SYNTHESIZING EXPERT SYSTEMS AND OPERATIONS RESEARCH TECHNIQUES: SYSTEM CLASSIFICATION AND REVIEW

H. Raghav Rao* B. P. Lingaraj** Maithili Rao***
*School of Management SUNY/Buffalo Buffalo, NY 14260
**School of Business and Management Sciences Indiana Univ-Purdue University
Fort Wayne, IN 46805
***Planning & Development Fallon Community Health Plan Chestnut Place
10 Chestnut Street Worcester, MA 01608

ABSTRACT

Expert system (ES) and operations research (OR) have many fundamental characteristics that can be used to complement and supplement each other. This paper surveys the synthesis of ES and OR and discusses and classifies various expert systems that synthesize the two for managerial problem solving.

Key Phrases: Expert system, Operations Research, Synthesis, Classification.

INTRODUCTION

Problems in industry and organizations can be highly complex, sensitive to change, subject to uncertainties, and may need fast, accurate responses to aid the decision making process. Traditional approaches to solving such problems include operations research methods that are either algorithmic in nature or involve simulation (Hertz, 1990). Such methods simplify the problem sufficiently (by constraining the scope) to be able to compute the optimum. However, a key to effective problem solving is to exploit the knowledge of the actual environment and its particular constraints. Expert system (ES) methods are particularly useful in such contexts.

Ever since the evolution of expert systems from its focus on research problems to real world problems, there has been considerable interest in the synthesis of ES techniques and operations research (OR) methods. The synthesis of the two disciplines could leverage human capabilities resulting in substantial progress in techniques for decision making in complex managerial situations.

ES and OR can both be considered as part of the normative theory of procedural rationality (Simon, 1987). That is, they both deal with how decisions are made, or about how decision makers should decide about optimal methods for use in any problem solving process. The goal of both ES and OR is to find powerful problem solving methods that give the least-cost or best-cost decision, net of computational costs. Therefore, it is no wonder that in recent years there has been a spate of interest in the integration of ES and OR.

This paper briefly reviews the characteristics of ES and OR methods that allow each to complement the other. It then focuses on real world applications that synthesize both expert systems and operations research techniques, and reviews such integrative attempts. A framework is developed for classification in order to provide a "simple method for discovering order in the bewildering multiplicity of nature" (Phillips, 1963; Rao and Lingaraj, 1988). Such a classificatory framework may help in finding trends in ES-OR integration efforts, and may help in finding areas where expert systems and operations research techniques may be successfully developed.

PROBLEM SOLVING IN EXPERT SYSTEMS AND OPERATIONS RESEARCH

In the recent past, several authors have expounded on the links between artificial intelligence and operations research (Finlay, 1990; Fordyce, et. al., 1987; Grant, 1986; Ignizio, 1990; Liebowitz, 1988; O'Keefe, 1988; Phelps, 1986; Grover and Greenberg, 1989). For the purposes of this paper, we focus on the expert systems aspects of artificial intelligence. (The areas of genetic algorithms, simulated annealing, tabu search, among others, will not be dealt with in this paper). In this section, we briefly review some of the characteristics of ES and OR in terms of the activity of problem solving.

Problem Solving in ES

Expert Systems are founded upon the part of computer science concerned with designing intelligent computer systems, that exhibit the characteristics we associate with intelligence in human behavior: understanding language, learning, reasoning, solving problems. They deal with symbolic, non-algorithmic methods of problem solving. A common thread that runs through definitions of

expert systems articulated in literature is the activity of problem solving (Barr, Cohen and Feigenbaum, 1989).

Problem solving in ES research is viewed in terms of three primary metaphors (Simon, 1987): a) search b) reasoning c) constraint satisfaction. These metaphors often overlap, and thus yield powerful techniques for taming complex problems.

