summarise the latest outcomes of researches related to the process of engineering transportation applications, developing and investigating an expert system. Moreover, this paper may widen our horizon on this subject. It is concluded that the expert system enables the performance engineers to analyse, determine and customise information to help relevant parties during decision-making processes. It is also inferred that the prospect of combining evolving methodologies advances would enable the development of more sophisticated models that hold the greatest promise for the future.

Keywords: Artificial neural networks, Expert system, Fuzzy expert systems, Knowledge-based systems, Transportation.

1. Introduction

Expert Systems (ES) are an important branch of artificial intelligence (AI) and are currently employed to manage various problems in the establishments by utilizing human knowledge on various fields for analysis and consultation [1, 2]. Consequently, expert systems are widely used to control complicated problems that require considerable knowledge, thereby leading researchers and establishments to develop several systems in various domains [2]. These expert systems can be applied in all sectors of knowledge [3]. An expert system is a computer program t manipulates facts, knowledge, and reasoning to solve problems efficiently and effectively in a narrow problem area that normally requires various expensive sources of knowledge and human experts. [3] Similar to human experts, these systems use symbolic logic and heuristic rules of thumb to find solutions. Artificial expertise enjoys certain advantages over human expertise; it is consistent, permanent, easy to transfer, and often cheaper. According to Bolloju, et al [3], by linking computers to the richness of human experience, expert systems would enhance the value of expert knowledge, thereby making it readily and widely accessible. Dogantekin, et al. [4] pointed out that an expert system provides a mathematically and logically robust evaluation of imprecise information that is particularly relevant in ecosystems, environmental pollution, and resource management. It is a branch of AI research that has many potentials uses in civil engineering. It also has an advantage over the program applications using reasoning and conceptual aspects. Thus, the use of logical representation for assessing systems is frequently required and necessary when available data are scarce or the current state of knowledge about a problem domain is too imprecise for classical mathematical methods [4].

In addition, expert systems preserve and disseminate knowledge efficiently at reasonable costs. This function is particularly essential in the transportation engineering problems such as in rigid highway pavements, flexible pavement, and a traffic accident. The lack of expertise and risk of knowledge loss due to the expert's death or retirement raise the need for the establishment for the expert system [4]. Furthermore, the expert data field is "fuzzy" and contains plenty of procedural facts; so, the knowledge engineer must be an expert in the process of information elicitation. The expert system represents a way of capturing, coding and reusing of information. Fundamentally, an expert system comprises of some representation of expertise or a problem to be solved, and some mechanisms to apply the expertise to a problem in the form of rules [5].

Expert systems have been employed to assist and manage various problems in the establishments by improving analyses and providing advice [6]. Consequently, expert systems have been used to manage complicated problems that require considerable knowledge, thus enabling researchers and establishments to develop systems in several domains [7].

The Road Construction Material Selection System (RC-MSS) is a prototype that supports pavement designers in making decisions during the material selection stage by providing different alternatives [8, 9]. It is created a rule-based expert system to help pavement designers in designing flexible-pavement structural systems. In the field of highway geometric design, ES was designed for a knowledge-based system to select optimum routes for the alignment of new roads [10]. In the highway pavement construction field, ES was attempted to develop a knowledge-based system that only included written sources to control construction problems in rigid pavements [11, 12], developed an expert system for auditing quality management in construction. Tagherouit et al. [13] presented an expert system using fuzzy logic for prioritizing rehabilitation of sewer networks by Zeeger et al. [14], Falamarzi et al. [15], Boonsiripant [16], Omran et al. [17], Shen et al. [18] and Prasad et al. [19] in which, applying traffic calming strategies using ES which can enhance the safety of non-motorized transportation users and residents of local neighbourhoods. It used different traffic calming strategies including vertical deflections, horizontal deflections, narrowing measures and volume control measures. In order to implement the traffic calming strategies an increasingly alarming traffic safety issues, such as speeding and cut-through traffic, led engineers and urban planners are necessary. Before proceeding with the implementation of measures, creating a system to identify projects with higher priorities is essential. Employing traffic calming strategies in all residential streets is not cost effective or may not be necessary. Furthermore, restriction in the allocation of funds is a major concern for decision-makers. Hence, finding a methodology and a framework to prioritize the alternatives is an extensive task [16].

This study provides valuable knowledge about the expert system with respect to its characteristics, its working mechanism, its components, and its advantages. Furthermore, this study reviews the expert system application in the domain of engineering transportation like flexible pavement, rigid pavement, mix design concrete, pavement evaluation and rehabilitation.

2. Characteristics of Expert System

The source of knowledge in the expert system is the information. The energy of the expert system framework lives in particular, amazing learning it contains about undertaking spaces. In expert systems, knowledge is separated from its processing, for instance, the split of the knowledge base and the inference engine. A conventional program as assembly language or a high-level compiler language (C, Pascal, COBOL, FORTRAN, etc. a mixture of knowledge and the control structure to process this knowledge [5]. However, any change to the code would affect both the knowledge and its processing and would harden the understanding and reviewing the program code. The expert system consists of base knowledge, collected facts, and a set of rules for every circumstance portrayed in the program. Sophisticated expert systems can be enhanced by additions to the knowledge base or to the set of rules. The expert system can be built using a development software known as a ‘tool’ or a ‘shell’. A shell is a complete development environment for building and maintaining knowledge-based applications as shown in Fig. 1. It arranges a well-ordered procedure, and easy to understand the interface such as the graphical interface, for a learning engineer to be speedily instrumental in building and encoding the knowledge [5].

Characteristics of the Expert System are listed below:

- The ES gives an excellent execution that solves perfectly complicated programs in a domain and better than the human experts.
- ES possesses vast quantities of domain-specific knowledge to the minute details.

