SME

Expert Systems

Strategies and Solutions in Manufacturing Design and Planning

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Preface

In recent years, the number of applications of expert systems has steadily grown. Manufacturing design is one of the most promising of these applications. This book focuses on some of the latest advances in the development of expert systems for the design and planning of manufacturing systems.

The concept of decision-based design is introduced in Chapter 1. It is postulated that both a partition of an artifact to be designed and a plan are required to facilitate the decision-making process. A conceptual model for unifying the processes associated with design, manufacturing, and maintenance is defined, and characteristics of an expert system for partitioning an artifact model into subsystems are discussed.

Chapter 2 analyzes the state of the art in knowledge-based systems and their applications in manufacturing. It also illustrates new tools for knowledge acquisition and transfer. The technologies underlying knowledge-based systems are well advanced and it is possible to develop major decision support systems for manufacturing. The technologies critical to applications are the expert system support environment providing tools for interfacing with and validating the knowledge base, and knowledge acquisition tools for transferring knowledge from human experts to the knowledge base.

In Chapter 3, representation schemes commonly used in artificial intelligence (AI) are viewed as belonging to two broad categories--one based on predicate calculus and the other on structured objects. A review of the features of some of these schemes is provided, along with a discussion of the use of one representation scheme from each category in representing manufacturing knowledge. It is suggested that, given the complex structure of the knowledge base that is commonly used in addressing many manufacturing problems, there may be a significant advantage to using a structured object representation of knowledge. Finally, a unified framework--based on the "object-oriented" approach--is proposed for knowledge representation and control.

Chapter 4 introduces a new automated process planning approach that incorporates the machine learning capability. Unlike the majority of existing AI-based process planning systems which make use of a built-in knowledge base to generate process plans, this approach enables the process planner to refine its knowledge or acquire new knowledge by deriving and observing example plans. The explanation-based learning technique is used in creating a learning-augmented knowledge-based process planning system. It is shown that, through explanation-based learning, the process planning system is able to learn new heuristics or schemata for achieving better performance.

A method of protocol analysis that is tailored for solving manufacturing problems is discussed in Chapter 5. The Machinist expert system, developed using that method, creates process plans for prismatic parts. Its planning technique, derived from human machinists, solves a portion of the process planning problem that was not clearly understood in the past. The Machinist system uses interactions between the parts to construct the solution.

Chapter 6 presents an approach to designing an expert system for process planning of rotational parts, identifying the features required to describe such parts. Once a part is described using the features, the system--which is capable of handling parts that can be described by as many as six features--identifies and sequences the operations to be performed and generates the process plan. Recommended cutting conditions, tools, cutting fluids, single-point tool angles, total machining time, and the time for which each tool is required are specified for each operation.

A framework for the development of a set of geometry-based reasoning strategies for a robotic formalism planner for assembly is provided in Chapter 7. This formalism planner allows a program of servo commands for assembly operations to be generated directly from a CAD database. It also enables manipulator actions to be specified by their effects on objects rather than by sequence of manipulator motions for the accomplishment of the task. World information for the planner can be represented using a three-dimensional CAD modeling system. However, interpretation requires that the CAD information be translated into a neutral graphics data format, thus eliminating dependency on a specific CAD modeler or modeling technique.

A knowledge-based system (KBGT) for solving the group technology problem is discussed in Chapter 8. The formulation of the group technology problem involves constraints with regard to machine capacities, material handling system capabilities, machine cell dimensions, and technological requirements. This expert system, developed for automated manufacturing systems, considers alternative process plans and multiple machines and takes advantage of the developments in AI and optimization.

Chapter 9 presents a knowledge-based system (KBML) for layout of machines in an automated manufacturing environment. KBML combines the optimization and expert system approaches and considers both quantitative and qualitative factors while solving a machine layout problem. The system, which is coded in Common LISP and implemented on a SYMBOLICS 3650 machine, is illustrated with a sample user-system session and a numerical example.

An explanation of the structure of a prototype expert system based on integrated AI and an operations research approach is offered in Chapter 10. This expert system provides support to process or quality control engineers in selecting the proper type of control charts. The functionality and operation procedures of this system are demonstrated through a sample user-system session.

The ways in which a manufacturing process representation can assist in distributed diagnosis and determination of possible sources of signaled errors are illustrated in Chapter 11. An architecture for distributed diagnosis in a flexible manufacturing system is also explained. By using a hierarchy of diagnostic agents and corresponding monitor systems, it is possible to limit communication among diagnostic agents to the set of preconditions and between monitor systems and diagnostic agents to the requested orderings of subprocesses.

