Reviewing the Artificial Intelligence-Based Applications in Operational Research

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The purpose of this paper is to present a comprehensive literature review on artificial intelligence-based applications in operational research. The findings indicate that operational researchers within the field of artificial intelligence exhibit significant interest in the development of expert system applications. The identified expert systems are employed across a diverse range of functional areas and problem domains within organizations. Notably, the area of production and operations management stands out as the most widely adopted domain for expert system-based applications. Moreover, most of the applications are designed to tackle semi- or unstructured problems and aid in operational-level decision making. Furthermore, the majority of the applications primarily support individual decision making rather than providing support for groups or organizations.

The literature review strategy employed in this research is referred to as a 'domain-specific comprehensive literature review' (Szendrey, 2016). This approach involved conducting a thorough examination of the operational research literature by exhaustively reviewing all papers published in top-tier journals, including the Journal of the Operational Research Society, The European Journal of Operational Research, Management Science, Omega – The International Journal of Management Science, and Interfaces. The analysis of the literature revealed several emergent themes, which clustered around four primary research areas, i.e. the relationship between operational research and artificial intelligence, artificial intelligence modeling, methodological issues regarding artificial intelligence, and artificial intelligence-based applications. The first three areas of the research are explored in a separate paper (Szendrey, 2017). The focus

of this paper is to review the artificial intelligence-based applications. The emergent themes clustered around five functional areas, i.e. production and operations management, logistics and distribution, sales and finance, engineering, and advisory services. Additionally, the paper includes the presentation of five comprehensive bibliographies on literature pertaining to expert systems-based applications.

Production and Operations Management Applications

The most extensive part of the related business literature focuses on expert system[1] (ES) applications within the production and operations management problem domain (Eom et al., 1993). These applications have been specifically developed to address various problems, including production planning (Duchessi and O'Keefe, 1990), production planning and scheduling (Lawrynowicz, 2008), production planning and controlling (Rodger and Edwards, 1989), production scheduling (Kerr and Ebsary, 1988), production scheduling and controlling (Pierreval and Ralambondrainy, 1990), scheduling repair job (Grant, 1986), and controlling stock levels (Thorpe et al., 1989). More generally, the paper by Kusiak and Chen (1988) provides a comprehensive overview of ES applications for production planning and scheduling problems.

Duchessi and O'Keefe (1990) propose an ES approach to address production planning problems. Their approach involves establishing production rates, workforce levels, on-hand inventories, and overtime for product families. These production plans are required to take into consideration long-term marketing and production requirements, as well as financial and policy constraints. The authors emphasize that production planning problems are conventionally solved in operational research (OR) using optimization techniques and heuristic approaches. However, they argue that these techniques are not as widely utilized by management as one might expect. They identify several reasons that could contribute to the limited adoption of quantitative techniques, including: (a) managers' inadequate knowledge of these techniques, (b) discrepancies between managers' and developers' perspectives of the problem, (c) credibility concerns,

[1] Expert systems are a specific set of tools, methods and problem solving strategies in the field of artificial intelligence.

(d) high costs associated with developing and utilizing such models, (e) excessive data requirements, and (f) changing decision variable values across time periods. Consequently, many companies opt to forgo achieving optimal results and instead rely on experience-based approaches for developing their production plans. In such cases, production planners apply a simple trial-and-error technique to select feasible combinations of decision variable values for each period, representing the resulting plans in a simplified tabular or graphical format. They sacrifice optimal results for a technique whose mechanics are sufficiently simple to understand, easy to use, and capable of producing feasible solutions. Duchessi and O'Keefe suggest the development of an ES model for production planning that incorporates the important knowledge of an expert production planner. This way, the ES can perform at the level of a human production planner who employs the trial–and–error technique. Furthermore, it is capable of analyzing a significantly larger number of plans compared to its human counterpart.

While, Lawrynowicz (2008) demonstrates how a combination of an ES and a heuristic search algorithm, specifically a genetic algorithm, can support production planning and scheduling problems. The decision regarding a scheduling method requires careful consideration, as it involves choosing between a method that provides an optimal solution, which takes a long time to calculate, and a suboptimal solution that can be calculated quickly. Moreover, in an uncertain environment, there is a need for rapid re-planning and re-scheduling. Lawrynowicz suggests the development of an intelligent system capable of quickly responding to changes and executing re-planning and re-scheduling. The proposed approach consists of two phases. In the first phase, a combination of a traditional approach and a genetic algorithm is used to generate the preliminary schedule for the medium time horizon, which may be suboptimal. The second phase focuses on determining the flexible manufacturing system and is divided into two steps. Firstly, an ES is employed to create a detailed production plan based on customer orders and manufacturing system constraints. Through an interactive dialogue, the human expert can influence this production plan. In the second step, a genetic algorithm is utilized to construct a detailed schedule that adheres to the constraints of the detailed production plan. The described intelligent system offers advantages by providing not only short-term production planning and scheduling to meet dynamic market

requirements that can better utilize the available capacity of the manufacturing system but also support for control.

Finally, Thorpe et al. (1989) developed an ES to analyze stock records and identify anomalies in the data or parameters associated with individual items in an automated stock control system. During the learning phase, multiple runs of the simulation were generated with various known anomalies, resulting in patterns of behavior consistent with specific anomalies. These patterns were then supplied to the learning module of the ES to generate a system of production rules. Subsequently, the ES could be used to detect and classify any present anomalies based on their symptoms. To evaluate the ES's performance, it was applied to identify errors in a simulated stock control system with a predefined set of possible errors.

Logistics and Distribution Applications

Logistics and distribution applications have been developed to address various problems, such as vehicle scheduling (Waters, 1990), vehicle routing (Potvin et al., 1990), vehicle queuing (Flitman and Hurrion, 1987), empty railcar distribution (Beurrier et al., 1990), transport terminal design (Abacoumkin and Ballis, 2004), and navigation in hazardous close waters (Grabowski and Wallace, 1993).

Waters (1990) outlines the characteristics of a general ES for the vehicle scheduling problem. Conventionally, vehicle scheduling problems are solved in OR using computerized algorithms. These applications were expected to offer several benefits, such as a 10-15% reduction in total travel distance, reduced scheduling time, improved result representation, analysis of operating statistics, and communication with other systems. However, Waters noticed that despite these significant potential benefits, most companies are reluctant to adopt computerized vehicle scheduling due to the algorithms' inability to address the actual problems encountered by the vehicle schedulers. Real-life scheduling problems involve complexities and subjective elements that existing algorithms fail to capture. There is also uncertainty and mistrust regarding the solutions generated by these algorithms. In contrast, expert schedulers can handle the complexity and consider subjective constraints when developing manual schedules. They do so by utilizing a combination of skills, intuition, experience, and applying common sense and subjective

reasoning. One way to leverage the abilities of experienced schedulers is to develop interactive applications. Such a system should automatically generate initial routes using algorithms, which are then reviewed and modified by schedulers to obtain final results. Initially, there was a concern that human intervention would disrupt the scheduling process, leading to longer processing times and lower solution quality. However, it was soon recognized that, on the contrary, human intervention could actually improve solution quality and even transform an unacceptable solution into a viable one. Therefore, Waters proposes incorporating the knowledge of expert schedulers into an ES, taking advantage of their expertise.

While, Flitman and Hurrion (1987) present an ES designed to control a simulation model of train and lorry queuing in a coal-yard. During the learning phase, multiple runs of the simulation were generated, each resulting in different control strategies. These strategies were then supplied to the learning module of the ES to generate a system of production rules. Subsequently, the ES could be used to control the simulation model. The ES can be further validated through simulation. Flitman and Hurrion acknowledge that, in their study, combining the controlling knowledge from different individuals into an ES resulted in a better performance compared to what the best individual could achieve alone.