- The Expert frameworks apply heuristics to manage the arguments whereby lessen the review zone solution.
- A unique feature of an expert system is its explanation capability. It enables the experts to review their own reasoning and explain their decisions.
- Expert systems frameworks utilize representative thinking when considering an issue. Symbols are used to simulate various sorts of learnings, for example, realities, ideas, and guidelines.
- The expert system can advise, modify, update, expand, and deal with uncertain and irrelevant data [17].

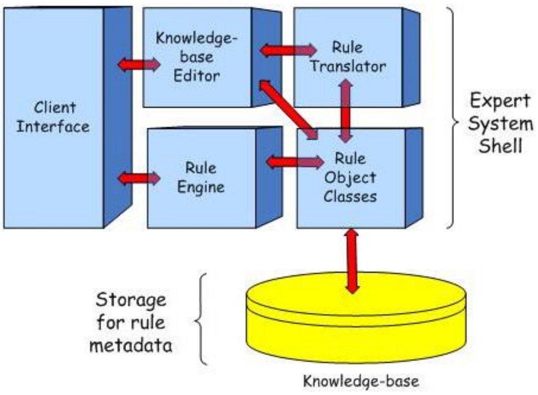

Fig. 1. Architecture of expert system.

3. Numerical Domain

A specialist framework device, or shell, is a product advancement condition containing the fundamental parts of master frameworks. The centre segments of expert systems frameworks are the knowledge base and the thinking engine. A knowledge base is considered as the essence of an expert system; it consists of facts and rules that provides all the knowledge and information about the problem domain [5].

A knowledge base is the storage of the domain-specific knowledge captured from the human expert through knowledge acquisition. The knowledge base of an expert system contains both factual and heuristic knowledge and representing the knowledge in the form of production rules, frames logic etc. Factual knowledge is a widely shared knowledge obtained from textbooks and journals. Heuristic learning is infrequently [17]. These systems aid in solving problems, especially complex ones, by utilizing artificial intelligence concepts. These systems are mostly used in problem-solving procedures and to support human learning, decision making and actions [17].

3.1. Inference engine

An inference engine implements the reasoning process of artificial intelligence; which is an identification of human reasoning [17]. It works with the available data from the system and the user to solve the problem. The purpose of an inference engine is to extract information and from the database for providing the answers, predictions, and suggestions just like a human expert. Backward chaining and forward chaining are the two types of inference engines [17]. In backward chaining, the system firstly found the desired solution and work backwards to find facts that support the solution [17]. Backward chaining is a target-driven; therefore, it is used when the solution is known. In forward chaining, the system first collects data, which is used when the solution is known. Forward chaining is the data-driven; thus, it is used when the absolute solution is absent [18].

3.2. Knowledge acquisition

The knowledge acquisition is responsible for providing the knowledge to the database in an expert system [18]. It operates an editor for entering the knowledge directly into the expert system. Editing of knowledge can be carried out in two ways: either by the knowledge engineer or the expert system itself to generate and modify the file of rules [18]. Knowledge acquisition serves as an interface between the expert system and the experts that provides a means for entering the domain-specific knowledge into the knowledge base. The knowledge acquisition facility aids the process of knowledge elicitation from the expert and codes into the knowledge base. Its overall purpose is to provide an efficient and convenient mean of capturing and storing all the components of the knowledge base [18].

3.3. Explanation facility

The explanation facility provides a particular solution by showing a path to the user in order to reach a certain conclusion [18]. Most expert systems have explanation facilities. It basically how recommendations are derived. The user can know how the expert system arrived at the solution, why some alternatives were rejected, why some information was asked for etc. The explanation facility simply answers these questions by referring to the system goals, data input and the decision rules [19]. For example, in the case of loan proposal evaluation, the expert system's explanation facility will clarify on probing why one application was approved and why another was rejected [19]. In the case of a medical expert system such as Mycin, this facility builds confidence in the user about the expert system and the solution it provides to the problem [19].

3.4. User interface

The user interface manages the dialogue between the user and the system. It provides facilities such as menus, graphical interface, etc. [3]. Thus; it is an intermediary tool that allows communication between the user and the system. The function of the user interface is to ease the usage of an expert system for developers, users, and administrators [18]. The user interface is well presented in a Natural language processing and it is a form of artificial intelligence that helps computers read and respond by simulating the human ability to understand everyday language and, mostly supplemented by menus and graphics.

3.5. Knowledge engineering

Knowledge Engineering is the process constructing the expert system. Human resources as the domain expert, the user knowledge engineer, and the system maintenance, personnel are contributory to developing an expert system. Domain expert has special knowledge, judgment, experience, and methods to give advice and solve problems [18, 19]. Knowledge engineer is involved in the development of the knowledge base, the inference Engine, and the user interface. The expert and knowledge engineer should serve the user's need while designing an expert system [19]. Finally, there are two components of developing an effective and intelligent educational system in any domain are the knowledge base and the inference mechanism engine. Concerning the knowledge base, there are many knowledge representation and management techniques, like lists, trees, semantic networks, frames, scripts, and the production rules as shown in Fig. 2 [19].

