Knowledge engineering for an FMS advisory system

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ABSTRACT

A system combining expert system, database and simulation techniques is described which acts as a decision support system for planning flexible manufacturing systems. The system interacts with the manager of a computer integrated manufacturing system both at the equipment procurement stage and at the system operation stage to aid him in planning machine acquisition, placement and operation. It consists of four modules: a database of machinery; a machine grouping optimizer; a simulator of flexible manufacturing system configurations; and an expert system shell containing advisory rules on flexible manufacturing systems. This paper gives the design considerations for the system, describing the expert system architecture, presenting the knowledge engineering considerations involved in its development, and illustrating its operation.

INTRODUCTION

We are in the midst of an intellectual revolution in manufacturing. Developments in numerically-controlled machine tools, materials handling, industrial robotics, and the understanding of human aspects of productivity and quality-assurance, have led to new approaches to manufacturing whose cumulative effect is revolutionary rather than evolutionary [2, 19, 22, 26, 41, 44, 58].

A number of major changes in manufacturing technology are apparent:-

i) There has been a shift from mass-production transfer lines highly optimized for long runs of a particular product towards flexible manufacturing units coping cost-effectively with shorter runs of a range of products [7].

ii) There has been a shift from discrete manufacturing processes towards continuous flow processes based on robotic materials handling [9, 25].

iii) There has been a shift from production of piece parts, perhaps at different specialist sites with sub-assembly and assembly at other sites, towards single-site integrated manufacturing [1, 31].

iv) There has been a shift from high-volume, single-site manufacturing and widespread geographic distribution towards lower-volume manufacturing replicated at multiple sites chosen to minimize distribution costs [54, 31].

v) There has been a shift from the use of people as attachments to production lines doing small repetitive sub-tasks towards the use of people in a supervisory role with emphasis on responsibility for complete products [43, 31].

Computer integrated manufacturing (CIM) support such shifts by allowing automation and mass-production techniques to be applied to fairly short runs of diverse items compared with the long runs of limited variety required in the past [20]. The flexibility, customization and localization offered are attractive but generate a new class of management problems [56]. The information flows required in manufacturing increase greatly with the diversity of product being handled and the rapidity of change between products. The knowledge required to manage these information flows is not readily available. Setting up a flexible production line requires different and higher-level skills than those required to operate it once running. A variety of additional skills are required to design a flexible manufacturing system capable of handling a diversity of products [21, 32, 39].

Management support systems are needed for the planning, implementation, configuring and operation of CIM [8, 38, 40]. *Expert systems* provide a technology to cope with the diversity and complexity of the information involved [28, 33, 36]. However, an expert system alone cannot cope with the volume of information about different machine tools and robots, the computation required in grouping and the provision of numeric simulations for interactive planning and testing. An adequate support system for managing CIM involves the combination of expert system and simulation-based decision aids with numeric computation, databases, communications, and, if it is to be used in operations instrumentation and control systems [34, 42, 55].

Expert system technology can be applied at a number of levels in CIM including product design [29], flexible manufacturing system (FMS) justification [57], job-shop scheduling [10], simulation [5], on-line process control [4] and robot control [30]. However, the problem of major concern is the design stage at which manufacturing system has to be specified in terms of its performance and a range of diverse machine tools have to be brought together in an integrated system design. This stage presents a number of major conceptual difficulties currently that are impeding the rapid diffusion of new manufacturing technology into appropriate industries. It is typical of the problems that because of their complexity and diffuseness they have to be "managed" and are very susceptible to support through expert systems [23].

This paper is concerned with the development of advisory systems combining expert system, database and simulation technologies in order to support the decision processes of managers responsible for configuring FMSs.

A TECHNOLOGY MANAGEMENT SYSTEM FOR FMS PLANNING

The considerations above have led to the design of a decision support system for planning FMS which is part of a larger project on the development of *Technology Management Systems*. The system combines database, optimization, simulation, knowledge base, expert system and human-computer interaction technologies in the decision-support system shown in Figure 1.

