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Process Capability Models for Design and Selection of Processing Equipment

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Abstract

Due to the increased complexity of modern manufacturing facilities and the increased demands for product variability and system flexibility there is a need for coherent formal representation of the basic knowledge domains supporting manufacturing applications such as equipment selection. The paper presents an integrated framework for equipment selection based upon describing process capability at generic, machine tool and manufacturing system levels. The decision making process is designed as a sequence of steps for transforming component design information into processing requirements which are mapped into specific physical machines organised as a processing system.

1. Introduction

Equipment selection is a complex and time consuming process which requires a number of important decisions to be made and a large number of inter-related factors to be taken into account (Kochhar and Pegler, 1991). Many of the difficulties faced when attempting to formalise the decision making logic for equipment selection arise from the need to transform information, at several levels, between closely inter-related domains of components, manufacturing processes and manufacturing resources used for their production. Knowledge integration to facilitate transformations between the three domains is one of the crucial issues to be addressed during development of equipment selection systems.

Engineering design has the major objectives of ensuring that products fulfill specific functional requirements and can be manufactured. Frequently these objectives can most usefully be expressed through a description of the product in terms of a set of inter-related features. The functionality and manufacturing requirements to assure the component's performance can be described by a unified feature-based part representation which forms an important part of the information and knowledge required by various activities such as detail design, process planning, assembly process planning and inspection operation planning.

Manufacturing processes were traditionally closely associated with specific types of machine tools used for their execution (Alting, 1982; Eversheim, Marczynski and Cremner, 1991). The advent of multi-axis machining centres and the general increase in capabilities of machine tools, however, has reduced the relevance of such close linking and has underlined the need of machine independent process representation which can capture the exclusive and the repeated processing capabilities of different machine tools.

The research reported here is based on the development of an integrated model of the relationships between some of the important parameters influencing equipment selection. The model is then used as the basis for developing a decision support system for equipment selection. The methodology is generic and can easily be extended to include other factors that influence equipment selection not directly considered in this work.

The methodology embeds a novel feature representation based on a feature taxonomy within a proprietary CAD system providing a feature-based description of component attributes. The multi-component data held in a knowledge base is then processed through a work content analysis module to attach multiple technological solutions to component features based on process capability models. A component grouping module is used for optimising the partitioning of the component set into part

families based on their resource requirements. A functional description of the processing system is produced and is used for the final selection of machine tools taking into account the manufacturing system constraints.

2. Feature Based Component Data Model

The input to the system is a feature based component description. Component features are considered as geometric entities which have significance in the context of component design and manufacture. Examples of such features are hole, step, pocket, etc., each of which is uniquely classified and described within a component model.

Features are treated as volumes enveloped by entry/exit and depth boundaries. Feature geometry is described by deciding on its external approach directions, i.e. the number of imaginary faces included in feature definition, its form variation with respect to its depth axis. Component form features are organised into a hierarchical structure for their definition and classification which includes categories, classes and sub-classes (Gindy, 1989).

Component connectivity which describe the relationships between adjacent features is represented by two types of links: external access directions for relating individual features to the basic component directions; and inheritance links that relate adjacent features, with some features becoming parents to other features (Gindy, Huang and Ratchev, 1993). At the component level, the technological relationships (geometrical and positional tolerances) between features are also recorded.

The attitude adopted in this research is that it is more natural to re-configure geometric modelling systems so that feature-based part data can be created through the interactive CAD interface and transferred to other application systems without further human assistance then using feature recognition (Case, 1994). The research resulted in a prototype design by features system which takes advantage of the facilities of a commercial solid modeller, but builds upon this to provide an enhanced feature modelling capability which uses a geometric reasoning mechanism for feature validation and feature enhancement

3 Integrated process capability models

Process capability is related to three fundamental levels. The first is "form generating schema" to be used for describing process knowledge at a level that is independent of the machine tool and machining facility used for process execution. The second level of abstraction is the "operation" level that is used to attach machine specific attributes to manufacturing processes. The third is the "resource element" level which is used to complete the loop by relating both the form generating schema and operation levels to the way in which machine tools are organised as a manufacturing system.