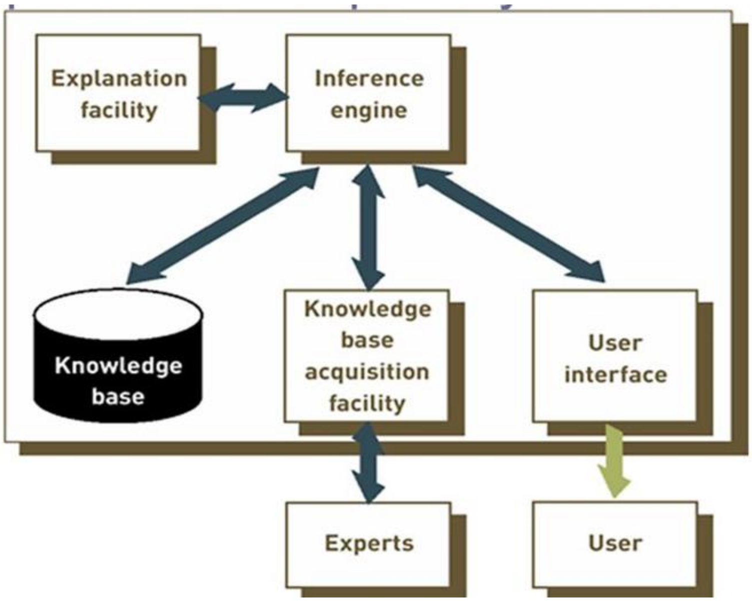

Fig. 2. Components of expert system [19].

4. Advantages of Expert System

In contrast to the traditional forms of software, the expert system has many advantages over human experts. The advantages of the expert system will be listed accordingly [19]:

- Accessibility: The knowledge of numerous human experts can be combined to give a more knowledgeable system as compared to a single person's knowledge. Expert systems are easily accessible for utilizing when human specialists are not promptly accessible. Besides, it can assist the human expert in solving the problem.
- Efficiency: An expert system is capable of reviewing all the transactions compared to a human expert who can only review a sample.
- Time constraints: The time spent on training engineers on an expert system is considerably less than the time spent on training a new human expert.
- Uniformity: Expert systems are less inclined to contain mistakes it has perfect knowledge representation and mistakes can be effortlessly counteracted.

The principle singularity between expert systems and conventional problem-solving programs is the way in which the problem-concerning expertise is coded. In the conventional implementation, problem expertise is encoded in both program and data structures. These systems attempt to solve in a straightforward manner. Moreover, expert systems are eligible for explaining how a special deduction is reached and why demanded information is necessary during a process. They just simplify the problems in a straightforward method and are incapable of expressing the "how, and why" questions. Also, the problem-solving tools those are present in the expert system are purely truant in conventional systems. Thus, different types of problems are ever solved by the experts in an expert system. Hence, the solution to the problem is more accurate than a conventional system Table 1 presents a comparison between the expert system and the conventional system.

Table 1. Comparison of Expert system with the conventional system [20].

Expert system	Conventional system
Knowledge base is clearly separated from the processing (inference) mechanism	Information and its processing are usually combined in one sequential program
Program does not make mistakes	May make a mistake
Explanation is a part of the most expert system	Explanation is part of most ES conventional system
System can be operated with only a few rules (as the first prototype)	System operates only when it's completed
Execution is done by using heuristic and logic	Execution is done on a step by step (algorithmic)
Can operate with incomplete or uncertain information	Need complete information to operate
Effective manipulation of large knowledge bases	Effective manipulation of large database
Representation and use of knowledge	Representation and use of data

5. Components of Expert System

The components of the expert system are described below as:

5.1. Knowledge-based system

Knowledge-Based System (KBS) is the essential element in the AI group. With the availability of advanced computing facilities and other resources, attention is now turning to more demanding tasks, requiring intelligence. The society and industry are appropriate knowledge oriented and rely on various experts' decision-making capacity. KBS can act as an expert on demand without extravagance time, anytime and anywhere. KBS can save money by leveraging expert, allowing users to function at a higher level and promoting consistency. One may consider the KBS as a productive tool, having knowledge of more than one expert for a long period of time [10].

5.2. Rule-based system

Rule-based expert systems can imitate the basic leadership capacity of human specialists. They are designed to solve problems as humans do, by misusing encoded human knowledge or expertise [10]. A rule-based ES is defined as one, which contains information obtained from a human expert, and represents that information in the form of rules, such as IF-THEN. The rule can then be used to perform operations on data to inference in order to reach the appropriate conclusion. These operations are essentially a computer program that provides a methodology for reasoning about information in the rule base or knowledge base, and for formulating conclusions [11].

5.3. Artificial neural networks (ANNs)

An artificial neural network (ANN) is a software tool designed to estimate relationships in data. An expected relationship is basically a function or a mapping that relates raw data to their features [10]. The ubiquity of neural systems depends on their wonderful flexibility and their capacity to deal with both constant and twofold information and create great outcomes in complex spaces. However, when the output is binary, the network works as a classifier, but when the output is continuous; the network can address prediction problems [11].

5.4. Fuzzy expert system

A fuzzy expert system is an ES that uses a mix of fuzzy enrolment capacities and standards, rather than Boolean rationale, to cause about information. The principles in a fuzzy expert system are normally of a shape like the accompanying: If w is low and *n* is high then *p* = medium.

The suit of rules in a fuzzy expert system is known as the rule base or knowledge base. The comprehensive inference process proceeds in three (or four) procedure [21]. Firstly, under fuzzification, the enrolment capacities characterized on the info factors are connected to their real qualities, to decide the level of truth for each govern commence. Secondly, Under Inference, the truth value for the premise of each rule is computed and applied to the conclusion part of each rule. Results in one fuzzy subset to be doled out to each yield variable for each rule. Generally, just a minor product is utilized as inference rules. In inferencing, the yield participation function is clipped off at a stature comparing to the govern premises registered a level of truth, (fuzzy logic).

In product inferencing, the yield participation function is scaled by the manage preface's registered level of truth. Thirdly, under the structure, the majority of the fuzzy subsets allowed for each yield variable are joined all the while to frame a solitary fluffy subset for each yield variable. Again, usually, Max or Sum are used. In max composition, the combined output fuzzy subset is constructed by taking the pointwise maximum over all of the fuzzy subsets assigned to a variable by the inference rule (fuzzy logic) [22, 23]. In Sum arrangement, the joined output fuzzy subset is built by taking the pointwise whole finished the majority of the fuzzy subsets doled out to the yield variable by the deduction inference rule. At last, is the (discretionary) Defuzzification, which is utilized when it is valuable to change over the fuzzy output set to a fresh number [24].

