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C H A P T E R 3

Case studies

This study addresses the applicability of Group Technology (GT) principles in part manufacturing. We distinguish two basic GT-principles: (i) exploiting processing similarities and (ii) exploiting routing similarities. A basic conceptual model is presented which indicates how the two GT-principles can be applied in parts manufacturing. Based on three case studies, we further explore the elements in the conceptual model. We show how the principles are, or can be, applied in practice. Important contextual barriers for applying the GT-principles are identified in our research. Furthermore, several suggestions for further research result from our study.

3.1 Introduction

During the last decades, the academic community has shown considerable interest in Group Technology (GT). This philosophy builds on the recognition and exploitation of similarities between products (see Suresh and Kay, 1998). According to an endless number of scientific papers, the ultimate result of applying GT is the establishment of manufacturing cells. A manufacturing cell is a physical grouping of machines dedicated to the manufacturing of a product family. This mode of operation—Cellular Manufacturing (CM)—benefits from similarities in manufacturing requirements among members of a product family, leading to reduced set-ups, less material handling, and more (Burbidge, 1975). Often, CM goes together with practices like pull production, family-oriented planning, transfer batches etc. (Hyer and Wemmerlöv, 2002).

A number of industrial surveys, conducted in different parts of the world, clearly show the limited adoption of CM in practice. Unbiased surveys (i.e. not aimed at users or likely users) indicate a certain CM adoption level ranging from 9.4% for small machine shops, with less than 50 machines (Wisner and Sifer 1995) to 50% for firms larger than 150 employees (Waterson et al., 1999). A certain adoption means that at least one manufacturing cell is present. Among likely users

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60% to 79% of the firms had adopted CM to a certain extent (Wemmerlöv and Hyer, 1989; Wemmerlöv and Johnson, 1997, 2000; Johnson and Wemmerlöv, 2004). Complete adoptions of CM, where each machine is in a manufacturing cell, are rarely found. Apparently CM cannot be applied in all manufacturing environments.

Little research has focused in-depth on the underlying problems of implementing CM. Burbidge et al. (1991) argue that the low degree of adoption of CM in the UK (according to the authors only 10% of suitable organisations used it) was solely due to ignorance, prejudice and fear. Several authors give other arguments for not adopting CM. Required layout changes may involve high costs, which prevent the change towards CM (see for example Choi 1996, Johnson and Wemmerlöv 2004, Waterson et al. 1999). Also product mix variations can be one of the reasons to maintain a functional layout. Molleman et al. (2002) present a case study in which a firm goes through several phases from a cellular to a more functional layout. Characteristics of new technology, organisational reasons, changing market conditions and altering strategic considerations played a role in the various transitions.

Although many firms do not (fully) implement CM, it is still likely that similarities among products are present within these firms. Hence, some form of GT may be applied to the operation of these companies. This thought opens the question how and to what extent GT may play a role in modern manufacturing. Our study is devoted to this question. The objective of this paper is to identify opportunities and limitations for the application of GT within manufacturing operations.

In our study, we distinguish two basic GT-principles that can be applied to improve manufacturing performance: 1) exploiting processing similarities and 2) exploiting routing similarities. These principles are related to early efforts made in coding and classification of part types and cell formation (i.e. Mitrofanov, 1966, Burbidge, 1963). Section 3.2 presents a conceptual model showing the link between the two GT-principles and their operationalization in the planning and control system and manufacturing cells. This conceptual model is the starting point for three exploratory case studies. The choice for case study research is explained in section 3.3. Section 3.4 gives short descriptions of the three cases explored in our study. In section 3.5 we present the results of our study. The main result is an extended conceptual model indicating the applicability of the two GT-principles and the contextual factors which play a role in their application. Section 3.6 discusses the results of our study and lists some implications and suggestions for future research in the area. Section 3.7 gives the conclusions of our research.