Furthermore, Beurrier et al. (1990) introduce a prototype knowledge-based decision support system developed for the distribution of empty railcars. They indicate that the distribution of empty railcars, based on supply and demand, can be considered a resource allocation problem. Typically, allocation problems are solved in OR using continuous and integer linear programming. However, in this complex scenario, the expert distributors were the ones who actually solved the problem, as they were able to incorporate a much greater level of strategic knowledge into the decision-making process compared to linear programming. To address this, Beurrier and his colleagues propose a knowledge-based decision support system containing several components: an ES module for determining priorities, an ES module for evaluating usefulness, an allocation algorithm, a forecasting module, and an interface to the central database. The purpose of this knowledge-based decision support system is to replicate the reasoning processes employed by the expert distributors.

Finally, Abacoumkin and Ballis (2004) developed an ES-based modeling tool for the comparative evaluation of conventional and innovative rail-road terminal designs. The project was based on the premise that, in line with the promotion of environmentally friendly transport modes, the transport industry has introduced several innovative terminal handling equipment pieces. On one hand, these systems are more expensive than existing solutions and may have significant indirect effects in case of failure. As a result, the combined transport market has been resistant to investing in innovative systems. On the other hand, manufacturers argue that the additional costs and risks associated with such equipment are offset by their superior productivity. To support the decision-making process, Abacoumkin and Ballis propose utilizing an ES supported by a simulation module and a cost calculation module. The main purpose of the ES is to assist in the development of technically sound transport terminal designs based on user-defined parameters and equipment selection. This includes determining the required terminal area and equipment, as well as calculating the equipment service cycle. The function of the simulation module is to verify and optimize the designs proposed by the ES. It transforms the equipment service cycle into train service time, truck service time, and dwell time, which are then compared against predetermined service quality criteria. Lastly, the cost calculation module calculates the costs associated with the accepted terminal designs. The integrated system provides output that includes the draft terminal layout, terminal area, equipment and personnel requirements, and the calculated cost.

Sales and Finance Applications

Sales and finance applications have been developed to address various problems, such as measuring customer performance (Vasko et al., 1990), assisting bankers in analyzing company accounts to extend loans (O'Keefe et al., 1986), and detecting suspected fraudulent usage of credit cards (Leonard, 1995). In a broader context, Nedović and Devedžić (2002) review several operational ES in finance and provide insights into the approaches and techniques employed. These applications are focused on various financial problems, including financial analysis of firms, portfolio management in banks, investment management, financial marketing, and currency exchange advising in international business transactions.

Vasko et al. (1990) discuss the development of a multi-attribute-based ES for measuring customer performance. The company recognized the need for a more consistent and objective approach to evaluating customers and their orders, as well as determining the key attributes that best describe customers and their orders. The framework developed for marketing and sales decisions ensured consistency, flexibility, and ease-of-use in performing customer/order evaluations. While, Leonard (1995) presents an ES designed to alert banks and other financial institutions about suspected fraudulent usage of consumer credit, particularly with credit cards, identified during the authorization process.

Engineering Applications

Engineering applications have been developed to address various problems, such as evaluating machining operation plans (G. Zhang and Lu, 1990), supporting engineering system design and simulation (Rozenblit et al., 1990), improving the design of large-scale computer communications network topologies (Pierre and Hoang, 1990), and assisting in the ore blending problem for blast furnaces in iron and steel enterprises (R. Zhang et al., 2011). More generally, Nurminen et al. (2003) analyze eight ES applications from the engineering field that were developed at the Nokia Research Center and have been successfully used in industrial settings for over ten years.

G. Zhang and Lu (1990) introduce an ES framework that integrates manufacturing and management systems to evaluate machining operation plans. The system aims to ensure the satisfaction of required specifications and the economic utilization of labor, material, and working capacity. While, Pierre and Hoang (1990) describe how the AI approach can improve the design of large-scale computer communications network topologies, emphasizing the importance of a high level of reliability. The model consists of three components: (a) the initial topology generator, which creates a good starting topology based on user-specified data, (b) the example generator, which applies the rule base to the starting topology, generating positive and negative examples, and ultimately proposes the best feasible solution at the end of the cycle, and (c) the inductive learning module, which stores the generated examples to improve the rule base.

Advisory Services

Some expert systems have been developed to provide support for **advisory services**, including a fingerprint development advisor for the police (Barton, 1987) and a university admission advisor (Edwards and Bader, 1988; Finlay and King, 1989).

Barton (1987) introduces a fingerprint development advisor ES. The purpose of this system is to provide support to police forces in challenging situations by offering advice. One advantage of the system is its ability to contain the same information as a paper manual, without any limitations on the amount of information that can be presented. Additionally, it is easy to update the system as new procedures are developed.

While, Edwards and Bader (1988) discuss the construction of an ES designed to assist in the annual task of selecting suitable candidates for admission to degree courses. The business and management degree program under consideration receives approximately 2,000 application forms for entry each year, resulting in a competitive ratio of 15 applications for a single available place. These applications are received by the university over a period of three months, and the selection criteria used by admission tutors may not always be clear to applicants and their advisors. The ES can support this decision-making process in three ways: (a) improving the consistency of decisions, (b) enabling the delegation of certain aspects of the admissions work from the admissions tutor to the clerical staff, and (c) making the selection criteria more explicit, thereby facilitating the training of admission tutors.

Similarly, Finlay and King (1989) present the development of an expert system (ES) called the Selection Advisor ES, which is designed for admitting experienced professionals into a part-time MBA course. The development process consists of three phases:

1. Rapid prototyping – The aim of the initial phase is to develop a simple prototype in an unstructured manner, which is useful for improving the understanding of the characteristics of the problem and the ES shell.
2. System analysis – This more structured phase focuses on creating a comprehensive and structured system. It involves refining the prototype and incorporating additional features and functionalities.

3. Incorporation of mathematical models – In this phase, a mathematical model is integrated into the ES to capture the decision makers' judgment. This enhances the decision-making process by providing a quantitative basis for evaluating candidates.

Bibliographies of the Literature on Expert Systems-based Applications

Some researchers have compiled comprehensive bibliographies of the literature on expert systems-based application (Eom et al., 1993; Wong and Monaco, 1995a, 1995b; Durkin, 1996; Liao, 2005).

Eom et al. (1993) conducted a review of the business literature and gathered 197 papers on ES applications for the period from 1975 to 1989. These papers were classified into eight business application areas: (a) accounting and auditing, (b) finance, (c) human resource management, (d) management information systems, (e) marketing, transportation, and logistics, (f) planning, (g) production and operations management, and (h) strategic management. The classification revealed that ES are employed across a diverse range of functional areas within organizations. The researchers also identified the top 21 journals that have published ES application papers in the field of business. The *International Journal of Production Research* was found to have published the largest number of papers in this domain, followed by two journals published by the Institute of Electrical and Electronics Engineers, i.e. *IEEE Computer* and *IEEE Expert* published.

Similarly, Wong and Monaco (1995a) conducted a review of the business literature and collected 214 papers on ES applications for the period from 1984 to 1992. These papers were classified based on the same seven business application areas as Eom et al. (1993), with the exclusion of the planning area. Their classification also revealed that ES are employed across a diverse range of functional areas within organizations. Wong and Monaco identified that the most popular ES-based application areas are production and operations management, finance, and management information systems. They also provided a summary of the characteristics of the identified ES applications, including the name of the ES, the development tool, the stage of development, and the computer operating environment. Furthermore, they identified the top nine journals that have published ES application papers in business areas. The *Computer and Industrial*

Engineering journal has published the largest number of ES application papers, followed by *Computers and Industry*, and *Expert Systems: International Journal of Knowledge Engineering*.