The search metaphor is concerned with the dynamic analysis of situations. Every situation is defined in terms of a state space. The state space is then searched for a solution point or a final state, through the application of a sequence of operators to transform the initial state to the goal state. The problem solution then consists of the sequence of operators that traverse the state search space from some initial state to a final goal state. Reasoning is the process of accumulating information by inference till the answer to the problem is found. Logical inference is normally done by theorem proving, through a procedure called resolution. Two mechanisms that are most often used for deductive inference are forward and backward chaining. The forward chaining process starts with a-priori information, and basic axioms and moves to the goal state. In contrast, the backward chaining process starts with the goal and proceeds to the facts. Constraint satisfaction starts with a large state space, and eliminates large chunks for applying successive constraints until it has narrowed down the original state space to a subset or unique element that satisfies all of the constraints.

Expert system approaches use heuristic search procedures. They are highly knowledge based, and take into account subjective judgment of the decision maker. Thus ES techniques emphasize knowledge elicitation and knowledge representation. Analysis in expert systems means developing, modeling and programming a human's cognitive and mental processes. It is an effort to understand and develop models for resolving and dealing with complexity, ambiguity, and ill formed problem structures.

Problem Solving in OR

OR is defined (Grant, 1986) as the application of quantitative techniques to determining an optimal solution for complex problems. It focuses on mathematical modelling and optimization techniques, with a numeric, algorithmic and procedural way of solving problems (Hertz, 1990). Thus, OR problem solving emphasizes optimization, derivation of the analytical properties of the mathematical model, and understanding the implications of the interaction of the model with the environment. An OR approach to a problem involves the construction of a model that extracts the essential elements of a real-life decision problem which is inherently complex and uncertain. The relative merit of alternative actions against the decision maker's objectives are compared, and the relationship analyzed. A solution technique including the mathematical theory is developed such that it can yield an optimal value based on the decision maker's objective. This is opposed to ES problem solving methodologies that try to mimic human cognitive processes.

Problems tend to be seen as a mapping of OR tools or techniques onto a wide variety of domains. Traditional OR techniques are simulation, network methods, combinatorial and heuristic approaches. The choice of techniques depends on problem complexity, type of model, choice of alternative and other factors. There are problems using each of the techniques; for example, network methods cannot be applied to situations which change dynamically; combinatorial procedures cannot be used when the problems are too complex, and simulations need to have skilled interpretations.

A Synthesis

The characteristics of ES and OR complement and supplement each other. Both ES and OR models are used to help the decision maker. OR methods have stressed on quantitative knowledge, ES techniques incorporate qualitative knowledge. The two fields have developed different solution techniques, one precise and numerical, the other inexact and inferential. Hence problem solving approaches that integrate ES and OR would allow the incorporation of both quantitative and qualitative aspects of a problem. Qualitative theories of ES can help OR researchers to expand their inventory of software tools (Kusiak, 1987; Leibowitz, 1988).

ES search techniques are often satisficing, thus relaxing optimality criteria of OR methods. These heuristic search methods can be applied to the solution of complex problems that cannot be modeled using optimization techniques, involve large knowledge bases, are characterized by ill-specified goals and constraints, or incorporate the design and discovery of alternatives of choice.

Heuristics can, for example, be used to provide structure to ill-structured problems, which can then be formally modeled and solved optimally (Duchessi, et. al., 1988; Fordyce et. al., 1987). [A case in

point is the use of a heuristic: elimination by aspects, to eliminate all dominated alternatives from a solution space, and then use OR techniques to optimally solve from the non-dominated set of alternatives.] Other beneficial interactions can be achieved through the use of optimization models for those parts of a system capable of mathematical description together with human style heuristic reasoning for the more complex and behavioral parts (Phelps, 1986).

CLASSIFICATION

Based on operational modes, expert systems are categorized into two classes:
(1) Stand-alone systems (Kusiak, 1987) and (2) Tandem systems (Kusiak, 1988).
1. An ES in a stand-alone mode uses data and constraints pertinent to the problem and solves it using simple procedures:

PROBLEM ------> ES ----->SOLUTION

It does not use OR procedures. Many existing systems fall into this class.
2. A Tandem system combines the OR and ES approaches to solve problems. Thus a tandem system may be thought of as an ES linked to a database of models and algorithms. It can handle qualitative as well as quantitative data. Since the models and algorithms are independent, various models and algorithms can be stored in an individual database.