3.2 A conceptual model for the application of GT in parts manufacturing

In this section we will explain the logic of the conceptual model of 3.1. This model shows that the planning and control system is essential to take advantage of the first GT-principle (i.e. processing similarities). The second GT-principle (i.e. routing similarities) is focused on the creation of manufacturing cells. The planning and control system is a moderating factor for the advantages achieved through application of the second GT-principle (i.e. routing similarities). In subsections 3.2.1 and 3.2.2 we will shortly explain the two GT-principles and the logic of the conceptual model. Subsection 3.2.3 discusses the link between the two GT-principles and the role of the conceptual model in our case study research.

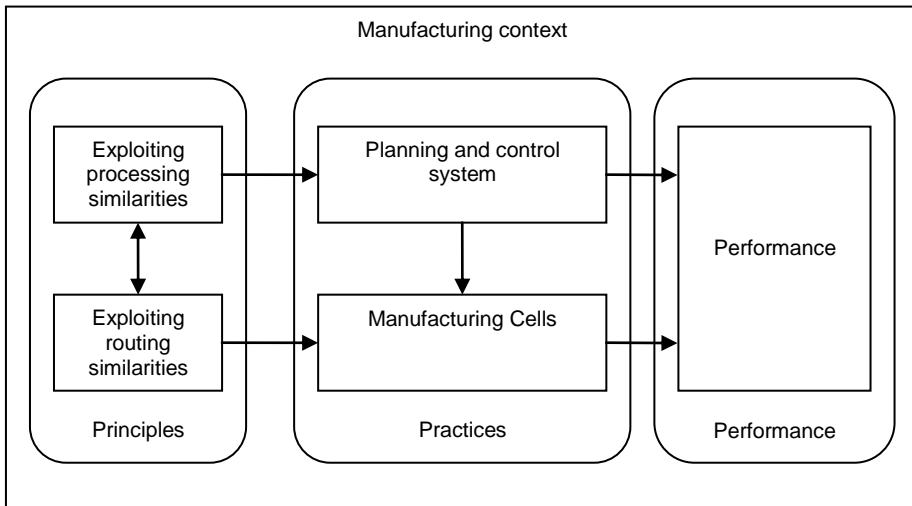


Figure 3.1: Conceptual model of the application of GT Principles

3.2.1 Principle I: exploiting processing similarities

The first principle concerns the *individual processes* performed within a company. It consists of efforts to reduce set-up times, processing times and material handling times by exploiting the similarities among parts. Especially set-up times can be reduced by clustering the operations on parts with similar manufacturing requirements. This is typically realized through the production planning and control system. Resources may be dedicated permanently through routing decisions, or temporarily during capacity loading decisions by assigning jobs from the same part family to the same machines. Lot-sizes may be defined on a family basis (e.g. Potts

and Van Wassenhove 1992). Order release and family-based dispatching may realize further set-up savings on the shop floor (Kannan and Gosh 1996a, Nomden et al. 2008, Bokhorst et al. 2008). Focusing resources on the operation of a narrow set of parts may also reduce processing and material handling times because of, for example, increased worker proficiency. In all cases improved efficiency may result in reduced throughput times and work in process levels (e.g. Suresh and Meredith 1994).

3.2.2 Principle II: exploiting routing similarities

The second GT-principle refers to the *flow* of materials and focuses on routing similarities of parts. This principle is oriented towards the establishment of autonomous manufacturing cells. Most research focuses on so-called real cells: products with similar routes are grouped into families, each of which is processed completely by a co-located group of complementary resources (Hyer and Brown, 2002). A relative new field concerns Virtual Cell Manufacturing, where workers and machines are dedicated to the manufacturing of a part family as well, but these cells are not reflected permanently in the layout of the manufacturing system (see Nomden et al. (2006) for an overview). Reduced handling distances inside a real cell will provide some benefits by themselves and may allow for overlapping operations. Product quality may be improved because of part similarities within a cell and short feedback loops. Multi-skilling of workers and the relative autonomy of a cell may improve labour quality. A common assumption is that a positive correlation exists between routing similarities and processing similarities, i.e. that parts with a similar route also share similar set-up requirements, demand characteristics, processing times and so on. Provided that such a positive correlation exists, benefits from the first principle might be realized inside a manufacturing cell as well. This will further reduce congestion, lead times and work in process levels (Suresh and Meredith 1994).