Furthermore, Wong and Monaco (1995b) conducted another review of the business literature covering a different time period, from 1977 to 1993, and identified 380 ES application papers. They made a comprehensive classification of the literature based on several factors:

- Year of publication
- Business application area, i.e. accounting and auditing, finance, human resources, information systems, marketing and distribution, production and operations, and strategic management
  The majority of the applications are found in the areas of production and operations, finance, and information systems.
- Addressed generic problem area, i.e. planning, monitoring, design, interpretation, prediction, diagnosis, control, debugging, repair, and/or instruction
  Expert systems are predominantly developed for planning problems.
- Problem domain, i.e. structured or semi/unstructured
  The majority of the applications are designed for semi/unstructured problems.
- Level of management, i.e. operational, tactical, or strategic
  The majority of the ES applications are developed for operational and tactical level decisions.
- Level of task interdependence, i.e. personal support, group support, or organizational support
  The majority of the ES applications involve personal decision making.
- Means of development, i.e. programming languages or ES tools/shells
- Corporate/academic interaction during the ES development, i.e. independent effort or corporate and academic joint venture
  The vast majority of the applications are the result of independent research efforts by either academics or practitioners.

- Integration of ES with other technologies

  Only a small number of the identified ES are integrated with other technologies, such as decision-support technologies.

Durkin (1996) identified 2,500 developed ES in an extensive review of journals, conference proceedings and books. He complemented this research by gathering reports from software vendors regarding the systems developed using their software. While he acknowledges that his survey, despite being extensive, is by no means comprehensive, he believes that the uncovered ES represents approximately 20% of all the systems, bringing the total number to 12,500 expert systems. Based on the analysis of the identified ES, Durkin drew the following conclusions:

- Types of applications, i.e. control, design, diagnosis, instruction, interpretation, monitoring, planning, prediction, prescription, selection, and simulation

  ES are predominantly developed for diagnosis problems because diagnosis is a typical role for experts to play, and inferring system malfunction from observables is a relatively easy problem. Diagnosis problems typically involve interpretation (inferring a situation description from data) and prescription (recommending solutions to system malfunctions).

- Application areas, e.g. agriculture, business, chemistry, communication, education, engineering, manufacturing, medicine, and transportation

  The predominant application areas of ES are business, manufacturing, and medicine because the majority of problems in these areas encompass a diagnostic component.

- Platform (e.g. PC, workstation, and mainframe) and software choices (e.g. shell, LISP, and PROLOG)

  The majority of ES are developed on a PC with the aid of a shell because it has provided an opportunity for individuals from a wider range of disciplines to develop ES.

- Rate of application

  The number of developed ES increased from 10-20 in 1980 to almost 500 in 1992, which is considered a rapid growth by historical measures.

- Commercial/scientific ES trends

  The ratio of developed commercial ES to developed scientific ES increased from 1 in 1980 to 7 in 1992. This is an additional measure to judge the value of ES.

Finally, Liao (2005) collected 166 papers on the development of ES methodologies and applications for the period from 1995 to 2004. He organized the papers into the following 11 categories: (a) rule-based systems, (b) knowledge-based systems, (c) neural networks, (d) fuzzy ESs, (e) object-oriented methodology, (f) case-based reasoning, (g) modeling, (h) system architecture, (i) intelligent agent systems, (j) ontology, and (k) database methodology.

IN CONCLUSION, the findings of the domain-specific comprehensive literature review indicate that operational researchers within the field of artificial intelligence exhibit significant interest in the development of expert system applications. The identified expert systems are employed across a diverse range of functional areas and problem domains within organizations. Notably, the area of production and operations management stands out as the most widely adopted domain for expert system-based applications. Moreover, most of the applications are designed to tackle semi- or unstructured problems and aid in operational-level decision making. Furthermore, the majority of the applications primarily support individual decision making rather than providing support for groups or organizations. Although artificial intelligence-based applications have proven to be a valuable and relevant field within operational research, in recent years, the level of interest among operational researchers in artificial intelligence has steeply declined.

Summary of the Literature: Artificial Intelligence Related Research Areas

Reference	Abstract	Research area	Application	Support/model
Abacoumkin and Ballis, 2004	The context of this paper concerns the structure of an expert system based modelling tool that was developed and used within the framework of a recent European research project. The objective of the expert system is to produce alternative ‘‘technically sound’’ terminal designs, based on a number of user-defined parameters (cargo volume, loading unit mixture, layout characteristics, operating conditions, etc.) and equipment selections (conventional or innovative transhipment systems, rail access systems, identification, location and positioning devices, semi-automatic control, information systems, etc.). Each of the above ‘‘technological bricks’’ is identified by its ‘‘compatibility’’, ‘‘performance’’ and ‘‘cost’’ attributes. The ‘‘compatibility’’ and ‘‘performance’’ attributes–through an interactive interface–enable the development of technically sound terminal designs while the ‘‘performance’’ attributes are also used for the calculation of the equipment service cycle. A simulation module converts the equipment service cycle into train service time, as well as into truck service and dwell times, which are then compared to specific quality of service criteria. The cost of the non rejected designs is calculated (using the ‘‘cost’’ attributes of all involved elements) and together with the draft terminal layout, the area equipment and personnel requirements, form part of the expert system output.	ES modelling (integration of ES and OR techniques)	comparative evaluation of conventional and innovative rail-road terminal designs	ES + simulation module + cost calculation module
Angelides and Doukidis, 1990	Intelligent tutoring systems (ITS) have recently found a wide range of potential applications across a multitude of disciplines and subject areas. This paper investigates the suitability and feasibility of developing ITS in the general context of OR as well as in a specific OR activity, simulation. It also examines how a current teaching aid for simulation model debugging can be transformed into an ITS and proposes a specification for the transformation process. The paper concludes that ITS could be useful in OR either for use as prime training systems or integrated in existing OR teaching packages. However, the field of ITS is in its infancy and development efforts are likely to be labour-intensive.	OR and ES (ES supporting OR education)		intelligent tutoring systems
Antunes et al., 1992	This paper presents a computer implementation of a multiple objective linear programming procedure base which is integrated with Expert System techniques in order to provide decision aiding to decision makers. In the context of an energy planning case study it is discussed how the integration of the procedural component with Expert System techniques can improve the decision maker's perception of the problem and guide the interactive search process, by using different levels of knowledge. The aim is to aid the decision maker in processing the information having in mind not just explore the problem but also his/her preference structure in order to obtain satisfactory solutions.	ES modelling (integration of ES and OR techniques)	planning of new units for electrical power generation	ES + MOLP