PROBLEM ---> Tandem System (Models + Algorithms + heuristics) ---> SOLUTION

Simulation based expert systems and algorithm based expert systems are two subsets of tandem systems that employ various representations to model some aspect of an uncertain world. Simulation based ES capture the change in the status of the system by focusing on the behavior of the individual components. In contrast, the algorithm based ES deal with the aggregate system behavior directly (Loparo and Widman, 1990; O'Keefe, 1988), and are designed to compute actions that are optimal.
The linking between ES and OR techniques can also be described in terms of two levels of coupling: shallow and deep. In shallow coupling, the OR models are treated as black boxes by the ES knowledge base, and are called as needed. In deeply coupled systems, the ES program has, for example, intelligent front end access to a knowledge base describing the OR models. The additional information allows it to select the best model for a given task, interpret the routine, and perhaps modify the models to match the problem better.
Real world applications of a combination of ES and OR methods need to be classified within a framework for better analysis and understanding. Gorry and Scott Morton (1989) have presented a framework based on levels of managerial activities: strategic and tactical, and the degree of structure in the decision being made: structured, semi-structured and illstructured. Expert systems work well in structured problem solving scenarios and reasonably well in the case of semistructured ones. However, illstructured problems are too difficult for expert systems to solve primarily because of their unpredictable characteristics (Andriole, 1990).
ES and OR approaches apply to both the tactical and strategic problems of the organization. Tactical problems that are concerned with daily ongoing activities, and are repetitive in nature include production scheduling and inventory control, balancing assembly-line facilities, facility maintenance and repair, and inspection for quality control. Strategic problems have a planning and more global orientation, thus bearing on the daily operations only indirectly. For example, selection of plant sites, plant-expansion programs, allocation of resources for space exploration are all strategic problems (O'Keefe, 1985, 1986, 1988).
Raiszadeh and Lingaraj (1986) propose a two dimensional framework of classification of ES/OR applications in research literature based on (i) orientation, whether strategically oriented or tactically oriented and (ii) decision, the degree of structure in the decision being made. In the framework proposed here, we adapt the Raiszadeh - Lingaraj, and the Gorry and Scott-Morton frameworks to include the operational mode of the ES in real world applications. Thus the resultant framework consists of three dimensions. The first dimension separates strategically oriented applications with long term implications and tactically oriented applications with short and medium term implications. The second dimension refers to the degree of structure in the decision being made. The distinction is

based on largely structured and semi-structured decisions. The third dimension is the operating mode, based on the tandem mode of the ES within which, the applications are simulation based or algorithm based. We discuss some of the existing systems in each of the quadrants shown in Table 1.

		TANDEM MODE (Algorithm Based)	TANDEM MODE (Simulation Based)
Structured		Vehicle Routing [8]	EFT Assessment [5]
	Tactical	Logistics [16] Rectangular Cutting Stock Problem [6] Equipment Failure - Terse [35] Fault Diagnosis and repair [26]	Time Warp Operating System [31]
Semi-structured	Strategic	Aurora [36]	Process Modeling for Management Decision Making [15] Strategic Level Gaming: Mark I [7]
	Tactical	Urogen [33] Flexible Manu-facturing System - Cellular Layout FMS Scheduling [19,20] Gate Assignment [3,34] Navy Personnel Assignment [4]	

Table 1. Classification of Systems

SYSTEMS FOR STRUCTURED PROBLEMS

In this sub-section, we describe the systems which are used for solving structured problems.

Strategic oriented: The systems described below are those with the decisions being of strategic importance. Some of them are also useful in tactical areas.