An integrated high-level model for information systems is introduced in the final chapter, Chapter 12. This new model allows for description of the object organization at two levels--the organization or management level and the conceptual or database level. A clear and accurate description of the organization is required for the organization or management level. The conceptual or database level is the interface between managers and engineers and computer specialists. Its most important feature is the ability to describe--in an integrated manner, using the database which supports the information system activity--both the organization behavior and the manipulation actions.

Andrew Kusiak
Editor

about SME

The Society of Manufacturing Engineers is an international technical society dedicated to advancing scientific knowledge in the field of manufacturing. SME has more than 80,000 members in 70 countries and serves as a forum for engineers and managers to share ideas, information, and accomplishments.

Technology is constantly evolving. To be successful, today's engineers must keep pace with the torrent of information that appears each day. To meet this need, SME provides many opportunities in continuing education for its members.

This continuing education is provided through:

- Educational programs including seminars, clinics, programmed learning courses, as well as videotapes.
- Conferences and expositions which enable engineers and managers to examine the latest manufacturing concepts and technology.
- SME publications include *Manufacturing Engineering* magazine, the *Journal of Manufacturing Systems*, the *Technical Digest*, and a wide range of books including the *Tool and Manufacturing Engineers Handbook*.
- Monthly meetings, through five associations and their more than 300 chapters and 165 student chapters worldwide, to provide a forum for membership participation and involvement.
- The SME Manufacturing Engineering Certification Institute formally recognizes manufacturing engineers and technologists for their technical expertise and knowledge acquired through experience and education.

As a leader among professional societies, SME assesses industry trends, then interprets and disseminates the information. SME members have discovered that their membership broadens their knowledge and experience throughout their careers. The Society of Manufacturing Engineers is truly industry's partner in productivity.

about CASA/SME

The Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME) was founded in 1975 to provide comprehensive and integrated coverage of the field of computers and automation in the advancement of manufacturing. CASA/SME is applications oriented and addresses-through integration-all phases of research, design, installation, operation, and maintenance of the total manufacturing enterprise.

CASA/SME activities are designed to meet the following objectives: a) provide professionals with a single vehicle to bring together the many aspects of manufacturing which utilize computer systems automation; b) provide a liaison among industry, government, and education to identify areas for technology development of the totally integrated manufacturing facility.

CASA/SME firmly believes in a standard of excellence that assures that application of computer and automated systems must always be timely and assure cost-effective manufacturing and quality products. The association also believes that the manufacturing companies which will survive in the coming decade will be those that now give serious attention to what their competition is doing and what they themselves should be doing in integrating mechanization and systemization for more automated production.

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Chapter 1

Introduction

Decision-Based Design: Some Concepts and Research Issues

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INTRODUCTION

In the future, information that is useful in designing for manufacture will be available almost instantly in quantity and quality heretofore not possible. Designers will negotiate solutions to open problems in a computer environment characterized by user-friendly desktop computers networked to much larger machines--machines with the capability to process symbols (words, pictures, numbers, logic)--and extensive databanks. We assert that the principal role of an engineer in this computer environment is to make decisions associated with the design and manufacture of an artifact.

To facilitate decision making in design, both a partition of the artifact to be designed and a plan for making decisions are necessary. Therefore, the concept of decision-based design and an approach called the decision support problem (DSP) technique (which is being developed at the University of Houston) are introduced in this chapter in an effort to establish a different perspective from which to develop methods that support both systems thinking and decision making in design for manufacture. In this context, we propose a conceptual model for unifying the processes associated with design, manufacturing, and maintenance. We describe the characteristics of an expert system to partition an artifact model into subsystems and components, discuss the characteristics of another (hybrid) computer program to develop a strategy and implement a plan of action for obtaining knowledge about an artifact to be manufactured, and identify some pertinent areas of research.

PARTITIONING AND PLANNING: AN OVERVIEW

In recent years there has been a surge of interest in building computer systems for "doing" design. A few representative examples are the work supporting the development of design methods by Brown,(1) Radford and Gero,(2) Hubka,(3) Pahl and Beitz,(4) and Tomiyama and Yoshikawa.(5) Examples of work that supports partitioning and planning, in general, are developing skeletal plans (Friedland (6)), developing plans through analogy (Carbonell (7)), recovery from a failed plan (Alterman (8)), revising existing plans (Steinberg and Mitchell (9)), and planning by using knowledge about successful plans (Maher (10)). The preceding are representative samples of the work being done by others. In this chapter we present our perception of design and the processes associated with it.