Reference	Abstract	Research area	Application	Support/model
Balestra and Tsoukiàs, 1990	This paper presents a possible representation of multicriteria analysis by means of artificial intelligence techniques. The decision process activities characterized by the existence of formal and technical knowledge were identified and attention was focused on the area of multicriteria outranking methods. The knowledge characteristics suggested the use of artificial intelligence techniques, based on a conceptualization in which the domain of discourse is the set of the multicriteria methodology concepts used in the analysed area of activities, and the relational set is the union of the admissible relations among the concepts and the relations elicited from experience. The suitable AI techniques were tested by implementing a knowledge-based interface between the outranking methods and a user who was not very familiar with this approach.	methodology (carrying out meta-analysis with ES)		
Barton, 1987	This paper describes some work carried out in the Scientific Research and Development Branch (SRDB) of the Home Office, intended to contribute to an overall aim of building up internal expertise in the field of expert systems. This was done by carrying out a number of pilot and demonstrator projects, two of which are described in some detail. The plan, which proved successful, was to build as far as possible on the relevant skills already possessed by an OR group in the branch. The lessons learned from these are summarized in the hope that they will be of use to other groups who wish to become involved in this important area.	application	fingerprint development advisor for police	
Beurrier et al., 1990	The assignment of empty railcars by the SNCF (French Railways) distributors according to supply and demand from the regions could be considered as a conventional resource allocation problem. As such, it would be suitable for processing by integer programming. However, as the problem is currently solved by the reasoning process of the distributors, it involves much more strategic knowledge than linear programming. Based on this observation, we developed an allocation system centred on an expert system designed to reproduce the reasoning processes of the distributors. This paper describes the system, and the reasons why the ES approach seems more adapted to the problem than the OR pure solution.	ES modelling (replacing traditional OR techniques)	distribution of empty railcars for the French Railways	ES allocation system (DSS)

Reference	Abstract	Research area	Application	Support/model
Doukidis, 1987	Simulation and artificial intelligence (Al) can be related in the following ways: the methodological similarities, the actual and potential uses of Al concepts in simulation, expert systems in simulation environments, and the gains for Al when applying ideas from simulation. This paper highlights the personal experiences of the author by discussing, for each of the four above-mentioned areas, a topic or a computer system in which he is directly involved. To highlight the similarities, it will be shown that the three-phase simulation model can be considered as a production-system model. A natural-language understanding system that was used in the definition stage of a simulation project will provide the basis for discussing Al concepts in simulation environments. An expert system used in the development and verification stages will provide an insight into the application of expert systems in simulation modelling. An expert-system development tool which is partially based on simulation techniques will be used to outline the gains for Al.	ES modelling (linking AI and simulation)		
Doukidis, 1988	This paper reports on a survey carried out on 67 ES to investigate whether they employ DSS concepts. The author examines several DSS frameworks and proposes a questionnaire model to conduct the survey. The survey data are analysed and the paper concludes that the three fundamental DSS issues: semi-structured task, support, and effectiveness are explicitly applied in ES. It shows also that although both DSS and ES have similar aims, they accomplish them in completely different ways. The differences are in the boundary of problem space and the way to tackle problems.	decision making		literature review (DSS)
Doukidis and Paul, 1985	The widespread availability of inexpensive computing power and recent developments in machine intelligence now makes it possible to consider computer assistance in the formulation phase of a discrete-event simulation model. The goal is to speed up this process. With this in mind, a series of prototype expert systems (written in LISP and run on an APPLE II) have been produced. The first prototype system was built using the 'MYCIN' approach. In the second prototype system a more informal approach was used, and the resulting computer-aided system is a natural-language understanding system. This paper outlines the need for such research and discusses the system development by describing the two main models and explaining why the natural-language approach was adopted.	ES modelling (linking ES and simulation)		ES assisting the formulation stage of a simulation project

Reference	Abstract	Research area	Application	Support/model
Duchessi and O'Keefe, 1990	This paper discusses a knowledge-based approach to production planning, the process of establishing production rates, work force levels and on-hand inventories for product families as a possible alternative to traditional operational research methods. It describes one company's experienced-based approach to production planning and how this was incorporated into a knowledge-based system. The production planning state-space, use of common planning constraints and heuristic procedures, and a prototype of a knowledge-based system that develops production plans for one product family are also described.	ES modelling (replacing traditional OR techniques)	production planning	knowledge-based system
Durkin, 1996	Reports of the decline of expert systems are greatly exaggerated. Survey results indicate impressive growth, as researchers develop systems to tackle difficult but commercially rewarding problems.		application	literature review
Edwards (1992)	Historically, the fields of Decision Support Systems and Expert Systems grew up from different backgrounds; Management Information Systems and Artificial Intelligence, respectively. As a result, many people still regard them as unrelated fields, although Operational Researchers are working in both of them. Expert Systems in particular have found it difficult to escape from an image of being isolated; not just from Decision Support Systems, but from all other types of computer system. Successful applications appeared to be confined to very well-defined tasks; either small systems for tasks of an operational nature, or large systems requiring expensive specialised computer support. The spread of Expert Systems into management and administrative applications from the scientific/technical domains of the early systems has been very slow. The view put forward in this paper is that for Expert Systems to be applied to problems in management or administration, the traditional 'closed-world' picture of an Expert System is usually inadequate. The real manifestation of the Expert System's role (and indeed that of the human expert) involves much more negotiation and interaction than in scientific/technical domains. The consequences for the resulting system are that it looks much more like the traditional picture of a Decision Support System than a classic standalone Expert System. The argument will be illustrated by reference to examples of 'Expert System' developments, including systems for production control, crime pattern analysis, telephone marketing, and the drawing up of contracts.	decision making		

Reference	Abstract	Research area	Application	Support/model
Edwards and Bader, 1988	This paper describes the construction of an expert system to help the admissions tutor for a university degree in business and management which receives some 2000 applications for entry each year, using the SAGE shell. What originally began as a 'demonstrator project' is shown to be of practical value, in terms of both producing a usable expert system and clarifying and questioning the selection criteria used by the admissions tutor. A particular conclusion emerging from this work which may be relevant to many expert systems applications is that ethical and practical considerations dictated that some questions involving judgement could not be delegated by the admissions tutor to the clerical staff. It thus became necessary to develop two versions of the expert system, one a full 'admissions-tutor system', the other a more limited version for day-to-day use.		selecting suitable candidates for admission to university courses	
Edwards et al., 2000	This paper begins by analysing decision making activities and information requirements at three organizational levels and the characteristics of expert systems (ESs) intended for the two different roles of supporting and replacing a decision maker. It goes on to review the evidence from many years of commercial use of ESs at different levels and in different roles, and to analyse the evidence obtained from a pilot experiment involving developing ESs to fulfil two different roles in the same domain. The research finds that ESs in a replacement role prove to be effective for operational and tactical decisions, but have limitations at the strategic level. ESs in a support role, as advisory systems, can help to make better decisions, but their effectiveness can only be fulfilled through their users. In the experiments, an expert advisory system did not save a user’s time, contrary to the expectations of many of its users, but an ES in a replacement role did improve the efficiency of decision making. In addition, the knowledge bases of the ESs in the different roles need to be different. Finally, the practical implications of the experience gained from developing and testing two types of ESs are discussed.	decision making		

