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A KNOWLEDGE-BASED APPROACH TO PART TYPE SELECTION CONSIDERING DUE DATES IN FLEXIBLE MANUFACTURING SYSTEMS

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A KNOWLEDGE-BASED APPROACH TO PART TYPE SELECTION CONSIDERING DUE DATES IN FLEXIBLE MANUFACTURING SYSTEMS

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Abstract

This paper applies artificial intelligence to the short-term production planning function of flexible manufacturing systems(FMSs). A knowledge - based approach is used to solve the part type selection and production ratio determination problems. The part type selection problem is to select a subset of the part types that have been ordered to be produced on an FMS, often with due dates and/or production requirements, for simultaneous machining over some upcoming period of time.

A knowledge-based system is implemented in the language, Knowledge Engineering Environment (KEE). This system both selects part types and determines their mix ratios under constraints on due dates and tool magazine capacity. Further research needs are also discussed.

1. Introduction

A systemic analysis of a manufacturing company shows three interrelated subsystems: ***management system, physical system,*** and ***information system***. The ***management system*** refers to the managers and their functions at the strategic, tactical, and operational levels. The business tasks of the managers consist of physical activities and information processing activities. The managers delegate their physical activities to the ***physical system*** which consists of physical manufacturing facilities and their operators. The managers' information processing activities are supported by the ***information system***. The ***information system*** uses models to process data into information useful to the managers so that they can direct the *physical system* effectively.

The growing global market competition and shortened product life cycle have emphasized the need for *flexibility* as well as *productivity* in the physical system. A flexible manufacturing system (FMS) is a high-technology solution to that need, which combines the benefits of a *flexible* job shop and a highly *productive* flowshop. The physical system of an FMS comprises computer numerically controlled machine tools served by automated materials-handling equipment and supervised by a computer to ensure practically no set up time wasted between different operations. The *flexibility* of an FMS allows the concurrent production of several part types through different routes and the production of modified new part types with minimal lead time and cost.

To highly utilize the *flexibility* in the physical system, *intelligence* in the FMS information system could be useful. Without the help of an *intelligent* information system, it could be difficult for FMS managers to perform well in dynamically changing FMS operation environments. Their decision making can fail quality and timing goals because of the difficulty and complexity in FMS operations.

An *intelligent* information system is different from conventional information systems in that it has a *knowledge base* and an *inference* *engine* as system components in addition to data and models. The *knowledge base* stores knowledge necessary to solve problems in a certain domain. The *inference engine* generates inferences and decisions using the stored knowledge to aid or replace human decision making processes.

The purpose of this paper is to propose a knowledge-based system, a component of an intelligent information system, which supports FMS managers' decisions on the use of production planning models in dynamically changing system environments. Models are defined here to comprise qualitative human judgments as well as quantitative models such as optimization models, algorithms, and heuristics.

Although several OR models and heuristics have been suggested to perform better on FMSs, the effective use of such quantitative models in real FMSs is not a simple task. The quantitative models have different assumptions and input data to generate solutions and may not be understandable to FMS managers. FMS managers usually rely on their judgments and simple analytical methods. For FMS managers to effectively and easily incorporate the solutions of the OR models and heuristics in their judgments, an *intelligent* information system would be useful.

Several studies [BrEL86] [ShCh86] [ThLe86] present knowledge-based approaches to FMS scheduling. Bruno et al. [BrEL87] use production rules to FMS scheduling problems in order to improve the tardiness-based performance. They state that the rule-based system provides FMS schedulers with more transparency, modularity, and flexibility than the previous system written in Fortran. Shen and Chang [ShCh86] suggest frames as a knowledge representation tool for FMS schedule generation. They show a pseudo-code for a frame representation of scheduling algorithms. Thesen and Lei [ThLe86] use production rules to represent some heuristics for dispatching parts to a manufacturing cell.

To FMS production planning, however, there is no extensive study using a knowledge-based approach. Before exploiting a knowledge-based approach to FMS production planning including due date information, FMS production planning problems will be reviewed in Section 2.

2. FMS Production Planning

According to Stecke [Stec85], FMS production problems can be decomposed into four: 1) design, 2) production planning, 3) scheduling, and 4) control.