Partitioning and Planning in Design for Manufacturing

In an order characterized by decreasing amounts of creativity, there are three types of design activities: original design, adaptive design, and variant design.*(4) In original design,** an original solution principle is defined for a desired system, artifact, or component and is used to create the design of a product. In adaptive design, as the name suggests, a designer is concerned with adapting an original design to different conditions; thus, the solution principle remains the same but the product will be sufficiently different that it can satisfy the changed conditions that have been specified. Original design may still be an appropriate description of the design process for subsystems of the artifact. Finally, in variant design, a designer is primarily responsible for varying the size or arrangement of parts of the chosen system, while the desired function and the solution principle remain the same.

All three types of design involve manufacturing, albeit in differing degrees. There is much to be gained through the development of a computer-based aid that would facilitate DFM in the short term and the integration of design and manufacturing in the long term. Clearly, such an aid should interact with a feature-based modeling system and provide information about the physical properties of the part being designed, as well as information about its manufacturability, quality, inspectability, and other life cycle considerations. To accomplish this for original, adaptive, and variant design we recognize that three problems need to be addressed, as follows:

- The development of a conceptual model for unifying the processes associated with design and manufacturing
- The development of the means to partition the model of an artifact into subsystems and components using process-based knowledge
- The development of a plan of action for obtaining knowledge about the artifact so that it can be manufactured.

The common element in design and manufacturing processes is decision making, and we believe the processes can be unified by developing an appropriate decision-based design scheme.

Decision-Based Design, Decomposition, Partitioning, and Planning in Design

Decision-based design is a new term coined to emphasize a different perspective from which to develop methods for design. In the context of decision-based design, we assert that the principal role of an engineer is

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* Original, adaptive, and variant design are akin to Brown and Chandrasekaran's three numbered classes of design.(11) We prefer to use the more descriptive terms of Pahl and Beitz.(4)

** In this chapter we highlight terms that have special meaning in the context of decision-based design. In some cases we have modified their classical definitions as a first step in establishing a glossary for the emerging field of design science.

to make decisions associated with the design of an artifact. This seemingly limited role ascribed to engineers is useful to provide a starting point for developing design methods based on paradigms that spring from the perspective of decisions made by designers (who may use computers) as opposed to design that is assisted by or based on the use of computers, optimization methods (computer-aided design optimization), or methods that evolve from specific analysis tools such as finite element analysis. In other words, we do not consider decision-based design as a subset or supraset of computer-aided design (CAD) or computer-based design. We see it in another role. Many design approaches were developed originally for purposes and uses now considered outmoded. Their continued use by designers is contingent largely on custom, tradition, familiarity, and most engineers' innate conservatism. Enter decision-based design; considering design as a decision-based process offers designers a new and different perspective for viewing established approaches, and it provides them with the basis for extending and developing anew these established tools of the trade.

Decision-based design is a heterarchical* set of constructs that embody a researcher's perceptions of the design environment and the real world. As a first construct, we define the term system as a grouping of associated entities characterized by a mental construct. The terms in this definition were selected for the specific meanings and associations they convey.

The term grouping conveys the impression that an act of forming and arranging is involved. Associated is used to indicate that there is an association among or that relationships may exist between the entities in a grouping without indicating the precise natures of the association of relationships. The entities could be anything with an essential nature that can be conceptualized, including other systems, concepts, ideas, symbols, and objects in the real world. The term characterized is meant to convey that the characterization of the grouping is unique and that it is coupled to the chosen grouping and mental construct. Only with both can a mental image of the system be created. A construct is "a complex idea resulting from a synthesis of simpler ideas".(12) The redundant qualifier mental serves to highlight the involvement of the human mind in the process of creating a construct.

In other cases, where systems are decomposed, the end result in each case will be the same, independent of how the process is accomplished or who is perfoming it. The result of decomposing a system is determined by the inherent structure and organization of its elements. The cleverness and intuition of the decomposer may make the process easy or difficult, but the result of the process is preordained. Usually, there exists the further connotation, taken from the mathematical definition of the term, that the elements are disjoint--separate and distinct and without common characteristics or members. As will become evident from the following sections, this definition is of primary importance for the development of methods rooted in decision-based design.

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* In a heterarchical representation, the relationships between the constructs are not ordered and, hence, not directed. No construct can be identified as the dominant construct.

Mechanical systems are composed of linked elements, from relatively large and complex subsystems to stand-alone individual components, arranged so as to enable interaction with each other through links across levels and between groupings of elements. The spatial relationship between elements in the model of a system and its subsystems gives a measure of the level of differences between elements. The links represent the relations between elements. The development of methods for dividing system design problems into subproblems that can be solved easily and then synthesized into a design for the system is important and is the principal focus of this proposal. This process is described in terms of decomposition, partitioning, and planning.