VEHICLE ROUTING: (Duchessi, et. al., 1988) An example of such a system is the Traffic Manager System. The traditional approach, MS/OR routing algorithms, are enhanced by using knowledge based expert system (KBES) modules to generate high quality routing for delivery trucks. A geographic DSS helps traffic managers choose routes for delivery by enabling the user to enter delivery requirements and routes, changes in routes, obtain delivery reports and view routes on the map. The KBES enhances the system by calling on an algorithm that generates routes and provides for sensitivity analysis. It attempts to identify problems such as excessive idle time, underloaded routes etc. in the same way an experienced traffic manager does.

ASSESSING ECONOMICS OF ELECTRONIC MONEY NETWORKS: (Coats, 1989) Electronic Fund transfer (EFT) is a replacement for checks and cash with electronic signals and records. Since banking analysts hold that participation in EFT networks is imperative for any bank to survive in the retail banking segment, there has been considerable pressure on banks to move in to EFT quickly. This involves long run, indelible consequences and thus it presents the bank manager with a problem of choosing the best network for his/her organization. To help meet the need to

explore EFT choices, Coats illustrates the use of simulation and ES technology to create an EFT decision support model. The simulation model emulates the behavior and economics of actual EFT networks. The interaction between the user and the model is handled with a query-response sequence using a structured-interactive natural language dialogue. The ES feature guides the user through the input process, provides explanation of input categories and reminds the user of the previous input. Its chief contribution, however, is its flexibility in understanding requests and responses from the user. Domain knowledge about queuing system and modeling rules drives the determination of what information is solicited from the banker during the interactive terminal session.

Tactical oriented: The systems discussed below deal with decisions which are of tactical importance to the organization.

ES IN LOGISTICS: (Helferich et. al., 1990) Many decisions in logistics are made under complex circumstances by acquiring information about particular problems and the applying "rules of thumb" obtained through experience. There are four broad areas in logistics where ES are well suited: (a) monitoring and control, (b) exception processing assistance, (c) as an on-line assistant in assisting routine decisions and (d) fault diagnosis of machines.
Here, we focus on the first. Monitoring and control of functions provide a method of assessing and evaluating functional performance. For example, the weekly reports from an inventory management control system can be used as an input into an ES designed to evaluate inventory performance in terms of percentage fill rates, backorders, stockouts, inventory value on hand etc. The"rules of thumb" input to the ES knowledge base are used during the inference process where the actual report results are compared to the facts in the knowledge base. The comparison leads to the computation of an inventory performance grade. Depending on the grade, the inventory manager can ask the ES for the reasoning behind the grade or request recommended actions for improvement.

RECTANGULAR CUTTING STOCK PROBLEM: (Daniels and Ghandfaroush, 1990) ES can be used to solve the two dimensional, rectangular cutting stock problem for determining how best to lay out a number of rectangular or square packages on a rectangular pallet. This system uses 13 basic rules to recursively examine the pallet space and the preferred layout. The rules determine how to arrange packages and how many packages may then be positioned on the pallet; keep track of the number of packages laid out; vary termination conditions and also handle situations where there is usable space left on the pallet.

NAVY EQUIPMENT FAILURE : (Wauchope, 1990) TERSE is a Knowledge based text reduction system for highlighting important information in the narrative portion of navy equipment failure messages. The system contains two knowledge bases for message evaluation, one equipment specific and the other, general. The system also contains general heuristics that use the equipment model network to infer causal relationships believed to be implicit to the message. The general portion of the system performs semantic normalization, infers and tags key categories of information and finally ranks the causes of equipment failure by applying user evaluation criteria, represented as numeric scores assigned to various patterns of information types.

FAULT DIAGNOSIS AND REPAIR: (Pate-Cornell, et. al., 1988) A system may fail in such a way that it may be unclear from the symptoms how the failure occurred and what repairs are needed. Traditionally optimization methods have been used to conduct a diagnosis search given some criterion (minimization of costs or minimization of time). A number of practical problems result when fault problems arise due to a system's complexity which make analytical methods impractical. For example, how to handle a large number of potential failures or how to treat probabilistic dependencies and functional dependencies among failures of different parts are typical problems. (Probabilistic dependencies mean that along the diagnosis path, the probability that a yet unchecked part has failed, depends on the information obtained thus far. Functional dependencies would mean that the system could be dependent on other physical parts or subsystems). Systems that solve the fault diagnosis and repair problems rely on the recommendation of an expert whose expertise is encoded in a knowledge base and used when a failure occurs.