Design problems include the choice of machine tools and layout, the selection of material handling systems, and the computer control architecture. The *production planning* problems include five subproblems :part type selection, machine grouping, production ratio determination, resource allocation, and machine loading. The solutions to these planning problems for system set-up provide that all cutting tools required for each operation of the selected part types are loaded into the appropriate machines' limited capacity tool magazines. Once the FMS is set up, FMS *scheduling* is the next function. This problem include determining of part input sequences and releasing parts into the system. *Control* problems include monitoring the shop floor situations.

The first subproblem of the FMS *production planning* function - *part type selection* problem - is to select a subset of part types that have been ordered, often with production requirements and due dates, for concurrent and actual machining over some upcoming period of time. The objectives of the part type selection problem are to meet due dates (or minimize mean tardiness) while trying to maximize system utilization. Part type selection must satisfy the following constraints: 1) the production requirements of part types should be produced by their due dates; 2) the cutting tools required for all operations of the selected part types are loaded into the appropriate machines' limited capacity tool magazines; and 3) the number of fixtures of each type is limited.

The approaches to production planning can be classified into two categories: *flexible* and *batch approaches*. A *flexible approach* [StKi86] to select part types is implemented as follows: when the production requirements of some part type(s) are finished, spaces in tool magazines are freed up. Some new part type(s) can be introduced into the system for immediate and simultaneous machining, if this input can help system utilization. A *batch approach* [WhGa84] [Hwan86] [Raja86] partitions the part types into separate batches and distinct machining horizons. All production requirements of the selected part types are produced continuously in one batch. The tools are changed for the next batch.

For different types of FMSs, either a flexible or batch approach is appropriate. In general, using the *flexible approach* enables the system to be more highly utilized [StKi87]. Moreover, the *flexible approach* seems to cope better with due dates, which has not yet been incorporated in the previous studies. There are some situations where the *flexible approach* to solve the short-term production planning problems is useful: 1) production requirements of some part type(s) are finished; 2) some urgent order arrives; 3) some production orders change; 4) one or more new part types begin production; 5) a machine tool goes down; and 6) preventative maintenance is to be performed. The *flexible approach* is employed in the design of the knowledge-based system to FMS production planning.

3. A Knowledge-based Approach to FMS Production Planning

The proposed architecture for an intelligent information system for FMS production planning is shown in Figure 1. The architecture has a knowledge-based system and a data base management system. The knowledge-based system can store and retrieve data about FMS operations in the data base of the data base management system. The knowledge-based system has three components: 1) knowledge base including model base; 2) inference engine; and 3) user interface.

To design the knowledge-based system, we extract FMS planning knowledge from FMS managers and FMS modelers. According to Thesen and Lei [ThLe86], the present situation in FMSs differs from other application of knowledge-based systems in two important aspects. First, there are not many expert FMS managers available. Second, the problem is well structured in the sense that it is possible to build simulation models that predict the effects of applying acquired knowledge from FMS modelers.

A graphical method, diagram, is used to aid the knowledge acquisition process. The diagram in Figure 2 shows a set of FMS