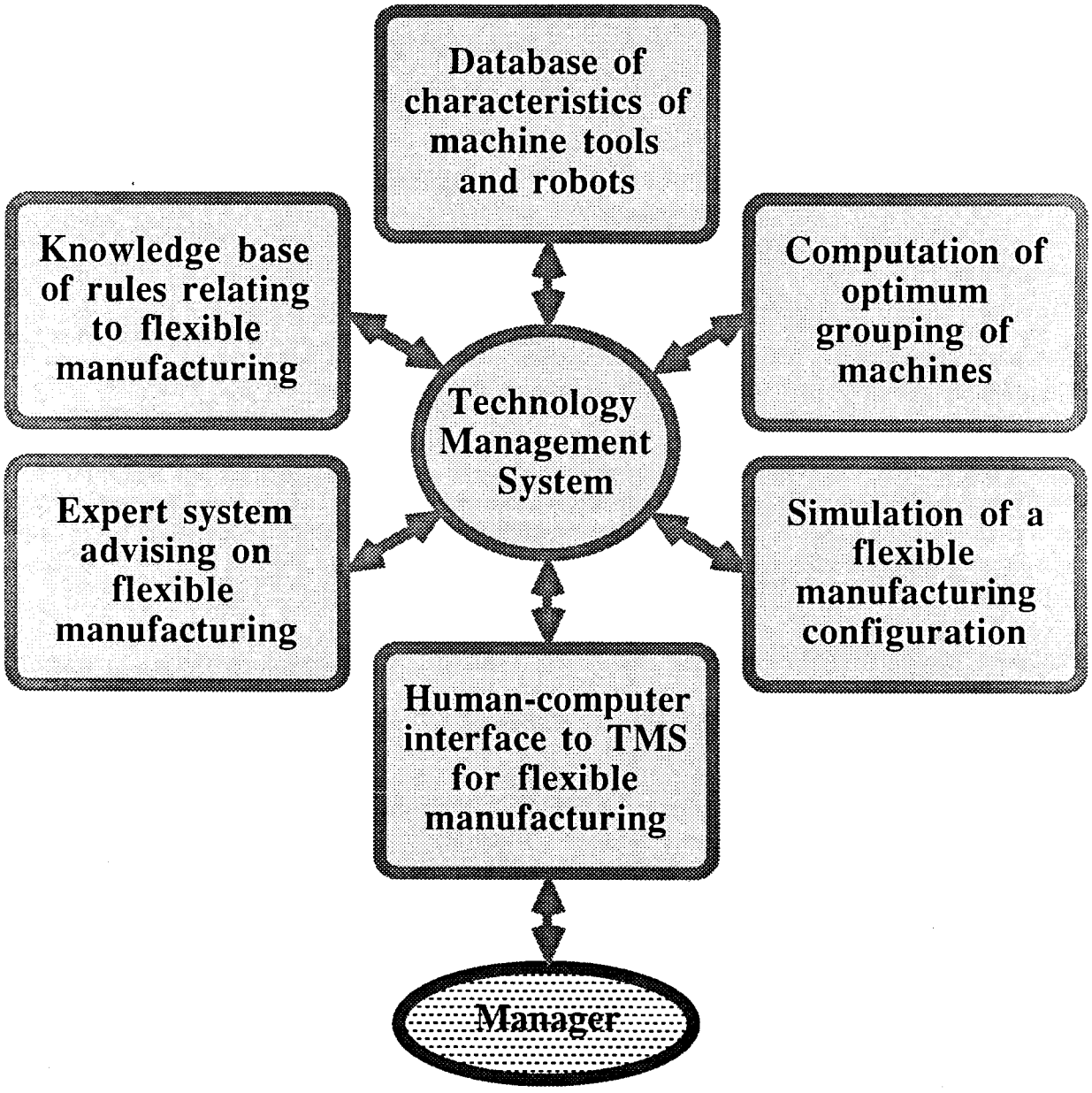

Fig. 1 Technology Management System for Planning Flexible Manufacturing Systems

The Technology Management System is designed to:

a) provide a simple, straightforward human-computer interface to a variety of tools for the design and management of an FMS;

b) use a knowledge-base of FMS design and procurement procedures to elicit the critical factors in the requirements for a FMS such as throughput, workpiece sizes, machining activities, precision requirements and so on;

c) use an expert system to advise on the feasibility of the applications, possible configurations and the types of equipment required;

d) use a database of machine tools and robots to match the requirements range against a variety of tool and materials handling configurations;

e) compute the optimum grouping of tools to meet the specified requirements;

f) make available through simulation, operating parameters such as set-up times, throughput rates, tolerance range, failure rates, and so on, for a variety of jobs within the requirements range;

g) when reasonable matches between requirements and performance are found, refine the design at a greater level of detail including operational factors and overall cost-effectiveness for a variety of job mixes and production runs;

h) finally, produce full specifications of the FMS including set-up procedures.