Reference	Abstract	Research area	Application	Support/model
Eom et al., 1993	This paper provides a comprehensive bibliography of the application of expert systems (ES) in business areas from 1975 through 1989. Initial compilation of ES application was based on the references of major ES and other related textbooks. From 1984 to 1989 the most important source of information has been the Compact Disc-Read Only Memory (CD-ROM) version of ABI/INFORM database by University Microfilm International (UMI)/Data courier. One hundred and ninety-seven application articles are classified according to eight functional areas of business. This survey also identifies the top 21 journals that have published ES application articles as well as annual counts of those articles over the last 15 years.		application	literature review
P. N. Finlay et al., 1988	Recent research has demonstrated that little validation is carried out during and after the building of operational research models for decision support. In a subject are that has been of great interest for more than a decade, this reflects the fact that validation is not yet firmly embedded into the methodology of mathematical modelling that underpins conventional decision support systems. With the interest now being shown in expert systems, it is important to devise an appropriate methodology of validation for such systems. This paper contributes to this development by describing the types of validation that should be performed with decision support systems, and compares and contrasts the feature found in the validation of mathematical models with those required of validation of expert systems.	methodology (validation of ES)		
P. N. Finlay and King, 1989	An expert system to assist in admitting students onto a part-time postgraduate course has been developed through three phases, using an expert systems shell. The first phase was an unstructured approach, which demonstrated the feasibility of the system but led to difficulties in development. The second phase followed a simplified systems analysis and resulted in a more comprehensive and structured system. However, its operation was cumbersome and unfriendly. The third phase involved developing a mathematical model of the decision-maker's judgement and led to a simpler, more effective and easier to use system.		MBA admission	
P. N. Finlay et al., 1989	One recommended approach to the building of expert systems is to start with a very simple system and to expand the level of detail as the system evolves. With this approach there is the practical problem of organizing the rules as the system develops. This paper describes the use of a folding editor for easing this administrative overhead.	methodology (improving rule alteration)		ES (folding editor)

Reference	Abstract	Research area	Application	Support/model
Flitman and Hurrion, 1987	This paper describes experiments designed to test the feasibility of linking discrete-event simulation models with expert systems. Two microcomputer systems are used: one contains the simulation model, while the other contains the expert system. The paper shows that by linking a simulation model with an expert system, it is possible to use the combination for simulation parameter learning, expert system development and expert system control of a simulation model.	ES modelling (linking ES and simulation)	vehicle queuing	ES for controlling simulation
Fordyce et al., 1987	In recent years, interest in artificial intelligence (AI), especially expert systems (ES), has been explosive. We try to bring you news of the latest directions in AI/ES, examples of innovative work, comments on what worked well and what didn't, information on new software and hardware products, and highlights relating progress in AI/ES to the state of the art in modelling and decision support. Our purpose is to help answer for AI/ES questions facing the MS/OR professional today: (1) What are artificial intelligence and expert systems? (2) What in AI/ES is of value? (3) How are AI and MS related? (4) How might the "AI/ES wave" affect MS/OR?	OR and ES (including ES into the OR toolkit)		
Grabowski and Wallace, 1993	Increased maritime traffic, new types of vessels, and construction of oil and gas producing structures have made navigating in close waters more hazardous. In addition, attempts to increase shipboard productivity have results in fewer personnel on board the vessel. This paper reports on the development and evaluation of a prototype expert system to support the cognitive processes involved in piloting: manoeuvring and collision avoidance, and the practice of good seamanship. A model was constructed and implemented in a frame- and rule-based representation. The system was assessed using gaming with novice pilots in a merchant marine training facility. The results showed significant improvement in the bridge watch team performance, but no significant improvement in vessel performance in terms of track keeping. The paper concludes with a discussion of the motor. perceptual, and cognitive skills needed for piloting and how they could be supported by expert system technology as part of an integrated bridge system, an operational center for navigational and supervisory tasks aboard a ship.		navigating in hazardous close waters	

Reference	Abstract	Research area	Application	Support/model
Grant, 1986	This paper compares operational research (O.R.) with the currently fashionable topic of artificial intelligence (A.I.) at a detailed level. A.I. concepts, techniques and history are summarized, and O.R. and A.I. approaches compared. A case study-the development of a potential aid to scheduling repair jobs on RAF squadrons-is described. The paper shows where A.I. concepts and techniques were used in the prototype program, known as the Fault Identification & Expediting Repair (FIXER) system. Finally, some lessons for O.R. are drawn.	OR and AI (what can they learn from each other + replacing traditional OR techniques)	scheduling repair jobs on RAF squadrons	FIXER
Hendry, 1987	The fantastic claims made by Artificial Intelligence Experts could lead us to think that computers will inevitably have a great impact on disciplines such as OR, even to the extent of displacing them. However, we should question whether there is any evidence to support these claims. This paper considers the present capabilities of computers and looks at the impact that the AI community has had on the practice of OR. It also examines the potential success of current research and lists some of the obstacles to development. The evidence suggests that although AI will provide significant support to the work of OR researchers, the impact of AI on the OR community will not be as great as the claims suggest.	OR and ES (impact of ES on OR)		
Kastner and Hong, 1984	Expert systems have recently become popular and are attracting more and more attention. The high quality performance achieved by some systems in areas previously not considered practical for computational solutions has lead to great interest from many different disciplines. Most expert systems use a subset of techniques from the general area of computer science research known as artificial intelligence. However, some expert systems have been developed that incorporate more traditional mathematical modelling techniques. The combination of artificial intelligence techniques and more traditional mathematical techniques has been shown to be quite effective in developing several high quality performance computer software systems. The techniques used in expert systems may be what is needed to bridge the gap between classical operational research modelling and human decision making processes. This paper addresses how expert systems techniques are being used in problem solving and why someone in operational research might want to use them.	OR and ES (including ES into the OR toolkit)		

Reference	Abstract	Research area	Application	Support/model
Kerr and Ebsary, 1988	This paper describes the experimental implementation of a rule based Expert System for production scheduling in a small manufacturing company. An attempt was made to capture the local knowledge and informal heuristics used by the experienced human production scheduler and to reduce these to a set of rules which would operate on a relational database representing current shop floor status and projected future loading; the objective was for the system to produce schedules similar to those of the human. Some background information is given on the scheduling environment in the company concerned, followed by a general description of the Expert System itself. Some experiences and lessons learned from the experimental implementation are then discussed.		production scheduling	rule-based ES
M. King and Phythian, 1992	An expert system was developed as a support tool for a large electro-mechanical engineering company. The system was developed to assist in tender enquiry evaluation and the bid versus no bid decision. It was developed using repertory grid techniques based on the expertise of two senior managers. The importance of the system's validation is stressed and an appropriate formal validation framework developed. The results from the validation study suggest that the system provides an appropriate model of the organisation's consensual business perspective regarding the bid versus no bid decision. Furthermore, the study drew attention to some dissenting views amongst the organisation's senior management which the management believed to be helpful in clarifying their understanding of the issues affecting the bid versus no bid decision.	methodology (validation of ES)	tender enquiry evaluation	
Kusiak and Chen, 1988	In this paper, research and applications of expert systems in production planning and scheduling are reviewed. Components of expert systems are briefly discussed. Relationship between expert system and operations research approaches are presented. Integration of operations research and expert system techniques is explored.		production planning and scheduling	literature review

Reference	Abstract	Research area	Application	Support/model
Lawrynowicz, 2008	In the traditional approaches, processes of planning and scheduling are done sequentially, where the process plan is determined before the actual scheduling is performed. This simple approach ignores the relationship between the scheduling and planning. Practical scheduling systems need to be able to react to significant real-time events within an acceptable response time and revise schedules appropriately. Therefore, the author proposes a new methodology with artificial intelligence to support production planning and scheduling in supply net. In this approach, the production planning problem is first solved, and then the scheduling problem is considered with the constraint of the solution. The approach is implemented as a combination of expert system and genetic algorithm. The research indicates that the new system yields better results in real-life supply net than using a traditional method. The results of experiments provide that the proposed genetic algorithm produces schedules with makespan that is average 21% better than the methods based on dispatching rules.	ES modelling (replacing traditional OR techniques)	integration of production planning and scheduling	ES + heuristic search algorithm (genetic algorithm)
Lee and O'Keefe, 1994	Research and practice has produced numerous methods for expert system verification and validation (V&V) that augment traditional software and systems approaches to V&V. These methods, however, are not associated with software development methodologies, as has been the case with conventional V&V, and there is evidence that this is a considerable stumbling block in expert system V&V. This paper shows how to develop a strategy for expert system V&V. A strategy for V&V has three components: 1) the criteria by which an expert system will be judged as valid, 2) a life cycle model that specifies what V&V can be done when, and 3) the constraints (and opportunities) imposed by the characteristics of the system being developed. Starting with a development methodology, we shown how to map V&V methods onto the software life cycle and then match V&V methods to system characteristics. We give an example of our approach to developing a V&V strategy in the context of an expert system development project.	methodology (validation of ES)		
Leonard, 1995	In this paper, we present a rule-based expert system to help alert banks and other financial institutions to fraudulent usage of consumer credit, particularly with credit cards. The objective of this model is to identify suspected fraud during the authorization process. The paper first addresses the model building process, then describes prototype development, and finally, presents results from analysis of real data from a Canadian bank.		warning of suspected fraudulent usage of credit cards	ES