Although manufacturing cells offer many advantages on their own, an important moderating factor is the adaptation of the production and control system to the cellular system (see for example Olorunniwo 1996). Shorter throughput times will only be realized if the planning and control system takes care of a balanced loading of the cells. Family-oriented planning, release and dispatching may still be needed to realize set-up savings and subsequently reduce lot-sizes. Only then may all potential benefits of GT be materialized (Suresh and Meredith 1994).

3.2.3 Conceptual model

The conceptual model of figure 3.1 shows in general terms how the two GT-principles may influence manufacturing performance through their application in planning and control practices and manufacturing cells. In addition we have drawn an exclamation mark between the first and second GT-principle in the conceptual model. This exclamation mark indicates that the application of one of the principles may have impact on the applicability of the other principle, as discussed previously. The establishment of manufacturing cells by means of the second GT-principle may, for instance, reduce possibilities to form groups of jobs according to processing similarities (first GT-principle). Jobs which need an identical operation on a particular machine type may be assigned to different manufacturing cells. Each of these cells may therefore have a machine of that particular type. We have also put the phrase ‘manufacturing context’ in the conceptual model. We are interested to know how the manufacturing context influences the applicability of the GT-principles.

The model of Figure 3.1 can be seen as the conceptual proposition of the research presented in this paper. With the help of this conceptual model three cases will be analysed. This leads to the following results:

- Insight into the current and potential application of the two GT-principles within three manufacturing companies. These insights enrich the scarce literature on applying GT-principles in parts manufacturing;
- An overview of contextual factors that complicate the application of GT-principles. Our main objective is to gain a deeper, empirically-based understanding of the role of these contextual factors;
- Support for practitioners to assess the potential benefits and obstacles for GT-principles in their specific situation;
- The identification of relevant topics for further research.

3.3 Research design

There is a need to gain more empirical insight in the various aspects which play a role in gaining advantages from the application of GT-principles. Prior empirical studies concern surveys of (likely) users of CM, and some case descriptions of relatively successful CM implementations. Our focus is on gaining insight in the applicability of GT-principles in companies which are, more or less, representative for part manufacturing industry. We decided to perform case study research in order

to capture the complexities of reality and to determine useful future research directions.

Multiple cases were selected, which enhances the generalisability of our study (Voss et al., 2002). We sought companies active in small batch discrete parts manufacturing, but in different sectors. We pursued variety among cases by selecting for differences in terms of end-items, manufacturing technology, size, vertical integration etc., as is recommended by Meredith (1998). Peers were consulted to suggest companies (or business units) that applied GT-principles (especially CM) to varying degrees. As a result, we selected three companies. Since they were all part of the university's network, obtaining access was relatively easy.

Each company was visited several times, including a factory tour and multiple interviews. Interview respondents include shop supervisors and production engineers/process planners, as well as other functions depending on the specific case (e.g. purchasing officer, machine operator, technical assistant). The interviews were semi-structured, allowing to explore topics that were triggered by surprising events, spontaneous remarks, etc. All companies provided manufacturing datasets from their ERP-system. Using data from multiple sources and the different viewpoints of respondents helps to achieve construct validity (Yin, 1989). Each case was analyzed independently and explanations for the observed phenomena were given. The findings in each case were compared to the outcomes of the other cases, in an attempt to refute ad hoc hypotheses. This way internal validity can be achieved (Yin 1989). Finally, we used a case protocol to specify interview schemes and other data requirements. The obtained data, documents, observation notes and interview transcripts were coded into a spreadsheet. Specifying each individual case, this spreadsheet made up our case database to achieve reliability (Yin, 1989). The tabulated data facilitated finding patterns and building explanations.

3.4 Company profiles

In this section we provide a description of the three companies participating in our research. We also describe the extent to which they use principles of GT in their manufacturing operations. The main purpose of this section is to obtain appreciation for the manufacturing system design choices made by each firm. Table 3.1 presents some basic information about the three firms.