5.5. Case-based reasoning (CBR)

The basic idea of CBR is to adopt solutions that were used to solve previous problems and use them to solve new problems. In CBR, descriptions of the past experience of human specialists, represented as cases, are stored in a database for later retrieval when the user encounters a new case with similar parameters. The system inspection for stored cases with issue characteristics comparable to the new one finds the closest fit and applies the solutions of the old case to the new case. Successful solutions are tagged to the new case and both are stored together with the other cases in the knowledgebase. Ineffective solutions else are appended to the case base along with clarification as to why the solutions did not work [25, 26].

5.6. Modelling

Modelling methodology becomes an interdisciplinary methodology of ES so as to fabricate formal relationships with logical model design in different knowledge/problem domains. In addition, modelling technology can give quantitative techniques to analyse data to speak to or procure expert knowledge with inductive rationale programming or calculations so AI, building science, and other research fields could have more broad stages to complete advances for ES change [26, 27].

6. Application of Expert System in Transportation

Numerous expert systems applications exist in transportation engineering and highway construction as indicated in Table 2. Among ES in transportation engineering, systems were developed for pavement maintenance and rehabilitation, of which specialized in airfield pavements. Systems were also developed for pavement design, and for pavement material selection.

6.1. Expert system in flexible pavement

Inspectors and engineers have made field observations by assessing the conditions on concrete pavements using a rule-based Pavement Expert system. The proposed system has supported the decision making to automate the process of observation and pavement rating [28]. Numerous techniques were used in the computerization of pavement engineering and management [7]. According to Mosa et al. [29], highway engineers faced complicated problems that are influenced by various conditions during the construction of flexible highway pavements. Identifying such problems and recommending effective solutions would require considerable engineering expertise, which is difficult to obtain at all construction sites.

Thus, the development of an expert system can effectively help engineers' control and analyse such problems. In addition, an expert system can effectively archive the storage and distribution of expertise among pavement engineers. It also describes the development and evaluation of such an expert system. The first stage in the development of the proposed system was the elicitation of knowledge from written sources and from experts through literature reviews and interviews, respectively. The acquired knowledge was analysed, classified, and then represented in a form containing rules; these rules were subsequently coded as software. The following section describes the development and evaluation of the Expert System for the Control of Construction Problems in Flexible Highway Pavements.

Milad et al. [30] described the development of a prototype web-based expert knowledge system that could be used to maintain flexible pavement within a tropical region. The prototype system has provided the advantages of using existing web-based expert system technology. Currently, deterioration of asphalt pavement layers was one of the biggest problems in Malaysia and required maintenance to ensure that the roads remained open and able to guarantee the regularity, punctuality, and safety of all transport services. Thus, the acquired knowledge collection and the date concerning to domain expert system of the development web-based system was launched with knowledge representation IF and THEN rules and coded by PHP programming. The web pages that supported the user interface were created using a framework consisting of HTML, CSS, and J-Query. The prototype web-based expert system used the knowledge of a pavement maintenance expert or a specialist in pavement problem remediation to emulate a portion of their professional reasoning abilities that could be used to assist with the maintenance of existing roads and enhance the efficiency and accuracy of the professional engineers tasked with the assessment of all available remedies. Therefore, the system has increased the performance level of the engineers in analysing, discerning and customising the information assisting decision makers throughout the project, so the probability of making the right decision and treatment were implemented at the right time.

Nishikawa et al. [31] used image-analysis computer programs for pavement-distress detection. Bosurgi and D'andrea [32] developed computer programs to evaluate highway geometric-design problems. Ismail et al. [33] performed a literature review and created classifications for developing expert systems in the pavement management field. The review includes no expert system in the field of flexible-pavement construction. The main stages of flexible-pavement construction were as follows: material handling and stockpiling, mixing, hauling, spreading, and compaction. Strict quality control measure must be applied during the construction to obtain high-quality pavement. The use of high-quality materials and well-maintained equipment in combination with good management and competent senior staff yielded excellent results. However, problems may arise during any stage of construction. These problems must be remedied to reduce their effects on the construction work. In addition, the causes of such problems should be determined and precautionary measures should be adopted to prevent their recurrence [34].

Construction of a highway system as a part of the public infrastructure is a significant way for any country to improve its economy [35]. Transportation in developing countries typically depends on a road network rather than on other modalities. Therefore, there was high demand for construction of high-quality, durable, smooth new roads to connect city centres with the new expanding districts and other locations [29]. Pavement can be considered the most critical part of highway construction [36]. However, very few researches on pavements especially rigid pavements were conducted as well as compared to flexible pavements [36]. Thus, the research on this topic is still of a great demand [37].

6.2. Expert system in rigid pavement

Rigid pavement is a concrete slab supported by a roadbed [11, 38]. Imperfections in plastic concrete can reduce pavement strength and durability, which leads to severe deterioration in the pavement surface and structure and subsequently reduces its serviceability. Maintenance the deterioration requires cost, time and efforts as well as obstructing the highway under maintenance and interrupting the traffic. Avoidance of imperfections in plastic concrete prevents several types of failure in the rigid pavement. Therefore, preventive measurements should be adopted during concreting. However, if such imperfections occur, corrective actions should be applied to prevent pavement deterioration. In addition, if concrete imperfections are diagnosed after concreting, the surface and structure of the pavement must be tested and evaluated and corrections should be made to defective parts. The nature of these problems was suitable for representation in a rule-based expert system environment, as they require diagnosing and solving. Nowadays, employing expert systems was a common problem-solving technique in many fields of civil engineering [38]. Through the literature review previously described, a number of expert systems had been developed in the domain of concrete mix design, rigid pavement maintenance and rehabilitation, and other transportation engineering field.