Liao, 2005	This paper surveys expert systems (ES) development using a literature review and classification of articles from 1995 to 2004 with a keyword index and article abstract in order to explore how ES methodologies and applications have developed during this period. Based on the scope of 166 articles from 78 academic journals (retrieved from five online database) of ES applications, this paper surveys and classifies ES methodologies using the following eleven categories: rule-based systems, knowledge-based systems, neural networks, fuzzy ESs, object-oriented methodology, case-based reasoning, system architecture, intelligent agent systems, database methodology, modelling, and ontology together with their applications for different research and problem domains. Discussion is presented, indicating the followings future development directions for ES methodologies and applications: (1) ES methodologies are tending to develop towards expertise orientation and ES applications development is a problem-oriented domain. (2) It is suggested that different social science methodologies, such as psychology, cognitive science, and human behavior could implement ES as another kind of methodology. (3) The ability to continually change and obtain new understanding is the driving power of ES methodologies, and should be the ES application of future works.		application	literature review
Ligęza, 1988	An approach to building decision support systems based on expert systems methods is proposed. The relatively weak basic assumptions include only stationarity (repeatability) of the decision in the same environment (circumstances) and ordering of the values of all the attributes with regard to the decision maker's preferences. The proposed approach is aimed at reflecting the experienced domain expert's and decision maker's knowledge and preferences, both in the form of facts and reasoning rules. Among the purposes of the described class of decision support systems there are the storage and retrieval of the expert's knowledge and decisions, decision making support and ranking of admissible decision alternatives. A general model of the decision process is proposed and a language for representation of the expert's knowledge is introduced in brief. The structure, reasoning control, and an example of application of the proposed system are discussed and possible further extensions are pointed out.	decision making		DSS

Reference	Abstract	Research area	Application	Support/model
Mingers, 1986	There is currently much interest in the development in expert systems. Knowledge acquisition - developing the knowledge base from an expert - is one of the most time-consuming aspects of the process. Work is under way on methods of automating this procedure, one of which is rule induction from a set of examples. This paper introduces rule induction and evaluates some of the practical difficulties.	methodology (rule induction)		
Mingers, 1987	Rule induction has been proposed as a way of speeding up the acquisition of knowledge for expert systems. Quinlan's ID3 algorithm has been used successfully but can only deal with determinate data. This paper explores extensions to deal with statistical data.	methodology (rule induction)		
Neale, 1990	The benefits of a qualitative modelling approach to building knowledge-based systems include better project control, communication between participants, more accurate validation and easier maintenance. Knowledge acquisition from experts will be more successful if a conceptual model is developed from a knowledge level description, to act as a publicly examinable basis for system design. Analytical tools are available to structure both content and process knowledge on paper, before any commitment is made to implementation. The role of abstraction in developing models of generic tasks as a set of templates for conceptual model development is reviewed, with particular regard to knowledge acquisition tools. Modelling problem-solving methods, especially for constructive tasks such as planning, is more difficult than modelling content knowledge. Epistemological support for conceptual abstraction, particularly at middle levels, remains inadequate.	methodology (improving knowledge acquisition)		

Reference	Abstract	Research area	Application	Support/model
Nedović and Devedžić, 2002	This paper surveys a number of well-known expert systems in the domain of finance. The idea is to illustrate the span of typical expert systems in finance and to provide an insight into the approaches and techniques they employ. The systems considered in the paper are all working systems, and come from different fields of finance. Specifically, the systems considered are FINEVA (from the field of financial analysis), PORT_MAN (banking management), INVEX (investment advisory) and FAME (financial marketing). The paper also briefly presents DEVEX, an expert system for currency exchange advising in international business transactions. Financial institutions in less-developed and undeveloped countries that deal with currency exchange often face some specific problems that do not exist in well-developed regions of the world- DENVEX helps bank employees to cope with such problems. Since business transactions between developed countries and Third World ones represent an important part of the world's financial affairs, the problem covered in DENVEX go beyond local financial institutions.		application	survey of some financial ES systems
Norman and Naveed, 1990	Using an observational study of the operation of a cement kiln and a set of operational rules published by Peray and Waddell, five knowledge-based advisory systems have been developed encapsulating the supervisory expertise of the process operators. The advisory systems were developed in the logic language PROLOG. Each expert adviser was applied to a set of plant data previously logged from the kiln, and the advice offered was compared with the actions taken by the operators. statistical tests have been applied to the outcome of the comparisons in order to determine which expert advisor emulated the operator performance most successfully. The results demonstrate the value of such tests in quantitatively validating expert systems. In addition, the supervisory technique that the operators were using in practice were identified.	methodology (validation of ES)	cement kiln operation	statistical tests

Reference	Abstract	Research area	Application	Support/model
Nurminen et al., 2003	This case study analyzes eight expert system applications that have successfully been in industrial use for a long time. We have personally been involved in the development of these applications and are thus in a good position to analyze what is important for a successful application and what kind of mistakes can be made. Since the development of the applications started in 1986–1990 and some of them are still in use we are able to observe what has happened to those applications during their lifetime. Our key observations are related to the scope of the applications, to the trade-off between usability and automation, to the role of human experts in the use and development of expert systems, on the technical solutions used, on aspects of the operation of the expert system and on the similarities between expert systems and information systems. The key findings are expressed as 20 hypotheses for successful expert systems. The support of each application to the hypotheses is discussed.		application	evaluation of several engineering applications
O'Keefe, 1985	The aim of much operational research and expert system work is similar - helping a decision maker do his job. Liaison will produce mutual benefits. Expert systems development will benefit from the experience of operational research. The operational research community is well placed to support and develop the use of such systems by management.	OR and ES (what are the mutual benefits)		
O'Keefe et al., 1986	Increased awareness of expert systems technology, and the availability of relevant software, has tempted many O.R. groups to investigate the expert systems approach. This paper considers the strategies open to O.R. groups interested in employing expert systems, reviews some of the relevant software, and discusses what those O.R. groups who have already investigated the use of expert systems methods are actually doing. Some of the authors' experience of developing expert systems is discussed. The development of an expert system that helps bankers analyse company accounts is presented. The use of expert system methods as vehicles for decision analysis, and the possibilities for producing systems that act as O.R. consultants are also discussed.	OR and ES (the experience of using ES)	helping bankers analyse company accounts	

