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Virtual cellular manufacturing

Nomden, Gert

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Summary

This thesis presents research on how Virtual Cellular Manufacturing can be used to improve throughput time performance of small-batch discrete parts manufacturing operations. These improvements can be realised by combining product and process orientations in the design of manufacturing systems.

A process-oriented, or functional, organisation can accommodate low volumes of a great variety of parts and is robust against mix changes and disruptions. A product-oriented manufacturing system, that usually takes the form of Cellular Manufacturing within small-batch discrete parts manufacturing, has been used to improve throughput times. But the performance benefits are uncertain, especially in dynamic circumstances, and there may be high costs involved in acquiring and relocating equipment.

With Virtual Cellular Manufacturing, groups of resources, i.e. Virtual Cells, are dedicated to the manufacturing of a part family, just like conventional Manufacturing Cells. However, the original (functional) layout is retained: the cells are formed, and only exist, in the planning and control system. It thereby combines the advantages of both Cellular Manufacturing and a functional organisation.

This thesis consists of two parts. The first part concentrates on an overview of existing research (Chapter 2), and the examination of three industrial situations (Chapter 3). The second part consists of simulation studies of family-based dispatching under various conditions (Chapters 4–6).

Chapter 2 sets the scene for the rest of the thesis by reviewing 25 years of research into Virtual Cellular Manufacturing to determine the appropriate methods and scope for the research to be undertaken. First, the evolution of Virtual Cellular Manufacturing is discussed. This results in a framework which identifies the principles underlying Virtual Cellular Manufacturing. This framework is used to classify and discuss the various Virtual Cellular Manufacturing concepts, and to identify potential issues for future research. This review concluded that most of the research to date has focused on using mathematical models and simulation studies to establish appropriate designs and operational rules for virtual cells. There have been a limited number of industrial surveys and case studies that address Virtual Cellular

Manufacturing, and these show that a fair number of companies rely on some form of Virtual Cellular Manufacturing. Much analytical and simulation work remains to be done, both for the design of Virtual Cells and to better understand their operational performance. The chapter also highlights a major need to better understand the industry reality that surrounds Cellular Manufacturing (virtual or physical) through additional and more rigorous empirical research. Chapter 3 responds, to some extent, to this identified need.

As such, Chapter 3 investigates the applicability of Group Technology in industrial practice. The chapter distinguishes two basic Group Technology principles: the exploitation of (1) processing similarities and (2) routing similarities. Three case studies undertaken in parts manufacturing companies were carried out to explore the applicability of these two principles. The case studies show that the first principle is implemented through planning and control practices that reduce set-up times, processing times and material handling times by making use of the similarities among parts. The second Group Technology principle is reflected in practices related to the flow of materials that distinguish part families with similar routings. The benefits of this principle can be realised through the establishment of permanent physical cells, dynamic cells or virtual cells. Contextual factors may hinder the application of Group Technology principles. The most common barriers found were linked to the manufacturing technology. Other important barriers include inadequate information technology and organisational constraints. Despite these potential constraints, the first Group Technology principle, exploiting processing similarities, is relatively easy to apply: it can be applied to a single operation and it does not require a reorganisation of the factory layout.

The conclusions drawn from the industrial case studies provide guidance in developing the second part of this thesis, by serving as a valuable reference and source of inspiration for the simulation studies. The remaining chapters focus on the first Group Technology principle (exploiting processing similarities) in the form of family-based dispatching. Here, jobs are grouped and processed family-wise to reduce the number of major, family-specific set-up changes and, consequently, performance in terms of throughput time may be improved. Family-based dispatching decisions assume a two phase approach: a part family is chosen before the choice of which specific job is to be next processed is made.

Family-based dispatching has wide practical applicability, but its basic effects on shop performance have not been well understood. In an attempt to clarify the benefits, simulation studies have been undertaken and are reported in the remaining

part of this thesis. Simulation has been selected because it is the only quantitative method that can adequately handle dynamic processes and complex controls. The simulation models have been restricted to the smallest possible systems, and only include a limited number of experimental factors, in order to deliver insights that are not obscured by overly complex systems (elaborate job shops etc.).

Chapter 4 focuses on the application of family-based dispatching in a single-machine shop. The effects of including data on upcoming job arrivals are studied. A classification framework is developed to discuss and analyse existing family-based dispatching heuristics and their decision logic. As an intermediate result, two new family-based dispatching rules are proposed. In addition, the heuristics are adapted to use information on upcoming job arrivals. A simulation study compares the throughput time performance of the two new rules with rules currently applied in practice. The best rules are those that focus on reducing the total time spent on setting up machines for the various jobs to be completed. Significant improvements are achievable by employing near future arrival data because this introduces the possibility to start setting up equipment prior to the job's actual arrival.

Chapter 5 extends the single machine situation to shops with several identical machines operating in parallel. Virtual Cellular Manufacturing is considered in the form of family-based dispatching that should reduce the number of major set-ups. Two industrial cases which shed light on this issue are first discussed; the central managerial issue seems to be how investments in additional routing flexibility can improve the shop's throughput time performance. These investments in routing flexibility influence (1) the number of alternative routes available for a product family (level of routing flexibility), (2) which product families have access to which machines (distribution of routing flexibility) and (3) the number of secondary resources which can be shared among machines (tools, fixtures, dies etc.). The chapter considers alternative applications of Virtual Cellular Manufacturing in a simulation model of a parallel machine shop. The best results are achieved when job allocation and dispatching decisions are taken simultaneously: jobs that best fit the current machine set-up are then 'pulled' from a central queue by the machines. The level of routing flexibility significantly affects performance, but low levels of routing flexibility are sufficient to capture most of the potential benefits. Linking all available machines through product routings, or so-called chaining, offers the most options in distributing peak loads over the entire shop. Adding additional secondary resources is most beneficial in situations with a small number of product families and a small set-up to run-time ratio, i.e. when the demand for such resources is greatest.

Chapter 6 extends the single machine case further to a small manufacturing network of three machines, and further considers situation both with and without labour constraints. This situation was inspired by one of our industrial case studies. It explores the impact of applying family-based dispatching to a key machine on the cell's throughput time performance. Other experimental factors considered are load variations between machines and the routing of jobs. The simulation outcomes for manufacturing cells without labour constraints show that job routings and load variations should have an impact on the decision as to where to locate family-based dispatching. Not surprisingly, family-based dispatching has the greatest impact when it is applied at a bottleneck station. When jobs with the same routings also belong to the same set-up family, family-based dispatching causes a more irregular flow of jobs to subsequent station. This leads to increased waiting times at those stations. In contrast, in cells with labour constraints, the beneficial effects of family-based dispatching are much less vulnerable to such issues. Since workers form the bottleneck in these cells, the specific machine at which the set-up times are reduced is less important.

The findings of this thesis, especially those relating to family-based dispatching, may be relevant to many small-batch discrete parts manufacturing companies. The focus on relatively simple simulation models has promoted an understanding of how local family-based dispatching decisions influence both local and shop-wide performance. Nonetheless, there still exist interesting avenues for further research, such as the development of information systems for the design and operation of Virtual Cellular Manufacturing.