TIME WARP OPERATING SYSTEM (TWOS): (Reiber, and Jefferson, 1990) This operating system, developed at the Jet Propulsion Laboratory for the Caltech Mark III Hypercube multiprocessor

has the primary goal of concurrent execution of large, irregular discrete event simulations at maximum speed. The main innovation that distinguishes TWOS from other systems is its complete commitment to an optimistic style of execution, and to process rollback. The optimistic style of execution assumes at each moment that the messages already in the input queue are the "true next" ones and proceeds accordingly. Process rollback involves setting back the process to a time just before time t for a message that arrives with a timestamp t less than some that have been already executed.

SYSTEMS FOR SEMI-STRUCTURED PROBLEMS: The following systems are used for semi-structured decision problems.

Strategically oriented: The systems discussed here are used in decisions which are of strategic importance to the organization.

AURORA: (Yu, 1988) The Automatic Reasoning with Operations Research Applications (AURORA) is a system which decomposes and solves planning problems with operations research and expert system techniques. The problems addressed are general planning problems, including assignment, routing and scheduling with knowledge of a variety of solvable subproblems and available techniques. AURORA attempts to stimulate the human thought process. It uses a sophisticated metaplanner to solve the scheduling subproblem of tactical air planning problems. A pattern matcher is used to identify multiple occurrences of a specified pattern and in particular a linear subproblem. An automatic programming system produces an executable code to solve the linear subproblem using the simplex technique.

PROCESS MODELLING FOR DECISION MAKING: (Hall, 1988) This approach is used to conceptualize an organization as a system of resource flows controlled by an interacting set of policy making processes. The process model in an organizational context describes how things are decided and done by people and groups. The model involves two parts: the first part attempts to model and simulate how the organization works as an integrated flow of resources and the second part attempts to provide a rule based system that captures the essence of the collective decision making behavior of managers in an organizational setting. The model can be used as an alternative policy tool for companies in crisis where the effect of the natural policy making process on corporate systems is not giving the desired results and the reason is not obvious.

STRATEGIC LEVEL GAMING: (Davis et. al., 1989) The Rand Corporation has developed a large scale program modelling and simulation system in the domain of game structured military strategic analysis that combines features of human political-military war gaming and analytical modeling. Known as Mark I, it involves a synthesis of knowledge-based modeling and more traditional simulation modeling. It replaces human teams by automated models called "agents". Mark I assumes that the decision making agents would depend primarily on qualitative heuristic rules rather than on optimizing algorithms.
The system is characterized by four agents: a red agent who makes decisions for the Soviet Union and the Warsaw pact countries; a blue agent who makes decisions for the US and NATO; a scenario agent who makes decisions for non superpower countries; and a force agent who simulates results of combat and other military operations and also controls simulation time. The red agent makes decisions by (a) comparing a 15 dimensional characterization of the current world state with a set of world states previously considered and identified in data (b) choosing the world state that is closest to the current one and (c) following rules associated with that state. The scenario agent is a rule based model built in an English-like Rand ES language called ROSIE that allows users to review and change rules interactively. The force agent consists of simple combat simulation models developed in previous Rand work.

Tactical oriented: The systems discussed below deal with decisions which are tactical in nature.

UROGEN: (Scherer. et. al., 1987) UROGEN is an ES that is intended to aid the physician in the treatment and diagnosis of female urogenital complaints. It is also intended as a learning aid since it enables the user to observe the probabilistic results of different management strategies on hypothetical patients. It uses a combination of probabilistic information and expert rules to provide information regarding the value of certain diagnostic tests and effectiveness of numerous treatment strategies.

UROGEN contains four sub-models of the female urogenital complaint problem. The sub-models determine the probabilities of the various underlying causes of the complaints, as a function of the current patient history. In addition, a fifth model, the global model, calculates the probabilities of the patient having combinations of the sub-problems and the probability of the patient having none of the considered problems, using a Bayesian updating algorithm.