3.1 Form Generating Schemas

Form generating schema (FGS) is defined as technologically meaningful combination of tool of specific geometry, set of relative motions between a part and the tool, and nominal levels of technological output that can be associated with using that combination of tool and relative motions (see Figure 1). Form generating schemas are machine independent, but can be used to provide a generalised description of machine tool capabilities.

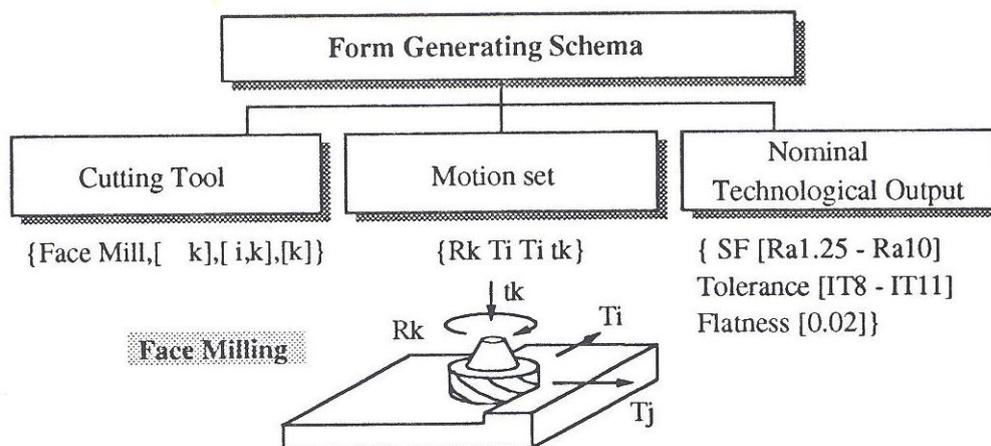


Figure 1. Form generating schema - an example.

The links between the form generating schemas and the component features are provided through feature transition diagrams (FTD) - collections of form generating schemas capable of producing specific feature geometry and various levels of technological output. Feature transition diagrams reflect company specific knowledge on how features are machined.

Process selection is based on finding the set of terminal nodes in a feature transition diagram which match the feature requirements in terms of surface finish and tolerances. All feasible, equally weighted processing sequences are then selected through backtracking.

3.2 Machining operations

A form generating schema acts as the root for defining various machining operations. Operation inherits the attributes of the FGS it originated from and the division of motions between a part and the cutting tool from the machine tool used for its execution. A machine tool performing an operation also provides the specific levels of technological output to be attached to machining operations.

A typical example are the machining operations originated from FGS "drilling" when performed on a lathe and on a drilling machine - their tool and motion set are identical with the only difference being that on a lathe component is rotating and the tool is translating while on a drilling machine both motions are given to the tool.

3.3 Resource Elements

Many manufacturing facilities contain identical machines and several machine tools with overlapping capabilities in terms of form generation and technological output. During equipment selection, however, a methodology is needed for computing machine capabilities to provide a basis for deciding between alternatives before a final selection is made.

The set of machine tools defining a manufacturing facility are described using a set of resource elements (RE). Each RE represents a collection of form generating schemas which define uniquely the exclusive machine tool capability boundary and the shared boundaries between machine tools (see Figure 2).