Knowledge Engineering for an FMS Technology Management System

The systems analysis required for a system encompassing the specified capabilities is a major task. This type of analysis has come to be termed *knowledge engineering* in the expert systems literature because it involves eliciting from experts the detailed knowledge processes that they use in performing the tasks involved [14, 15, 16, 24, 52, 53]. What is characteristic of major real-world systems, however, is that the knowledge required for their operation is not localised within a single expert but distributed over a number of specialists with diverse skills in different parts of the organisation. In expert system terms knowledge engineering is required over a very wide domain which cannot be encompassed by one person.

To cope with this problem it is necessary to fragment the problem domain into a number of *knowledge islands* which are characterized by their internal coherence—within an organization they usually correspond to functional specialities. The knowledge engineering for each island generally involves interviews with only one person or, if the relevant material is well-codified, analysis of a particular handbook or manual—the *Flexible Manufacturing Systems Handbook* [7] is a prime example of such codified knowledge. We have implemented techniques for carrying out the interviews automatically through computer interaction with the experts that elicit their constructs, their basic dimensions of thinking [11, 12, 46, 47, 48, 49, 50, 51], and are developing techniques for deriving the construct systems embodied in text automatically. The implicational structure of the construct systems can also be derived automatically and used to generate rules priming an expert system shell [3, 17].

Knowledge Islands for FMS

Figure 2 shows a preliminary analysis of the main knowledge islands involved in a technology management system for planning FMS.

The ***overall requirements specification*** is the starting point of any feasibility study of FMS. The key constructs here were found to be the obvious pair: *low-volume—high-volume* and *low-variety—high-variety,* but other significant constructs were also elicited that affect the feasibility of FMS implementation such as *FMS-already-in-use—FMS-not-in-use* and *committment-to-existing-machines—new-plant.* The experience dimension and the difference between restructuring and green-field situations are obviously relevant to the decision-making but could be missed in an analysis that concentrated only on quantititative parameters.