According to Mosa et al. [11], problems face the highway engineers in the domain of rigid highway pavements construction are almost complex and affected by different factors. This is because the process is sophisticated, and involves many activities like concrete placing, spreading, compacting, finishing, texturing, curing, protecting, jointing, testing, and other sub-activities. Diagnosing of these problems and suggestion of suitable solutions requires a significant amount of engineering knowledge, which is almost difficult to be confined at all sites of construction.

Therefore, construction problems in rigid highway pavements represent an excellent domain for development of a system that contained a knowledge base cover description, causes, and solutions of these problems. In another study by Mosa et al. [39] declared that the imperfections of plastic concrete can cause severe deteriorations in rigid pavements surface and structure and reduce its life and serviceability. Diagnosing these imperfections, identifying their causes, and applying effective remedies as early as possible can prevent costly repairs in rigid pavements. However, if these imperfections are not remedied in the correct time, the deteriorations in rigid pavements shall be reminded to avoid worsening the pavement condition. The knowledge is acquired from written sources in the form of textbooks, papers, journals, manuals, electronic files, and any other written references.

According to Mosa et al. [38], the knowledge was documented, analysed, and represented in a form of a dilated flowchart that can be used as a suitable tool to understand the problems and find the solutions. The flowchart was then converted to a computer program by coding the knowledge using VISUAL BASIC programming language. The developed program named KBS-CCPRP represented a knowledge base system to control construction problems in rigid highway pavements. The system was verified and validated in three ways: by extensive testing, a comparison between system performance and expert reasoning, and case study. It was concluded that it could be therefore employed with confidence by end users.

6.3. Concrete mix designer

Concrete mix designer is a rule-based expert system developed to provide knowledge on the testing mix proportion of concrete. It represents information in the form of IF-THEN rules, which are combined together as frames. Every frame represents a component of the concrete, such as the amount of coarse aggregate, and includes an expert system goal [40]. Smith [41] developed a rule- and frame-based expert system called COMIX that offered recommendations on the design of normal weight concrete mixes. It was developed to provide expert knowledge to concrete technologists, design engineers and consultants. In COMIX, the mix design was based on the New Zealand guide to specifications for concrete, the knowledge was represented using frames and production rules. Two case studies were carried out to evaluate the performance of the system. In these case studies, the overall performance of the ESBAC was found to be satisfactory [42]. Malasri and Maldonado [43] developed concrete mix designer, a prototype rule-based expert system. The system has provided the proportions for a trial concrete mix and was useful particularly for practising engineers. However, the main limitation of the system it was developed only for normal weight concrete with a strength ranging from 17 to 35 MPa without using any admixture.

Akhras and Foo [44] developed an expert system named EXMIX, a rule-based, goal-driven knowledge-based system for proportioning normal concrete mixtures. It selected proportions of mixing water, cement, and aggregates while air-entraining admixtures and moisture conditions of aggregates were taken in the consideration. EXMIX was developed in accordance with Canadian Standards Association 1990 (CSA A23.1-M90). Bai and Amirkhanian [45] developed a rule-based expert system called CONCEX, which was to assist the user in the concrete mix design, including making necessary adjustments to the design. The system could handle mix designs for normal, heavyweight and lightweight concrete. Aside from workability, consistency, strength, durability and density, the expert system has also considered other criteria such as admixtures, transportation and air temperature that affected the concrete mix design. The selection of concrete proportions by the system was compared favourably with that of the experts.

Mohd. Zain et al. [46] developed High-Performance Concrete Mix design system using an expert system named as (HPCMIX). It could select the proportions for mixing water, cement, supplementary cementitious materials, superplasticizer and aggregates. It took into consideration, the effects of air content and water contributed by the superplasticizer and the moisture conditions of aggregates. Aside from proportioning concrete mixes, HPCMIX offered recommendations on the adjustment of mix performance. Mohd. Zain et al. [47] developed an expert system for concrete mix design called SRCA. It was similar to HPCMIX and used the same concepts and depended on the same sources of knowledge, like relevant published research and human expertise acquired from Malaysian experts in the domain of concrete technology. However, SRCA was helpful to improve the concrete quality in a sulphate environment by reducing mistakes in selecting concrete components.

6.4. Expert system for pavement evaluation and rehabilitation (EXPEAR)

Expert System for Pavement Evaluation and Rehabilitation (EXPEAR) is a knowledge-based system, which is designed as a tool to assist the highway engineers. Initially, the system was developed for the Federal Highway Administration and the Illinois Department of Transportation provided continued support for the development of the system [33]. The knowledgeable and experienced pavement engineers provided information to the system for the identification of the type and general causes of deterioration existed in the pavement. Three pavement types were considered by the EXPEAR system: Jointed Reinforced Concrete Pavement (JRCP), Jointed Plain Concrete Pavement (JPCP), and Continuously Reinforced Concrete Pavement (CRCP). EXPEAR is an operational system [48]. Road maintenance and rehabilitation of pavement models were developed throughout the world, where an expert system was adapted to sustain the pavement maker of choice. Prediction of future pavement performance of a road network is a crucial step in a pavement management system equipped with a corresponding annual budget. Researchers used soft computing, like fuzzy logic, neural network, and so on in enhancing the pavement management systems [49] and pavement deterioration modelling [49, 50].

Several expert systems were also developed in the domain of transportation engineering. Alshawi and Cabrera [51] developed an expert system called PAVEMENT EXPERT to assist inspectors and engineers in condition assessment and field observation of rigid pavements. The system was established for rigid pavements but could be extended to include flexible pavements. Seiler [52] developed the Airfield Pavement Consultant System (AIRPACS) for rehabilitating airfield rigid pavements. It focused on the functional, structural, operational and safety aspects of HPCMIX the airfield system.