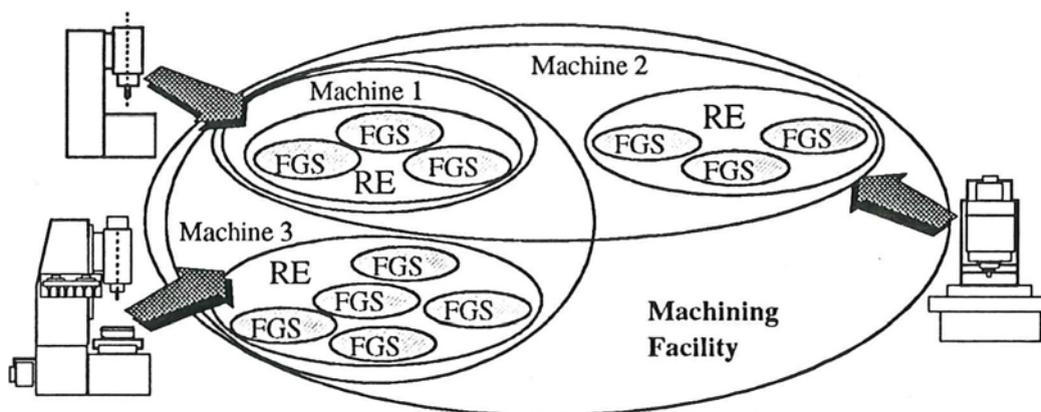


Figure 2. Machining facility represented using resource elements.

Resource elements are machining facility specific and capture information relating to the distribution (commonality and uniqueness) of form generating schemas among the machine tools included in the machining facility.

Although an RE may be attached to several machine tools, a form generating schema can belong only to one RE. A machine tool has to be capable of carrying out all the form generating schemas of the REs associated with it.

4 Concurrent Grouping Methodology and Cluster Validation Measure

Two fundamental problems limit the practical usefulness of clustering techniques used for part family formation in modern cellular manufacturing systems: (1) the unrealistic nature of the distribution of components in the groups formed by the clustering algorithm; (2) the lack of a representative cluster validity measure for partitioning components into meaningful groups - a problem known as cluster validation. Several aspects relating to both problems have been addressed in this work by developing a

concurrent grouping methodology for component family formation and machine grouping using fuzzy clustering techniques (Gindy, Ratchev, 1993).

The methodology is based on iterative definition of component groups and machining cells/functional areas until an optimum partition is achieved (see Figure 3). The approach uses resource elements as basic grouping primitives. It also utilises new machine/resource element membership function and methodology for incremental decomposition of the target component set .

Grouping starts with two groups and continues until the number of groups reaches a value beyond which grouping is not feasible. At each step partitions are validated by a cluster validation measure assessing the compactness and repetition of the component /machine groups:

$$R = \lambda / r$$

where λ measures the average group/cell compactness (component deviation) and r is the measure of the resource element repetition between the clusters (capability overlapping). The partition with minimum R is selected as 'optimum'.