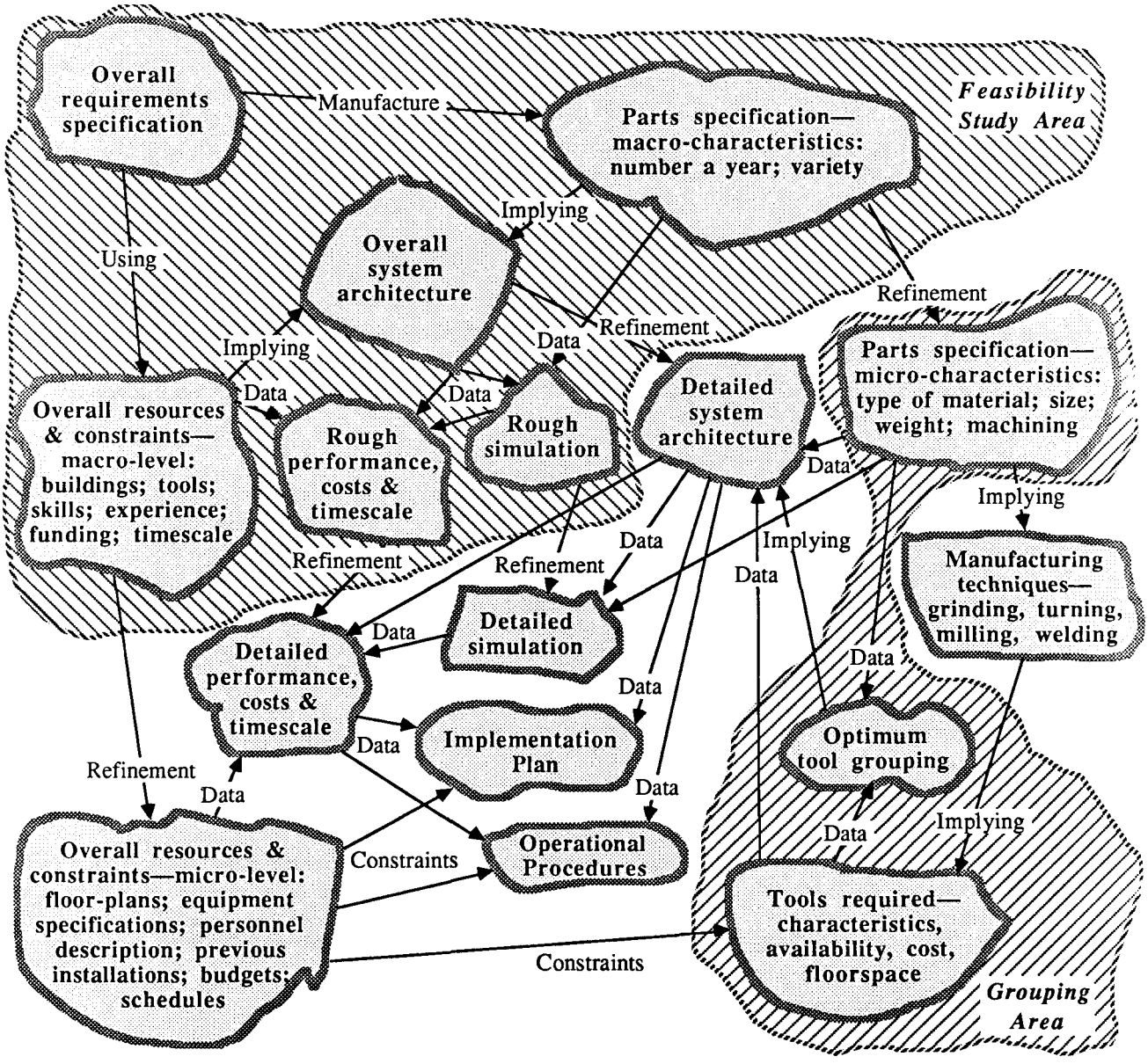

Fig. 2 Knowledge Islands and Areas Underlying the Knowledge Engineering of Expert Systems Supporting the Planning of Flexible Manufacturing Systems

The experience/resources dimension refines naturally to the knowledge island concerned with ***overall resources and constraints***. The volume/variety dimension refines to a quantitative description of the ***parts specification*** in parts per year and the number of different parts. Figure 3 shows the conventional wisdom about the suitability of different forms of automated manufacturing dependent on the parts specification. Coding the knowledge involved for a computer shows up several features that tend to be forgotten in the conventional analysis. For example, what advice do you give when a requirement falls outside all the boxes?—the answer is to restructure the requirement by grouping or splitting as shown by the gray areas in Figure 3. Another complication is that part variety is not adequately represented by number of different parts—similarities between parts are very significant in system organization and feasibility so boundaries based on numbers alone are fuzzy. They can be modified by qualitative considerations of part groupings well before they are refined to detailed considerations of machining requirements.

Consideration of the resources and parts islands can give enough information to prime the ***overall system architecture*** island based on a more detailed version of Figure 3. This is in its turn can lead to ***rough performance*** estimates. Surprisingly it can also provide sufficient data for ***rough simulation*** using the fuzzy linguistic model approach [13, 59]. The performance estimates and simulation presentation form a basis for conclusions about the feasibility of an FMS for a particular requirement and the six knowledge islands involved may be grouped together as a *feasibility study area*. This sub-system is already a useful tool for the preliminary stages of FMS planning.

The knowledge islands described may be refined to a further level of detail on two main paths. The macro description of resources and constraints may be refined to a micro description that lists floor-plans, personnel, machines and so on. Much of this will be available in existing administrative databases but some information will probably be missing. The macro description of parts may be refined to a micro description that completely characterizes each part and its manufacturing process [6]. Much of this will be available in existing corporate engineering and production databases but again some will be missing.

The ***parts specification*** leads naturally to a ***manufacturing techniques*** knowledge island which itself leads to that for ***tools required*** [27]. The parts and tools islands form another useful sub-system, the *grouping area*, where the ***optimum tool grouping*** knowledge island takes the detailed specification of parts and their machine utilization requirements and uses these to derive nearly optimal groupings of machinery.

The central region of detailed architecture, performance and simulation is complicated more by the data requirements than by the complexity of computation required. It is unlikely to be cost-effective for any organization to gather the detail required on a wide range of machines and field-experience (although as widespread use of the manufacturing automation protocol, MAP [18, 35], develops much more data is potentially available economically). The knowledge islands in this area will evolve through successive refinements of those already described in a way determined by mainstream industry trends and cost-effectiveness. The phenomenon where leading suppliers tend to be used again because there is more knowledge of their products is one phenomenon of this region.

Implementation

The *feasibility study area* is being implemented on an Apple Macintosh in the *Nexpert* expert system shell which offers highly interactive facilities for forward and backward inference, hypothesis formation, explanation and graphical presentation of the structure of inferences and the knowledge base. Figure 4 shows a Macintosh running a consultation in Nexpert on the overall requirements specification and system architecture. The database of machine tools and parts specifications will require facilities that go beyond those of either of these systems [38] and is being implemented on a Sun 3. The FMS simulation is being written in SIMSCRIPT II.5 [60] as a module which takes in the conclusions of the expert system and gives a dynamic graphic presentation of the FMS operation and its performance parameters. The *grouping area* sub-system is being implemented using algorithms previously described [32] on a Xerox 1108 Lisp machine in the ***Loops*** language which offers good facilities for simulation, graphic interaction and rule-based expert system specification.