Monarca and Cecchini [53] developed a prototype called ESPRESSO, which stood for an expert system for pavement maintenance and rehabilitation strategies. ESPRESSO was developed using an expert system shell named Level 5 Object, which was tested by knowledge engineers and evaluated by independent experts in the Ohio Department of Transportation. Hanna et al. [54] developed a knowledge-based system called Pavement Management Advisory System (PMAS), which was in new found land, Canada, where the system was used in selecting appropriate maintenance strategies for both flexible and rigid pavements in cold regions. Three types of surface distress were considered in the PMAS system: alligator cracking, transverse cracking and rutting. The system was used several factors such as surface condition, riding comfort index, traffic volume and climate in selecting and recommending rehabilitation strategies.

In the same manner, Tsao et al. [55] developed a rule-based vision system allowed the evaluation of concrete distress in pavements without the need for human interaction. The knowledge base of this system contained facts and rules pertained to prominent features of different types of distress. The reasoning procedure was performed by gathering information on the input image and then deciding on the most effective sequence of image processing operations. Kaetzel and Clifton [56] developed HWYCON to assist highway department personnel involved in diagnostics, material selection, repair and rehabilitation activities to make better decisions on concrete structures including pavements. The concrete materials component of the knowledge base in HWYCON gave recommendations on selecting materials for the design of durable concrete in corrosive, sulphate, freeze-thaw and alkali-aggregate reactive environments.

Dhitivara [57] developed a hybrid knowledge base expert system for designing asphalt concrete mixture containing waste materials and by-products (EXDAW). It was useful in designing asphalt concrete mixtures contained reclaimed asphalt pavement, a reclaimed aggregate material, crumb rubber modifier, mineral filler and conventional asphalt concrete mixture. EXDAW was developed based on the Marshall Hot Mix Asphalt (HMA) mixture design concept. Wanyan et al. [40] developed the Expert System For Pavement Remediation Strategies (ExSPRS) to assist road engineers in the domain of pavements on expansive clays with a high plasticity index (PI). ExSPRS allowed engineers to evaluate and improve road design allowing more rehabilitation miles with the same amount of funding and fewer future distress problems. Mansyur [58] developed an expert advisory system for the selection of implementation strategies for transportation management demand (E-ASSIST). The process of organizing available knowledge on transportation management demand strategies as well as the process led to the selection of one or more recommended strategies was encoded in the knowledge base expert system shell developed using Kappa-PC version 2.4, which adopted an object-oriented and high-resolution graphical user interface. The strategies recommended by E-ASSIST were evaluated and validated by comparing the system output against the recommendations made by transportation professionals. The evaluations indicate favourable results for the system.

6.5. Various practices of expert system in engineering transportation

Highway geometric design was a part of the planning process design for the physical highway to fill up a basic function of roads, to give good traffic service from one place to another. The important base of highway geometric design was the selection of a minimum cost route, which involved careful planning, design, right-of-way acquisition and construction. The characteristic of traffic flow, size of a vehicle, driver, sight distance, superelevation and topography were the variables of highway geometric design after finding the economy route and safety.

It was not easy to select an economical route by manual design because a good proposed route should involve the complex design process such as the detailed assessment of geographic features, potential land use for road construction and environmental evaluation. Therefore, Geographic Information System (GIS) was a potential solution for acquiring detailed information for the design process. Syamsunur et al. [10] proposed a model of computerized highway design based on GIS in order to greatly assist in evaluating several alignment alternatives. It was found that the model can reduce the cost and the project timing, and give reliable decisions in highway design features.

Pavement deflection data were often used to evaluate a pavement’s structural condition non-destructively. Pavement layers were characterized by their elastic moduli estimated from surface deflections through back-calculation. Using back calculation analysis, flexible pavement layer in situ material properties could be back-calculated from the measured field data through appropriate analysis techniques. Saltan et al. [36] focused on the use of Data Mining (DM)-based pavement back calculation tools for determining the in situ elastic moduli and Poisson’s ratio of asphalt pavement from synthetically derived Falling Weight Deflectometer (FWD) deflections at seven equidistant points. In the estimation of the elastic modulus and Poisson’s ratio, Data Mining (DM) method was used as a back-calculation tool before. Experimental deflection data groups from NDT were used to show the capability of the DM approaches in the back-calculation of the pavement layer thickness and compared each other. Results showed that K star method gives fine results with respect to other DM methods. It was highlighted that the back-calculation of pavement layer elastic modulus and Poisson’s ratio with DM were carried out for the first time.

Wanyan et al. [40] developed an expert system to assist pavement engineers in designing more realistic and practical low-volume roads in clayey areas. This expert system combined numerical and engineering analyses with heuristic information about the site to recommend optimal design, remediation, and construction alternatives. Common distress types were considered, in particular, numerical analysis is incorporated to predict the potential for longitudinal cracking of the section, which was reported in a survey throughout Texas to be the most prevailing distress. After assessment of the structural capacity, remediation methods were proposed to address the problem of the premature failure of low-volume roads on clays with a high plasticity index. Cost-benefit analyses were added to compare the cost-effectiveness of recommended alternative strategies. A preliminary study of typical low-volume roads built over expansive subsoils in Texas indicated that thicker and stronger pavement layers did not guarantee better performance. Instead, addressing the environmental factors related to changes in subgrade properties played a bigger role in serviceability and performance

Tan et al. [59] conducted a study to elicit knowledge of ventilation management to provide a baseline for evaluating the performance of an expert system for neonatal ventilation (FLORENCE). The modified Delphi method and focus group techniques were used to arrive at consensus management strategies on 40 hypothetical ventilation scenarios. The underlying cognitive processes of the experts were also explored further to assist in the development of the expert system. The strategies arrived were used to provide a performance level which FLORENCE was tested. The solutions were judged to be equivalent between FLORENCE and neonatologists in 29 of the 40 cases. In the remaining 11 scenarios; FLORENCE also provided adequate solutions. The focus group technique was more effective than a modified Delphi method in achieving consensus on ventilation management. This consensus on ventilation was used as the baseline to evaluate the performance of an expert system.