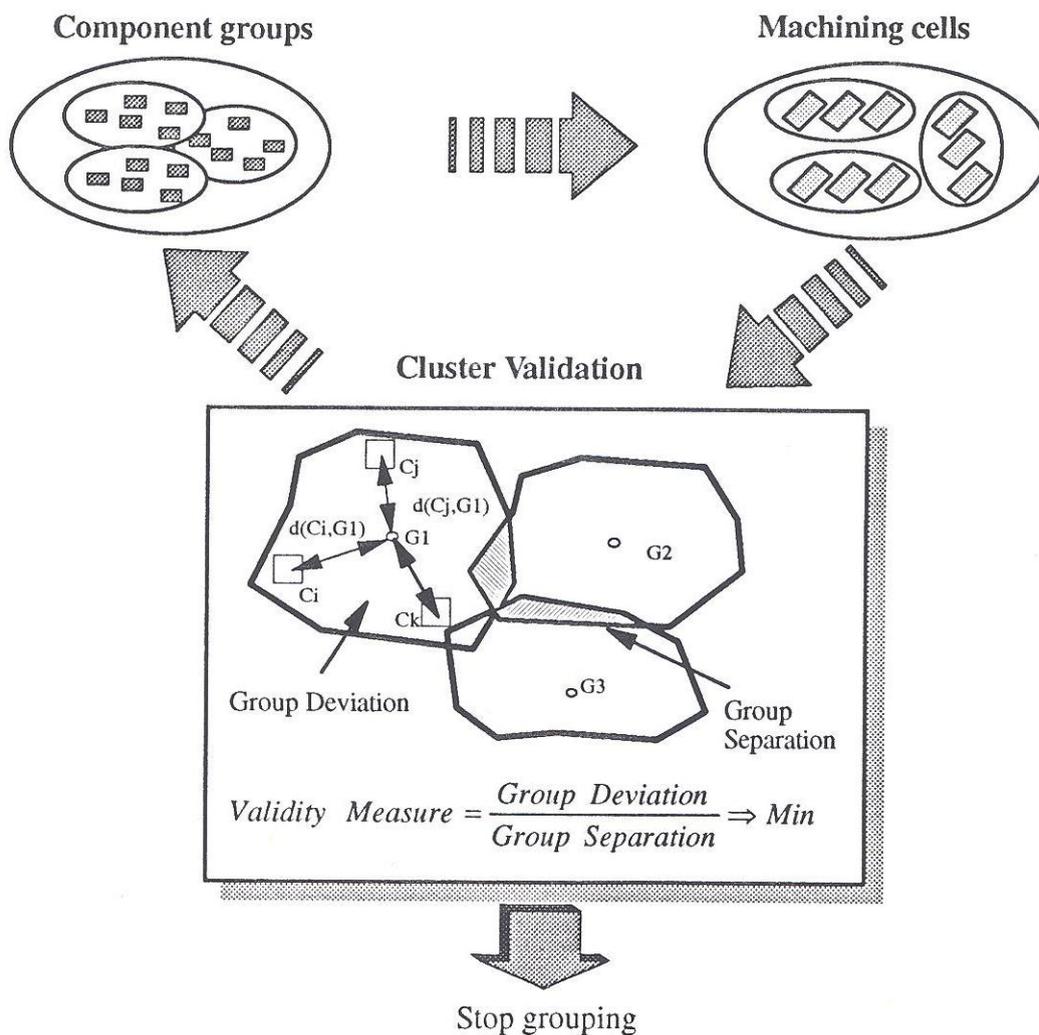


Figure 3. Concurrent grouping methodology

The proposed methodology and algorithms are aimed at improving the practical applicability of the fuzzy clustering approach for part family formation in cellular manufacturing environments. The developed methodology has been experimentally demonstrated using industrial data and compared with several well known grouping examples from the published literature.

5 Prototype System for Equipment Selection

The parameters used for describing component features, their manufacturing methods, the capabilities of processes and manufacturing system constraints are integrated to support the decision making process. The integrated framework for equipment selection and cell determination is described in Figure 4.

The selection procedure starts with a work content analysis module. Based on individual feature attributes, an FTD database is consulted and alternative TSFs (technological solutions at feature level) generated for each component feature of the target component set.

Deciding between alternative technological solutions for the component features is resource based. Each TSF is represented by a set of resource elements needed for its completion. The chosen optimisation strategy is based on selecting a combination of TSFs for the individual component features, such that variety of the resource elements used for processing the whole component set to be minimised. The result is a single TSF being attached to each component feature without pre-judging the set of machine tools that may be finally selected.

The capability requirements for each machining cell are defined by component grouping using resource elements as basic grouping primitives. The final step of the selection process is machine specification in terms of transforming the capability requirements of the designed machining cells into physical machines. The selection is carried out based exclusively on capability requirements without considering planning and scheduling issues at this stage.

6 Conclusions

Adopting modelling approach to integrating the information requirements of an application such as equipment selection has many advantages. The developed process capability models help simplify the decision making logic and facilitate development of structured and modular systems which are easy to update and maintain. The methodology employed can be easily extended to include other factors not considered in this research.

The work proposes several new and significant improvements to current grouping methodology and a new concept based on resource elements for component family formation for cellular manufacturing systems.

Although the application area of the work is in the selection of processing equipment, the developed capability models can be used in many manufacturing applications that require process capability information e.g. process planning, machining conceptual design or manufacturing cell determination. The research results have significant implications for the methodologies employed for manufacturing cell determination and the field of group technology as a whole.