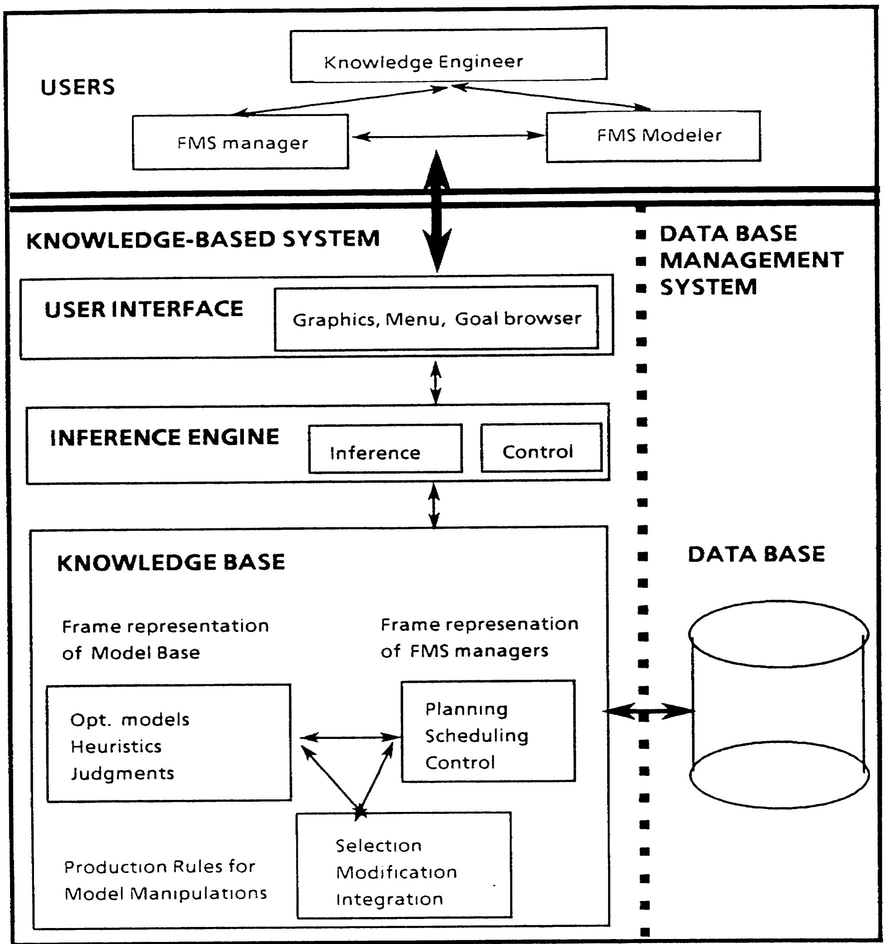

Figure 1. Architecture for an Intelligent Information System for FMSs.

production planning models connected by input edges and output edges. Input edges are used to represent sets of data necessary to produce information to be stored in output edges. The graphical representation is useful to represent knowledge using knowledge representation methods developed in artificial intelligence such as *frames* and *production rules*.

Applegate et al. [AKKN85] compare the advantages of each knowledge representation method with regard to the representation of models and model manipulations. A *frame* is a data structure describing an object or class of objects in a knowledge-based system. *Frames* are composed of slots which contain declarative and procedural information. *Frames* are useful for the representation of problems and model characteristics. *Production rules* are condition-action pairs of the form IF

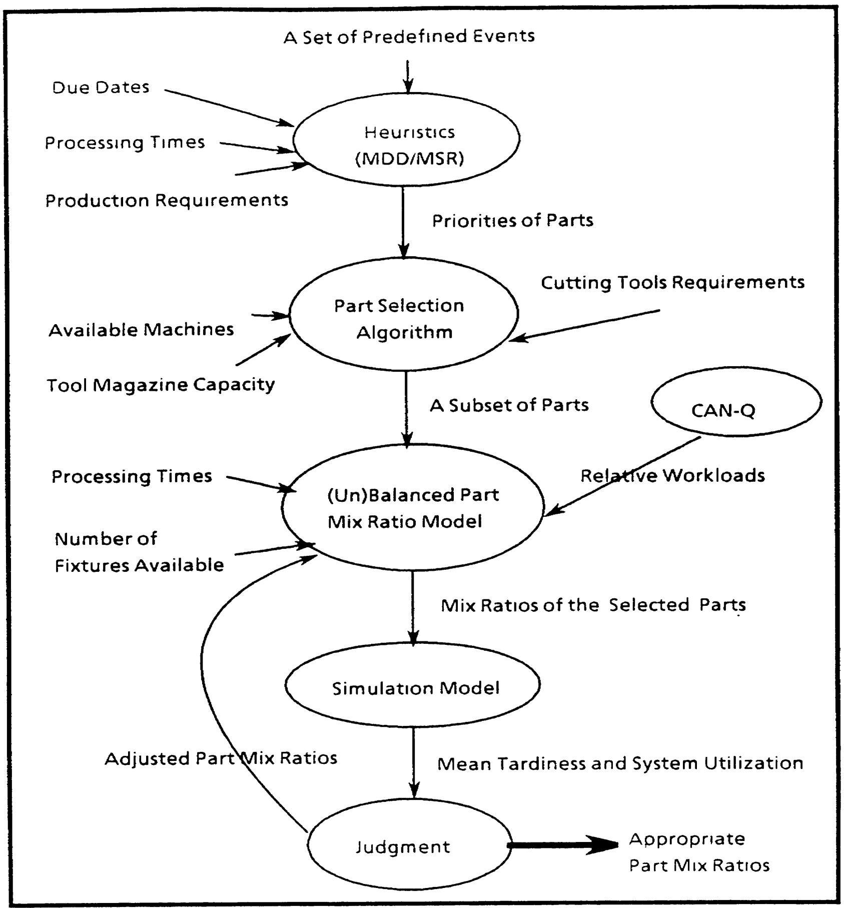

Figure 2. Diagram for Production Planning Models.