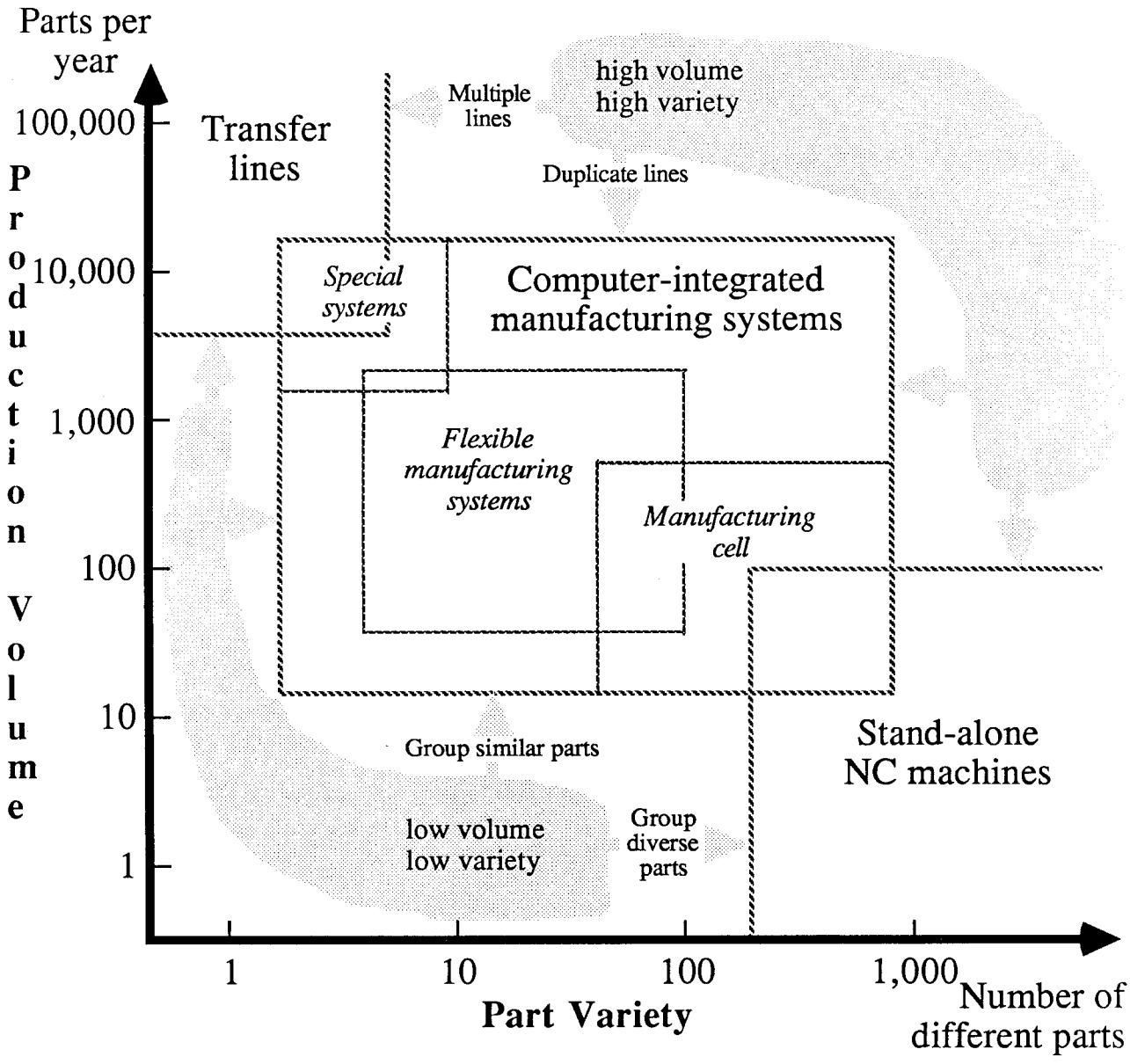

Fig. 3 Primary Variables Affecting Choice of Manufacturing Systems, and Strategies when Outside Ranges