GATE ASSIGNMENT PROBLEM: (Brazille, and Swigger, 1991; Srihari, and Muthukrishnan, 1991) The ES is used to monitor the allocation of gate space to arriving aircraft at an airline hub. It advises on how to allocate the gates to aircraft in a cost effective manner and helps recover a portion of hub operation costs by reducing ground delay for aircraft waiting for an available gate at a terminal. This translates into increased aircraft availability and crew utilization and increase in customer satisfaction. The gate assignment procedures obtained at the particular site become the rules of knowledge base. The system uses an external file known as the terminal record that describes the current scenario of individual gates occupied by specific flights for a specific time. A second file known as the arrival record describes the actual arrival sequence of the incoming flights. The system is capable of determining the suitability of all gates when a single arriving flight is specified. In order to arrive at a suitable gate for the arriving aircraft, ES utilizes a priority list as a knowledge based system parameter.

NAVY PERSONNEL ASSIGNMENT PROBLEM: (Clark, et. al., 1988) There are about 500,000 enlisted personnel and 70,000 officers in the US Navy. The task of assigning the personnel to jobs every month, was done manually till the development of the ES. By using the ES to provide an interface to a numerical optimization program, a composite system which allows effective development of numerical transshipment models for navy personnel assignment has been produced. The ES is able to examine the functioning and solution produced by the algorithm, including the effects of slightly changing the inputs, and report the findings to the user. The ES can also explain comprehensively why a particular component of the solution was selected by the algorithm.

ES FOR FLEXIBLE MANUFACTURING SYSTEMS: (Kusiak, 1987; Kusiak and Chen, 1988) There are two basic flexible manufacturing system problems: the design problem and the operation problem. The design problem can be further decomposed into product design consisting of part design and process planning, and system design consisting of equipment design and layout design. The FMS operational problem may have the following structure -aggregate planning, resource planning, disaggregate planning and scheduling. Both ES and OR approaches have been applied to almost all design and operational problems. A typical problem in cellular manufacturing involves the grouping of machines and parts, where each partial solution generated by the algorithms suitable for solving grouping problems is evaluated by the expert system, until the final solution is determined.
Similarly ES have been used to solve the FMS Scheduling problem. Bruno (Kusaik and Chen, 1988) has developed an expert scheduling system for scheduling parts in a flexible machining environment. The parts are grouped into batches, each containing 100 to 200 parts. In order to generate a release time for each batch a dynamic priority scheme is used. The reasoning process is partially controlled by the simulation subsystem. Bensana (Kusaik and Chen, 1988) has presented a job shop scheduling system called OPAL. When operations cannot be ordered by a constraint based analysis module, and no more precedence constraints can be discovered, the rule based decision support module is called upon to select a new pair of operations. The control strategy of the decision support module is based on fuzzy set methodology.
The description of the various expert systems are tabulated in Table 2.

CONCLUSION

Expert systems that synthesize ES and OR have been used in multiple ways, ranging from model selection and subsequent data extraction for satisfying the data requirements of the model, to constructing appropriate models or modifying existing models for use with specific problems, and even modifying solutions for ease of implementation. The majority of the systems surveyed, fall into the tactically oriented application category, and are algorithm based tandem systems. The fact that strategic applications do exist, (though small in number) is evidence of the promise of the applicability of tandem systems.

The fact that Expert system and Operations Research complement each other in many ways is a feature that has far reaching prospects for human-computer problem solving. The approaches that have been effectively used in real life problems, as shown in this paper, are evidence for the fact. Specifically, one can see interesting prospects when a decision maker and a decision support system that incorporates ES and OR techniques, interact to solve a problem. Such systems can supplement the knowledge processing capabilities of decision makers. For instance, they can give novices expert guidance, and thus help them to come up with the same quality of decisions as an expert in a specific domain. The synthesis of the disciplines could leverage capabilities resulting in substantial progress in techniques for decision making in complex managerial situations.