[condition] THEN [action]. The use of *production rules* in the model manipulations provides a powerful inferencing structure for model selection and query processing.

KEE (Knowledge Engineering Environment) is used to prototype the knowledge-based system. The knowledge base in Figure 3 shows frame-representation of models and FMS problems that FMS managers should deal with. The knowledge base also shows rule-representation of model manipulations.

A model is viewed as a frame which has slots for model input data, output data, and model processing procedures. An input data slot is a procedural slot which retrieves the input data from a centralized data base. If the data are not found in the data base, it calls for the execution of other model to get the required data. An output slot contains results of model execution.

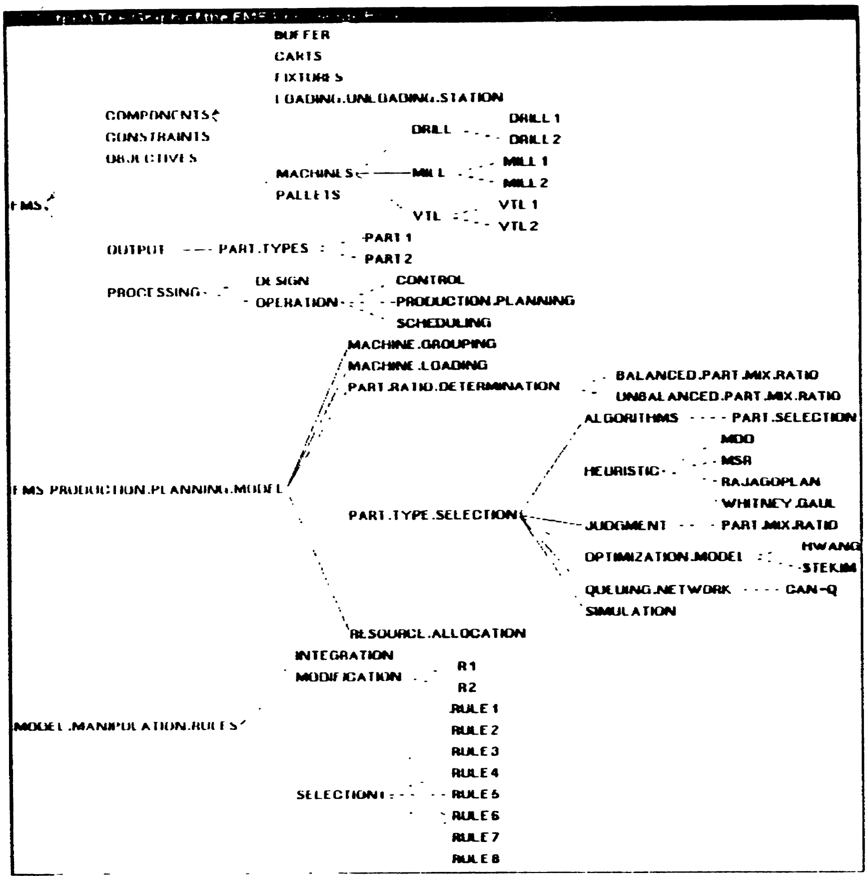

Figure 3. Knowledge Base.

As an illustration, the *unbalanced part mix ratio model* has an input slot which retrieves data about selected part types, number of fixtures available, processing time requirements, and relative workloads. The *unbalanced part mix ratio model* executes a *closed queueing network model*, CAN-Q [Solb77], to calculate the relative target workloads which provide the maximum expected production. The part mix ratios from the execution of the *unbalanced part mix ratio model* are stored in the output slot. The model processing slot contains procedures to call external solution packages such as LINDO [Shra81].

Model manipulations are represented in production rules. The production rules include selection rules, integration rules, and modification rules. The selection rules represent model selection procedures to provide the user with an appropriate model to solve problems. If there is not an appropriate basic model in the model base, the knowledge-based system is able to integrate a new model using existing basic models. Modification rules describe how models can be dynamically changed. Especially, models for adjusting part mix ratios can be modified by learning, based on data about their historical and statistical performances in the specific FMS environment.