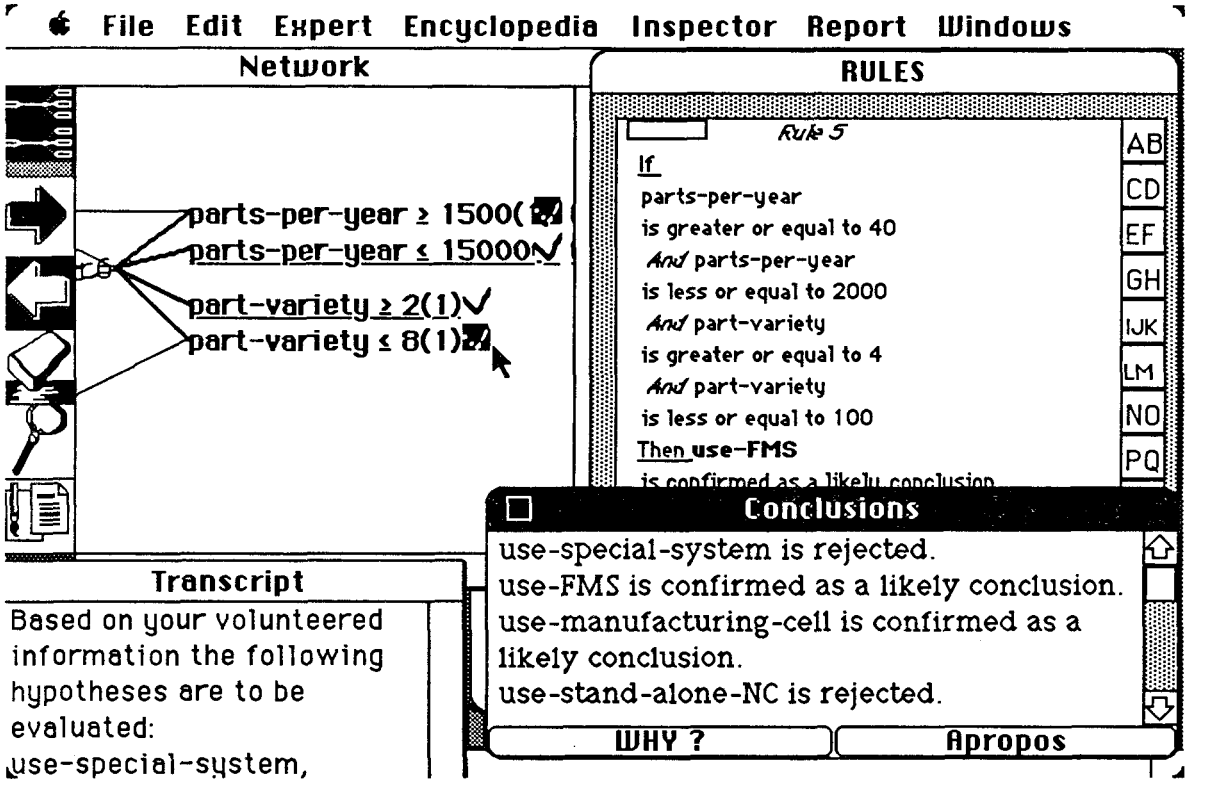

Figure 4 Operation of FMS Design Rules in the Nexpert Expert System Shell

CONCLUSIONS

Developments in computers, robotics, communications, electronics and materials are occurring at an increasing pace and have widespread impact on industrial manufacturing processes. In particular the combination of these new technologies offers opportunities for integrated manufacturing systems that increase productivity through improved reliability, reproducibility, flexibility, human factors and cost/effectiveness. CIM is applicable to a spectrum of industry from comparatively small firms up to large organizations. However, it is difficult for firms to keep up with the flow of information and experience on these rapidly changing new technologies.

Decision support systems for CIM present particular problems for today's expert system technology because manufacturing involves the dynamics of physical processes and requires knowledge-based systems that combine simulation techniques with those of current expert systems. They also present challenges in coordination because the expertise required is dispersed across a number of disciplines, between universities and industry, and between equipment manufacturers and users. However, the relevant technologies and knowledge are now at a stage where practical systems may be developed. The refinements of these systems through experience in their use, further analysis and data collection, will lead to the evolution of the totally-integrated manufacturing system.

ACKNOWLEDGEMENTS

Financial assistance for this work has been made available by the National Sciences and Engineering Research Council of Canada. I am grateful to my colleagues, Drs Kolodny, Moray, Turksen and Vanelli for discussion and comments.

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