Ahmadi and Ebadi [60] prepared spatial data for Geographic Information System (GIS) simultaneously during feature digitizing process from photogrammetric models reduced data editing phases after feature digitizing process. Therefore, the problems, caused by separating spatial data production process from preparation of this data were overcome as far as possible. To achieve this purpose, speciality and expertise required for spatial data structuring and preparation for GIS should be available in an interface system which established a direct connection between photogrammetric and GIS systems. When a user digitized a feature from a photogrammetric model, the decision-making process about the method of editing, structuring, layering, and storing of the feature in GIS database, could be carried out by such an interface system. Thus, according to the capabilities of expert systems for modelling the knowledge and deduction methods of experts, generating an expert interface system between photogrammetric and GIS systems, offered a suitable solution for this integration. The capabilities of expert systems for intelligent spatial data structuring and preparation simultaneously during feature digitizing process from photogrammetric models, were also investigated.

According to Pribyl [61], electronic payment for using road infrastructure was an area that was gaining importance in the realm of intelligent transportation systems (ITS). While preparing such an electronic fee collection system, the level of enforcement needed must be determined. This was not a trivial task, because it was affected by many technical and monetary factors. At the same time, it could not be expected that all decision makers were deeply involved in this field and were able to make an optimal decision depending on the recommendations of external experts. In order to decrease the possibility of manipulating the decision process by lobbyists and to save the money used for external consultants a described a Fuzzy

Expert System for Determining the Optimal Level of Enforcement (FESOLE) was needed. Pribyl [61] focused mainly on the major technical features of this model. A fuzzy expert system was used to approach the problem. It could extract and exploit the knowledge of human experts and convert it to a robust computational model. Suitability of this methodology for a given task was also demonstrated. Spundak et al. [62] attempted to provide an overview of the architecture and basic characteristics of the Rule-Based Systems (RBS), focusing on both their weaknesses and strengths. The RBS was recognized as probably the best solution for knowledge-based expert systems. Based on theory, a rule-based expert system for webshop error detection was proposed. The RBS built on the available application knowledge base and focused on the problem of detecting the possible error in the shortest possible time frame. The formalization of the whole process had a potential to significantly reduce the time required to detect the possible error.

Miller et al**.** [63] presented Asphalt Open, a visualization tool for Hot Mix Asphalt (HMA) paving operations and a data collection process to collect the input data for the Asphalt Open from HMA paving operations. Asphalt Open visualized the collected site-specific GIS data and GPS path tracing data of equipment's' motions together with the HMA's temperature behaviour. In this way, Asphalt Open allowed HMA paving professionals to understand and learn about the relation of machine operations and HMA temperature and its impact on the HMA compaction. To ensure the practical usability, Asphalt Open and the data collection process by conducting action research with HMA paving operators was developed. Overall, Asphalt Open has offered an easy-to-use tool for HMA paving companies to visualize previous asphalting operations. In this way, it opened up new ways for HMA paving contractors to improve and professionalize their paving operations.

Falamarzi et al. [64] developed a web-based advisory expert system for the purpose of applying traffic calming strategies on residential streets. Developing an expert system could assist and advise engineers for dealing with traffic safety problems. The expert system was developed to fill in the gap between traffic safety experts and people who sleeked to employ traffic calming strategies including decision-makers, engineers, and students. In order to build the expert system, examining sources related to traffic calming studies as well as interviewing with domain experts were carried out. The system included above 150 rules and 200 images for different types of measures. The system had three main functions including classifying traffic calming measures, prioritizing traffic calming strategies, and presenting solutions for different traffic safety problems. Verifying, validating processes, and comparing the system with similar works had shown that the system was consistent and acceptable for practical uses.

Salleh et al. [65] developed an expert system designed to train the young professional to implement mobility management strategies so as to shift from passive to active transport choice which was cycling and walking. One of the processes involved in knowledge acquisition of active transport strategies was to capture the views of transportation experts regarding the most appropriate strategies with regards to the shift from motorised transport to active transport. There were eight main transportation planning objectives to be achieved in organising an active transport system, such as congestion reduction, road and parking cost reduction, consumer cost reduction, crash risk reduction, air and noise pollution reduction, energy conservation, economic development benefits and liveable communities. Furthermore, apart from the main objectives, specific objectives on mobility management strategies were divided into four major categories according to how they affected travelling, including improvements in transport option, land use management, price incentive and other implementation programs. Based on these, an expert system shell was developed to achieve the purposes highlighted above by using Visual Basic.NET as a tool and MySQL as a supporting tool. The expert system would finally provide advice on the best strategy to be implemented based on the selection of the main objectives and the specific objectives by the user.

Abdelsalam et al. [66] considered the sustained and pervasive popularity of the private vehicle not only in Malaysia National University (UKM) but in most of the Malaysian Universities, what make people prefer to use a Bicycle rather than car or public transport? What will facilitate the use of bicycle paths to the promotion of more sustainable behaviour and the achievement of green transportation targets?

A web-based advisory expert system for the purpose of applying the geometric design of bicycle paths on residential streets was proposed. It was because of their currently a weakness in the educational outcomes and structured framework for the implementation of such strategies. Developing an expert system could assist and advise engineers for dealing with geometric design problems. The expert system was developed in this study to fill in the gap between sustainable urban design experts and people who seek to employ geometric design of bicycle paths including decision-makers, engineers, and students.