Reference	Abstract	Research area	Application	Support/model
O'Keefe and O'Leary, 1993	Assuring the quality of an expert system is critical. A poor quality system may make costly errors resulting in considerable damage to the user or owner of the system, such as financial loss or human suffering. Hence verification and validation, methods and techniques aimed at ensuring quality, are fundamentally important. This paper surveys the issues, methods and techniques for verifying and validating expert systems. Approaches to defining the quality of a system are discussed, drawing upon work in both computing and the model building disciplines, which leads to definitions of verification and validation and the associated concepts of credibility, assessment and evaluation. An approach to verification based upon the detection of anomalies is presented, and related to the concepts of consistency, completeness, correctness and redundancy. Automated tools for expert system verification are reviewed. Considerable attention is then given to the issues in structuring the validation process, particularly the establishment of the criteria by which the system is judged, the need to maintain objectivity, and the concept of reliability. This is followed by a review of validation methods for validating both the components of a system and the system as a whole, and includes examples of some useful statistical methods. Management of the verification and validation process is then considered, and it is seen that the location of methods for verification and validation in the development life-cycle is of prime importance.	methodology (validation of ES)		
O'Keefe and Preece, 1996	It is now ten years since Operational Research, and other groups that support management decision making, seized upon Knowledge-based Systems (KBS) as an alternative set of techniques and methods for building systems that support, augment or automate decision making. Success, as with most information technologies, has been mixed. This paper briefly reviews where KBS have been successful, and what benefits have been derived. It notes that interest in KBS has been rekindled by the present interest in business process re-engineering. Given the mature state of development tools, most KBS developers are now focusing on methodological and life-cycle issues. The paper reviews progress in understanding and using development methodologies, validation methods (now generally considered as crucial to technical success) and implementation. Some ideas about where KBS 'fits in' to the array of tools, techniques and methodologies available to the modem analyst and system developer are presented.	methodology (development, validation, implementation)		

Reference	Abstract	Research area	Application	Support/model
O'Keefe and Roach, 1987	Recent years have seen a number of attempts to apply both Al methods and Al software tools to the development of both simulations and simulation packages. This paper discusses the motivation behind such work: the increasing need for Al researchers to include simulation in Al systems and use simulation in research, and the need to model intelligent behaviour in OR simulation models. The current research and development effort is reviewed. A system called PROSS (the PROlog Simulation System), constructed to allow the integration of Al methods with traditional discrete simulation, is then briefly presented. It is concluded that Al software tools, and some of the novel approaches to simulation being taken by Al researchers, will have a considerable impact on simulation.	ES modelling (integrating AI with simulation)		PROlog Simulation System
O'Leary, 2007	This paper proposes a set of definitions for the concepts “validation” and “assessment” applied to expert systems (ESs). It develops a framework for this validation and demonstrates the framework on existing accounting and auditing ESs to elicit some of the research issues involved in ES validation. Validation is critical to the design and implementation of decision-making ESs. In a setting where objectivity is sought and variance is avoided, validation ascertains what a system knows, knows incorrectly, or does not know. Validation ascertains the system’s level of expertise and investigates the theoretical basis on which the system is based. It evaluates the reliability of decisions made by the system. The validation framework developed in this paper is research methods. It is designed to reflect the unique aspects of ESs (in contrast to other types of computer programs) and can be used by ES developers as a basis from which to perform validation and by researchers as a framework to elicit research issues in validation.	methodology (validation of ES)	auditing and accounting	
Paul and Doukidis, 1986	Research into computer systems to aid simulation model formulation has led to the construction of a natural language understanding system (N.L.U.S.). A description and short history of N.L.U.S.s leads into a discussion of the syntactic and semantic problems which have to be met. A classification scheme for N.L.U.S.s is proposed, and the simulation problem formulator described in this context. The N.L.U.S. simulation model formulator takes as input a sentence in English which conforms to a prescribed set of sentence structures. These restricted sentence structures resolve syntactic and semantic problems. The way in which the system accepts these sentences and organizes data structures based on them is outlined, along with the supporting error-handling mechanisms and editing facilities. A simulation model example is used to illustrate the flavour of the system by reference to complete interactive session listings.	ES modelling (linking ES with simulation)		ES assisting the formulation stage of a simulation project

Reference	Abstract	Research area	Application	Support/model
Phelps, 1986	A brief outline of A.I. is provided, noting problems, techniques and objectives which are similar to those found in O.R. It is intended that this will indicate to O.R. workers which A.I. areas might be worth following up as relevant to their own work and which problems in A.I. might be attacked by the O.R. community as part of the development of intelligent support systems.	OR and AI (similarities)		
Phythian and King, 1992	Assessing customers' tender enquiries to decide whether to bid or not is important for companies where the cost of tendering is high. In the case considered the expertise of two managers involved in assessing enquiries was developed into an expert support system. Knowledge was elicited from these managers by asking them to consider previous tenders and specify the factors used in discriminating between them. Their responses were represented in repertory grids. Analyses of these grids led to maps which showed the hierarchical nature of the relationships between the key factors used by the managers. The maps were confirmed by the managers and then rules were developed using statistical techniques on the data in the grids. The resulting expert support system improved the consistency of the enquiry review group, revealed unexpected aspects of the managers reasoning and was generally welcomed by the company.	methodology (improving knowledge acquisition)	tender enquiry evaluation	expert support system (repertory grid)
Pierre and Hoang, 1990	This paper presents an artificial intelligence approach to solving the network design problem. The major issue under consideration is the various topological aspects of a design, especially in the case of large computer networks. The combinatorial explosion can only be dealt with, hopefully, by means of heuristics, which drastically reduce the search space of candidate topologies. The proposed approach is essentially a general framework for integrating conventional approximate methods and knowledge-based systems. An inference engine is then a means suited to extending the realm of local transformations used in conventional heuristics. Sophisticated goal-directed searches can be achieved by using knowledge bases, which are large sets of detailed design rules.		designing large-scale computer communications network topologies	ES framework

Reference	Abstract	Research area	Application	Support/model
Pierreval and Ralambondrainy, 1990	One of the most important difficulties when developing knowledge based systems in manufacturing scheduling or control, is finding the required knowledge. We address here the problem of acquiring knowledge about the behavior of manufacturing systems. Learning algorithms are proposed to generate, from simulation experiments, a set of production rules. This set may be considered as a simulation meta-model, and may be used either directly by the shop manager, or inserted into a knowledge base. This approach is illustrated by the use of the learning program GENREG. It generates rules related to the behavior of a simplified flow shop when different dispatching rules are applied.	ES modelling (linking ES with simulation)	manufacturing scheduling and controlling	GENREG (generating rules through simulation)
Potvin et al., 1990	This paper shows how tools and techniques of artificial intelligence can be successfully integrated into a computer system working in the vehicle routing domain. The aim of this system, called ALTO, is to facilitate the development of routing algorithms for transportation vehicles. In this paper, we describe the general algorithmic framework and the rich interface provided by the system to the expert algorithm designer. We also introduce a methodology for acquiring useful knowledge in the domain, based on examples of successful and unsuccessful problem-solving strategies. With such knowledge, ALTO would then be capable of actively supporting the algorithm designer by suggesting good candidate algorithms for solving new problems.	ES modelling (integration of AI and OR techniques)	vehicle routing	computer-aided algorithmic design
Robinson et al., 2005	The performance of most operations systems is significantly affected by the interaction of human decision-makers. A methodology, based on the use of visual interactive simulation (VIS) and artificial intelligence (AI), is described that aims to identify and improve human decision-making in operations systems. The methodology, known as 'knowledge-based improvement' (KBI), elicits knowledge from a decision-maker via a VIS and then uses AI methods to represent decision-making. By linking the VIS and AI representation, it is possible to predict the performance of the operations system under different decision-making strategies and to search for improved strategies. The KBI methodology is applied to the decision-making surrounding unplanned maintenance operations at a Ford Motor Company engine assembly plant.	ES modelling (linking AI and simulation)	unplanned maintenance operations at a Ford Motor Company engine assembly plant	AI + VIS (improving knowledge acquisition)