Among engineers, it is common to speak of **decomposing** and **partitioning** a system as though the processes and the resulting organized separation of the system were same. In our opinion, the terms are not synonyms. The processes are different and if the result of decomposing or partitioning a system are the same it is only a coincidence. When such coincidences occur, it is not necessarily obvious that the processes and even the intent of the decomposer and partitioner are different. In the context of design, and particularly in the context of decision-based design, the differences in the meanings of the two terms are essential to distinguishing between the two processes and the uses to which they may be put by designers.

Fortunately, the etymology of the terms **decompose** and **partition** focuses on the essential differences between their meanings, which is useful to designers.* Decompose carries with it the connotation that the system under consideration has an essential nature, an underlying structure and organization of its elements which, although not evident, is undeniably there. In fact, the definition of the term system (given earlier) allows a designer or engineer to assume that this is true. If a system exists, these inherent properties of the system also exist. Two chemists who decompose a complex compound into its constituent parts or two physicists who decompose a beam of light into its constituent colors are engaged in the same process. They are "separating or resolving [a system] into its constituent parts or elements" (RHD). Partitioning a system can be defined as "dividing [it] into parts or portions" (OED). But this definition is too general for our use here, as in the examples above, decomposition and partitioning would be the same thing. This definition also fails to provide an idea of the process involved or the rationale for performing it.

In another section, The Oxford English Dictionary (OED) offers a definition better suited to our needs, referring to partitioning as a process of "analysis by systematic separation of the integrant parts of a thing," where the integrant parts in their sum are the thing under consideration. In this definition, let us consider the "thing" to be a system. A partition of the system would be for the purpose of and by means of a process established *a priori* by the partitioner.

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* The definitions of decompose and partition given here have been synthesized from sources including The Oxford English Dictionary (OED), The Random House Dictionary of the English Language, Second Edition (RHD), The Collins English Dictionary, and Webster's Ninth New Collegiate Dictionary.

The model of a system that results from one partitioning would not be the same as the one that results from another, and perhaps neither of them would be the same as the model that would result from a successful decomposition of the system. This difference is crucial to the way in which the terms decompose and partition are used. In later sections, the cited differences are used to achieve a partition of a system that particularizes a model of the system which can take into account specific design considerations.

We define decomposition as the process of dividing an artifact model into its smallest coherent sensibly self-contained elements, much in the manner of decomposing a chemical compound into its elements. A designer who uses decomposition is guided by the inherent structure of an artifact and the Newtonian principles of reductionism and mechanism and is motivated by the knowledge that (although it may not be clearly revealed to the designer) the solution being sought exists. This knowledge follows from the fact that the problem statement includes the condition of a closed environment.* Division using decomposition is unique in that it always results in the same subsystems, regardless of who performs the decomposition. Additionally, decomposition often reveals elements, usually components, that can be designed using information from a single technical discipline. Decomposition is appropriate when design synthesis is based on the principle of repeated analysis (for example, in the design of structural systems and in CAD) as it is widely used in industry today. Decomposition can be important in manufacturing (especially when assembly is required) and in maintenance (when disassembly is necessary). In decomposition, analysis (differentiation) progresses from the level of parent system to subsystems to components according to the structure that is revealed by the process. Synthesis (integration), the reverse process, progresses from component level to system level. The reversible nature of differentiation and synthesis in decomposition is unique. In adaptive and variant design (especially in those cases where we make use of CAD schemes), we exploit the reversible nature of the process, and in original design, we use decomposition only in a subordinate role to partitioning and planning. The presence of an open environment** in a problem statement precludes a designer from using decomposition at the outset. Nevertheless, the designer knows the design problem must be made manageable before the process for negotiating a solution can be identified and implemented. We believe this designer's dilemma can be resolved by appropriate partitioning and planning.

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* A closed environment is one that can be described completely by quantifiable parameters; its physical configuration is known, its dynamic characteristics can be prescribed, and the physical bounds in which the designed engineering artifact will later exist are completely revealed to the designer a priori. A design problem that includes a closed environment is analogous to a textbook problem, a puzzle that the designer must solve. Closed environments usually provide the starting point for variant and adaptive design, but not original design.

** An open environment cannot be described by quantifiable parameters alone. A design problem that includes an open environment is truly a problem, not a puzzle. Statements that characterize an open environment are an integral part of a problem statement for original design. A goal of any design process is to reduce the openness of the original environment.