7 References

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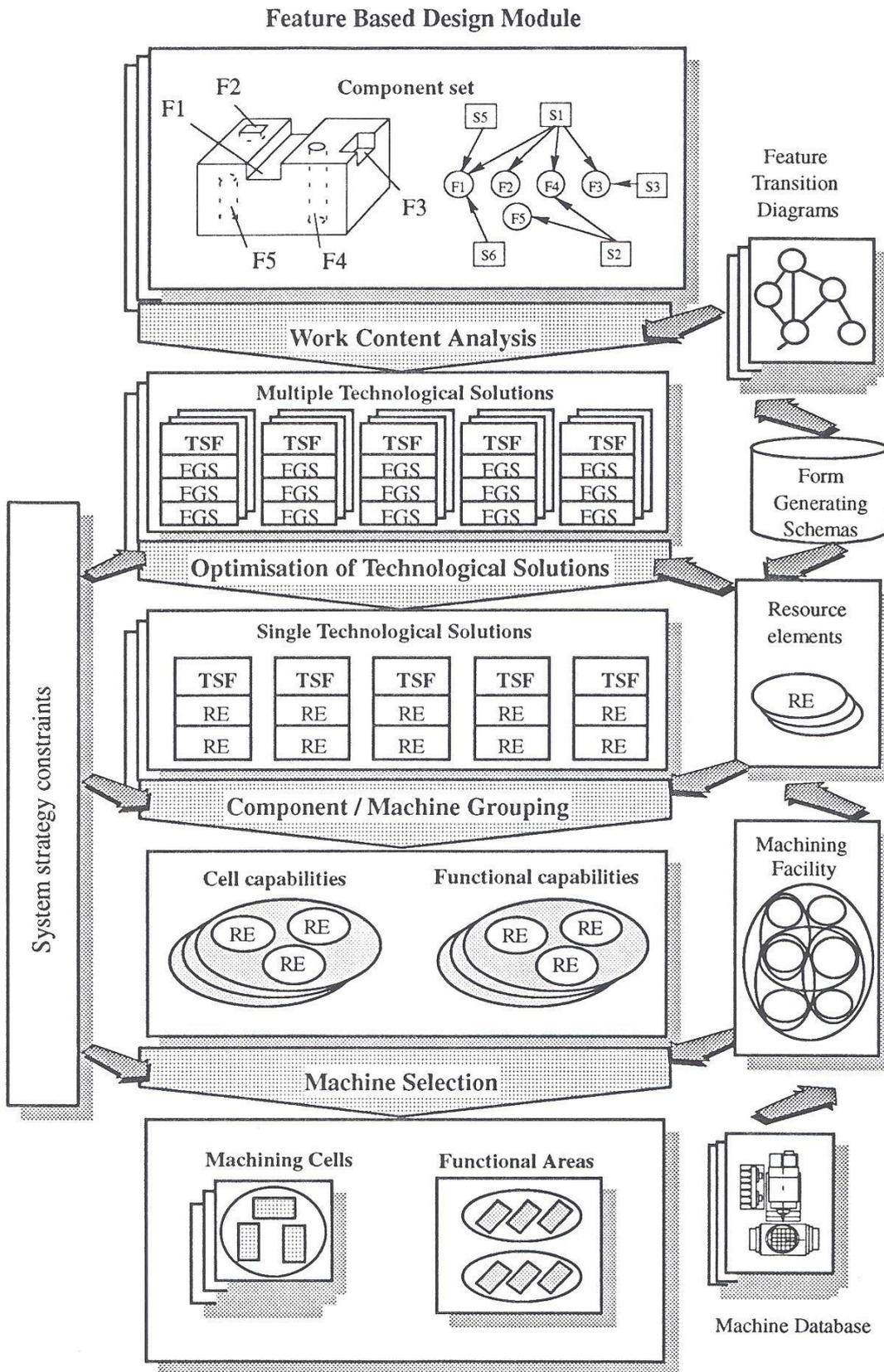


Figure 4. Prototype system for equipment selection