The system had more than six main functions including classifying, bicycle paths width, separation from a roadway, horizontal alignment, sight distance, and grades design. Verifying, validating processes, and comparing the system with similar works had shown that the system was consistent and acceptable for practical uses. In order to build the expert system, examining sources related to bicycle sharing path studies as well as interviewing with domain experts were carried out. The system included rules and images for different types of measures. Table 2 shows a summary of the recent expert systems developed in the domain of engineering transportation as illustrated above.

Table 2. Summary of expert systems developed in the domain of engineering transportation.

Reference	Name	Expert system
Wanyan et al. [40]	ES-DLVRO	Expert system for design of low-volume roads over expansive soils.
Tan et al. [59]	KEVNVES	Knowledge elicitation for validation of a neonatal ventilation expert system utilising modified Delphi and focus group techniques.
Ahmadi and Ebadi [60]	DIEISIP-GIS	Design and implementation of an expert interface system for integration of photogrammetric and geographic information systems for intelligent Preparation and structuring of spatial data.
Pribyl [61]	FFEXDOLE	FESOLE-fuzzy expert system for determining the optimal level of enforcement.
Spundak et al. [62]	WSUEDBRE	Webshop user error detection based on rule-based expert system.
Mansyur [58]	E-ASSIST	Development of an expert advisory system for strategy implementation in transport demand management (E-ASSIST).

Syamsunur et al. [10]	ES-HG-Design	Knowledge-based expert system for route selection of road alignment.
Chou and Tseng [35]	EXPBPODW	Establishing expert system for prediction based on the project-oriented data warehouse.
Choi [67]	QEIAMCPE	Quantifying the effects of interference for an alternative method of construction productivity estimation.
Saltan et al. [36]	BPLMPRDM	Backcalculation of pavement layer moduli and Poisson's ratio using data mining.
Miller et al. [63]	MVHMACPO	Measuring and visualizing hot mix asphalt concrete paving operations.
Mosa et al. [11]	CCPRHP	Classification of construction problems in rigid highway pavements.
Mosa et al. [12]	BSCPRHP	A knowledge base system to control construction Problems in Rigid Highway Pavements.
Castellanos et al. [68]	FAESOPP	Failure analysis expert system for onshore pipelines. Part-I: Structured database and knowledge acquisition.
Zain et al. [46]	EX-MDBAC	An expert system for mix design of brick aggregate concrete.
Ooshaksaraie et al. [22]	EX-SMPCSM	An expert system applied in stormwater management plan for construction sites in Malaysia.
Mosa et al. [29]	ESCCPFP	Expert system to control construction problems in flexible pavements.
Mosa et al. [38].	DEXOCPRHP	A diagnostic expert system to overcome construction problems in rigid highway pavement.
Mosa et al. [69]	EKBSCESC	An educational knowledge-based system for civil engineering students in cement concrete construction problems.
Mosa et al. [11]	ES-CCPRP	Classification of construction problems in rigid highway pavements.
Falamarzi et al. [64]	DWBAEXITCS	Developing a web-based advisory expert system for implementing traffic calming strategies.
Mosa et al. [39]	EXRCITERP	An expert system to remedy concrete imperfections and their effects on rigid pavements.
Salleh et al. [65]	ESMMSIAT	Expert system on selection of mobility management strategies towards implementing active transport.
Milad et al. [30]	WBEXFPM	A review of web based expert systems for flexible pavement maintenance.
Milad et al [70]	PWBFPM	Prototype web-based expert system for flexible pavement maintenance.
Falamarzi et al. [71]	ES -PTCP	Development of a fuzzy expert system to prioritize traffic calming projects.
Abdelsalam et al. [66]	DWBAGT	Developing a web-based advisor expert system for green transportation system.

6. Conclusions

The paper has reviewed the amplification and possibilities of the expert system in engineering transportation. It is found that the expert systems are able to provide some important benefits over conservative computerized models. Expert systems can solve issues expeditiously as they involve wide-range of expert knowledge and human intellectual that are too complex to be represented and implemented analytically. Reviews on appropriate publication have demonstrated that expert system was widely used in transportation engineering applications like pavements for highways, transportation management demand ,control construction problems in flexible pavements ,a diagnostic expert system to construction problems in rigid highway pavement, expert system for implementing traffic calming strategies using an approach that integrates human expert knowledge and explanatory strategies with a user-friendly personal computer program. However, there has been a gap total expert system in engineering transportation. This is due to the lack of agreement reached amongst experts and the inadequate number of procedures and tools, which concern with the knowledge domain. Consequently, an exploration on the conceivable application in engineering transportation expert system and an effective decision-making technique is very much required.

Abbreviations

AIRPACS	Airfield Pavement Consultant System
ANN	Artificial neural network
CBR	Case-Based Reasoning
COMIX	Concrete Mix Designer
CRCP	Continuously Reinforced Concrete Pavement
DM	Data Mining
ES	Expert System
EXMIX	Expert Mix
EXPEAR	Expert System for Pavement Evaluation and Rehabilitation
ExSPRS	Expert System for Pavement Remediation Strategies
FESOLE	Fuzzy Expert System for Determining the Optimal Level of Enforcement
FWD	Falling Weight Deflectometer
GIS	Geographic Information System
HMA	Hot Mix Asphalt
HPCMIX	High-Performance Concrete Mix
HWYCON	Highway Concrete
ITS	Intelligent Transportation System
JRCP	Jointed Reinforced Concrete Pavement
KBS	Knowledge-Based System
PMAS	Pavement Management Advisory System
RBS	Rule-Based System
RC-MSS	Road Construction Material Selection System

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