Synthesis of knowledge representation methods - frames and production rules - is achieved by an object-oriented view, where both frames and rules are considered as objects. KEE allows production rules to be stored within and activated from frames to make inferences. The strength of an object-oriented view lies in its ability to represent models and their interactions in cogent form, i.e., objects. It provides "inheritance" of attributes of models. It also can represent interactions among models by "messages" sent between them, which provides a natural way of representing the interactions.

The following sample session shows a sequence of fired production rules of which the IF CONDITIONS are met when an urgent order arrives. It also demonstrates the "message sendings" between the objects (boldface) in the knowledge-based system.

IF	<	Some urgent orders arrive >
THEN	<	The stage of **OPERATION** is part priority determination >
	<	Send a message to **FMS.CONSTRAINTS** to update due dates, processing times, and production requirements >
IF	<	The stage of **OPERATION** is part priority determination >
THEN	<	Send a message to **MODIFIED.DUE.DATE.HEURISTIC** to determine priorities of part s >
	<	The stage of **OPERATION** is part selection >
IF	<	The stage of **OPERATION** is part selection >
THEN	<	Send a message to **FMS.CONSTRAINTS** to update available machines and tool magazine capacity >
	<	Send a message to **PART.SELECTION.ALGORITHM** to select a subset of part types for simultaneous processing >
	<	The stage of **OPERATION** is part mix ratio determination >
IF	<	The stage of **OPERATION** is part mix ratio determination >
AND	<	The size of groups of pooled running machines is unequal >
THEN	<	Send a message to **FMS.CONSTRAINTS** to update the number of fixtures available >
	<	Send a message to **UNBALANCED.PART.MIX.RATIO.MODEL** to determine mix ratios >
	<	Send a message to **CAN-Q** to determine relative workloads >
	<	The stage of **OPERATION** is part mix ratio evaluation >
IF	<	The stage of **OPERATION** is part mix ratio evaluation >
THEN	<	Send a message to **SIMULATION.MODEL** to estimate mean tardiness and system utilization >
	<	The stage of **OPERATION** is part mix ratio judgment >
IF	<	The stage of **OPERATION** is part mix ratio judgment >
THEN	<	Send a message to **JUDGMENT** to examine whether mean tardiness and system utilization are improved >
IF	<	Mean tardiness and system utilization are improved based on **JUDGMENT** >
THEN	<	Send a message to **UNBALANCED.PART.MIX.RATIO.MODEL** to determine new part mix ratios >
IF	<	Mean tardiness and system utilization are not improved based on **JUDGMENT** >
THEN	<	Return the selected part types and mix ratios to the system user >

4. Conclusions and Future Research

This paper proposes a knowledge-based system, a component of an intelligent information system, to the part type selection/production ratio problems at the FMS production planning stage. KEE is used to prototype the knowledge-based system.

The knowledge-based system incorporates due date information in the production planning stage. The information has usually been considered in the scheduling stage. A machine learning mechanism is considered to make the proposed knowledge-based system *truly* intelligent. Especially, the learning mechanism helps compare the alternative part mix ratios by observing historical data concerning previous judgments and by analyzing and learning from such experiences.

The proposed knowledge-based approach for FMS operation also has the following advantages: 1) integration, 2) transparency, and 3) modularity. The knowledge-based approach provides FMS users with an *integrative* view of solution over different problem domains such as production planning, scheduling, and control. The knowledge-based approach provides a transparency and coherence in the representation of different types of models. The knowledge-based approach provides modularity in the use of the knowledge for FMS operations. Modularized production rules and frames can be easily added, modified, and deleted from the knowledge-based system.

To evaluate the performance of the suggested knowledge-based system, a simulation model will be written in a knowledge-based simulation language such as SIMKIT. Simulation results will show how much the performance of the FMS is enhanced by applying artificial intelligence to the information system for FMS production planning.

There are further research needs along these lines. This study should be extended to the subsequent production planning problems such as grouping and loading problems. Also, the proposed knowledge-based system for production planning problems should be integrated with those for FMS scheduling and control to help operate an FMS on-line.

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