Adding ES methods to the inventory of tools for OR researchers opens up new domains of application. It provides powerful methods for making use of non-quantitative information. Since ES uses a cognitive style compatible with that of managers, the ES/OR systems can give rise to a better expert that can deal with more complex problems effectively. For instance, ES production techniques in OR simulations is an area that has much promise. The handling of decision rules in OR simulations is generally fixed. An embedded ES system would enable the simulation to incorporate an intelligent choice of rules to better model human decision making.

Alternatively, optimization techniques can be used to help in resolving some of the limitations of ES methods. They could help in increasing an ES systems performance and produce better recommendations for decision making. OR can contribute its experience in knowledge acquisition and model building to the development of ES systems thus resulting in the production of ES systems based on OR expertise. Such systems may be useful in situations requiring models based on heuristics. They can also deliver guidelines derived from models, choose and formulate appropriate models, and interpret model results by formalizing the knowledge embedded in the applications of OR methods.

EXPERT SYSTEM (and system type)	ES METHOD	OR/ SIMULATION METHOD	DESCRIPTION	LANG. USED
AURORA (deep coupling)	Automatic programmer, Metaplanner and Pattern matcher	LP algorithms	Decomposes the planning problems using the pattern matcher and the metaplanner into subproblems that can be solved using OR algorithms	Zetalisp
UROGEN (shallow coupling)	Probabilistic information, expert rules and probabilistic rules	Bayesian updating algorithms	Makes use of the information provided by the patient's case history and makes inference using probabilistic information regarding the diagnosis.	NA
LOGISTICS (shallow coupling)	Knowledge base, evaluation rules	Algorithms	Uses the expert knowledge base and solves problems such as, exception processing assistance or on-line assistance in routing decisions, using heuristics	M1
GATE ASSIGNMENT PROBLEM (shallow coupling)	Feasibility rules, knowledge base	LP or IP algorithm	The knowledge base finds the gates suitable for a flight and then uses the OR algorithm for gate assignment	NA
FMS (shallow coupling and some deep coupling)	Knowledge based rules and frames	Optimization algorith	Used in operations such as job shop scheduling, planning where priorities are established using th are used	Prolog, LIS OPS5 FORT-RAN
RECTANGULAR CUTTING STOCK PROBLEM (deep coupling)	Knowledge based rules	Algorithms	The rules examine the pallet space and then uses the algorithm to give the preferred layout. This process is repeated until an optimal layout is achieved	PROLOG
VEHICLE ROUTING (shallow coupling)	Knowledge based rules	Route algo- rithms	The knowledge base helps select the best route based on experience.	Insight2 Pascal
TERSE (deep coupling)	Knowledge based rules	OR model	The system uses two systems, one equipment specific and the other equipment general to infer the messages that are sent and inferring the causal relations for equipment failure	OPS5

ELECTRONIC MONEY NETWORKS (deep coupling)	Modelling rules	Simulation	The rules formulate the user inputs in a teller machine into the form accepted by the model and offers explanation to the user of various input categories	Prolog
FAULT DIAGNOSIS AND REPAIR (deep coupling)	Rules derived from probabilistic analysis	Analytical optimization	The symptom-fault knowledge base, fault fixing knowledge base and verification knowledge base are used to both diagnose and offer solution to faults	NA
TIME WARP OPERATING SYSTEM (shallow coupling)	Rules for process rollback	Discrete event simu- lation	The system helps concurrent executions of large, irregular, discrete event simulations at maximum speed by using distributed roll back mechanism for synchronization	C
PROCESS MODELLING (shallow coupling)	Rule based	Simulation	The rules form corporate goals, maps environment, formulates plans and help add the qualitative information into the model which simulates corporate decision making	C
STRATEGIC LEVEL GAMING (deep coupling)	Rule based	Simulation	Simulated multiple agents war game in which rules are used to define the role of the multiple agents	RAND- ABEL ROSIE

Table 2: Expert System Details
* NA - Not Available

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