Reference	Abstract	Research area	Application	Support/model
Rodger and Edwards (1989)	Expert system technology can fairly be described as high profile at present. Yet its track record as a useful method for tackling problems is subject to widely differing views. This paper considers the domain of production planning and control, which has been described as a good application area for expert systems a domain where OR has had little success. The authors argue that mainstream expert system methodology is exploratory rather that problem-driven and thus is not suited to the domain. A problem-driven approach to expert system development is presented, an approach which makes use of soft systems methodology. The reasons for such an approach within production planning and control are discussed, ant the use of soft system methodology within the approach is reflected on.	methodology (problem-driven approach)	production planning and controlling	
Rozenblit et al., 1990	Research developments leading to implementation of an intelligent software environment supporting system design and simulation are presented. Knowledge-based system design and multifaceted simulation methodologies are a foundation for the system realization. The paper describes the major theoretical concepts and processes employed to develop and simulate design models. The environment implementing these concepts and methods consists of two basic components: one serves as a front end supporting the model construction processes; the other is an object-oriented, discrete-event simulator supporting evaluation of hierarchical, multi-component models. Current state of the system implementation and future work are discussed.		supporting engineering system design and simulation	KBDSE
Seagle and Duchessi, 1995	This paper describes a computer-assisted approach to help knowledge engineers elicit rules from a domain expert. The approach uses the decision table as a knowledge engineering tool, and incorporates a decision table analyzer that displays rule conditions which can be used to query the expert. The decision table analyzer also reports redundant rules and provides assistance for developing rules that use as few variables as possible. This has the benefit of limiting the number of questions to be asked of the expert. The approach is especially suited for heuristic classification problems where evaluative judgments are based on many combinations of values of the same facts.	methodology (improving knowledge acquisition)		

Reference	Abstract	Research area	Application	Support/model
Thorpe et al., 1989	The theory of the control of stock is well understood, and a large number of firms use automatic stock control and ordering techniques as a major part of their inventory control systems. However, the effectiveness of such automatic stock control systems depends on the correct selection of system parameters for each item in the inventory and on the accurate reporting of information. It is not unusual for errors to be made in both the selection of parameters and the entry of data, and regular failures of either can cause severe problems in stock control. It is generally difficult for a human stock controller to discover errors quickly because of the large number of items that is usually found in a company inventory. This paper describes the use of an expert system to examine stock records and diagnose anomalies in the data provided or parameters applied to individual items in a stock control system. The expert system 'reasons' from symptoms such as reports from the forecasting system or high stock levels, to defects in the stock model used or data-collection processes, and from there to possible remedial action. Results are presented for runs of the expert system on a simulated stock control system.	ES modelling (linking AI and simulation) application	controlling stock levels	running the ES on a simulated stock control system
Vasko et al., 1990	Sales and marketing people routinely evaluate and rank their customers to develop a marketing strategy and plan of action for utilizing available sales resources. Performing this evaluation informally makes it difficult to take into account all the significant customer attributes in a consistent and objective manner. In this paper an approach based on multiple attributes is developed to assist in evaluating customer performance. This approach is coded primarily in an expert system shell, which is run on a personal computer. The expert system shell was chosen over other software by the marketing people because they preferred its user-friendly capabilities. This system is being used by the Tin Mill Products Marketing office of Bethlehem Steel and is being considered for use by other product-line marketing offices within Bethlehem.		measuring customer performance	ES system

Reference	Abstract	Research area	Application	Support/model
Waters, 1990	Vehicle scheduling is one of the most commonly occurring problems of transport management. Traditionally, human schedulers tackle these problems, but over the past 30 years a considerable effort has been put into developing computer systems to replace or assist them. Despite this effort, very few organizations routinely use computerized vehicle scheduling. There are several reasons for this, including the difficulty in dealing with real complexity and uncertainty in algorithmic solutions. In recent years, interactive systems have tried to overcome these difficulties by using humans to play a part in the scheduling. A next step would be to include the schedulers' skills in an expert system. Unfortunately, there is considerable diversity in scheduling problems and little agreement about the facts or rules needed for a knowledge base. At present, some characteristics of a general expert system for vehicle scheduling can be suggested, but several practical difficulties must still be overcome.	ES modelling (replacing traditional OR technique)	vehicle scheduling	characteristics of a general ES
B. K. Wong and Monaco, 1995a	The purpose of this research is to present a comprehensive bibliography of expert system (ES) application research in business. Two hundred and fourteen ES application papers are identified through the exhaustive literature searches. A classification of these articles by application area reveals that ESs are being used for a diverse range of corporate functional activities, particularly in the areas of production/operations, finance, and information systems. Information on the name of each ES, the development tool, the stage of development, and the computer operating environment as reported in each article is included. Those journals which have published the most ES business applications are also presented.		application	literature review
B. K. Wong and Monaco, 1995b	A survey of expert system (ES) business application papers published between 1977 and 1993 indicates that an increasing amount of ES research is being conducted for a diverse range of business activities. The classification of literature by (1) year of publication, (2) application area, (3) generic problem area addressed, (4) problem domain, (5) level of management, (6) level of task interdependence, (7) means of development, (8) corporate/academic interaction in development, and (9) technology integration provides some insights in the trend. Implications to ES developers are discussed.		application	literature review

Reference	Abstract	Research area	Application	Support/model
Zahedi, 1990	The complexity of evaluating expert system (ES) products calls for a formal decision analysis method. This paper presents an attempt to introduce a formal decision analysis in this area. The evaluation process consists of four steps: identification of the ES tool's functional structure, quantification of the relative weights of the functional elements of the ES tools, comparison of the products for the functional elements, and aggregation of the product scores.	methodology (validation of ES)		formal evaluation process
G. Zhang and Lu, 1990	Recognising the importance of combining manufacturing and management systems for machining operation planning, this paper presents a new methodology for the evaluation of economic aspects in an operation plan. To ensure that the quality of machined parts satisfies the required specifications, the manufacturing system acts as an alternative generator that provides meaningful and practical plans. Through cost analysis, the variable, fixed, and total costs associated with the machining operation are quantitatively determined. The management system, which functions as an evaluation mechanism, then selects the optimal plan based on the defined goal. The proposed methodology has been applied in the framework design of an expert system. The program establishes a sequence of machining operation planning and searches for the optimal plan- This optimal plan integrates considerations from both managers and production engineers, and balances their needs for efficient machining of a quality product.		planning machine operations	ES framework for economic evaluation
R. Zhang et al., 2011	Literature illustrates the difficulties in obtaining the lowest-cost optimal solution to an ore blending problem for blast furnaces by using the traditional trial-and-error method in iron and steel enterprises. To solve this problem, we developed a cost optimization model which we have implemented in a multirole-based decision support system (DSS). On the basis of analyzing the business flow and working process of ore blending, we propose an architecture of DSS which is built based on multi-roles. This DSS construction pre-processes the data for materials and elements, builds a general database, abstracts the related optimal operations research models and introduces the reasoning mechanism of an expert system. A non-linear model of ore blending for blast furnaces and its solutions are provided. A database, a model base and a knowledge base are integrated into the expert system-based multi-role DSS to meet the different demands of data, information and decision-making knowledge for the various roles of users. A comparison of the results for the DSS and the trial-and-error method is provided. The system has produced excellent economic benefits since it was implemented at the Xiangtan Iron & Steel Group, China.		ore blending	knowledge-based DSS

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