3.4.1 Company A: Poseidon

The company designs, manufactures and sells centrifugal pumps for the (petro)chemical industry, horticulture market, and shipbuilding industry. Our study

has focused particularly on the mechanical processing department, which produces parts (casings, impellers, shafts, etc.) for the various assembly cells. Competitive forces drive the company towards more product customisation, since it can hardly compete on price against mass producers and low-wage countries. Due dates are often tight and the department struggles to decrease throughput times while remaining efficient at the same time. The customisation of pumps varies from customers ordering a unique pump configuration (assemble-to-order), up to purchasing and/or adapting parts of a pump on a customer's request (engineer-to-order).

Poseidon houses a set of 14 typical cutting operations (e.g. turning, milling, drilling, grinding, etc.) performed on about 40 machines (both CNC and conventional). Most operations require secondary resources, i.e. tools and fixtures, as well as operator attendance. Lot-sizes are small, one to tenfold; about 40% are customer specific parts and this number is likely to increase in the future.

The part mix can be divided in 10 natural part families, with a common base part type and routing for each part family. Each part requires three operations on average of a different type (for example turning, milling and bench work). It is difficult to change the order of the processing steps. Due to the high level of customization, the number and sequence of operations is not necessarily the same for all parts in a family. For most operations, multiple machines are suitable, though routing cards only indicate one work station per operation. Based on product size there is some dedication, which helps to save set-up time. Transfer batches are not used. The parts manufacturing shop layout is a hybrid one. In some instances, machines with equal functionality and controls—like the CNC lathes—are grouped together (functional layout), while other machines—used for the manufacturing of shafts—are grouped based on part routings (group layout). Assembly is organized in several cells. Painting and testing have their own facilities.

Within the mechanical processing department, there are 18 machine-operators in a single shift. The highly skilled workers master multiple machines and operation types. It takes about a year for a new worker to become a proficient operator. When necessary, operators also perform assembly operations. Nonetheless, each operator has a preferred scope of work. Assembly workers are also skilled to assemble different pump types, and they can take over warehouse operations. Parts manufacturing and assembly are supported by a small number of experienced technical workers.

	A: Poseidon	B: Heracles	C: Athena
End-products	Centrifugal pumps	Parts and simple assemblies from metal plate	Complex machined parts with tight tolerances
Strategic outlook	Pressure for more customization and speed, losing competition on price.	Faces competition from cheaper Eastern-European companies. Material prices dominate product costs.	Faces competition on price, eager to improve efficiency by reducing labour content, especially reducing set-ups.
Vertical integration	Product design, production engineering, parts manufacturing, final assembly, painting.	Production engineering, assembly, parts manufacturing, painting.	Production engineering, parts manufacturing.
Customisation	From ATO to ETO	MTO	MTO-MTS
Production technologies	Turning, milling, drilling, grinding, sawing, assembly, welding, finishing, painting, quality control and testing	Arc welding, spot welding, hydraulic and mechanical presses for deep-drawing, brake presses, plate cutting, finishing, powder coating	CNC machining, CNC turning, drilling, grinding, sawing, quality control
Shop layout orientation	Product and process	Process	Process
Workers per shift	22	70	65
Number of workcenters (machines, assembly tables etc.)	42	99	113
Special machines	Balancing, drilling	Roll welding, spotwelding robot	5-axis machining centre combining large dimensions with high accuracy

Important secondary resources	Tools and fixturing devices	Dies and fixturing devices	Tools and fixturing devices
Different parts/components per year	2308	1436	3150
Orders per part/component per year	7.4	4.2	1.1
Part families	Around 10, by part-type	Unique products	Around 19, by routing
Number of processing steps: mean (minimum-maximum)	3(1-7)	2(1-6)	6(2-13)
Outsourced operations within route	None	Surface treatment (galvanising)	Surface and heat treatment, some mechanical processing
Lot-sizes	One to several tens	Hundreds to thousands	One to several tens
Confirmed demand horizon	1-6 months	1 month-1 year	1 year and more
Current Production Planning and Control	Shop supervisor releases work daily, keeping 1 week of work on the floor. Operators dispatch customer specific jobs first, and then adhere to due-dates. They are allowed to apply family-based dispatching for half a day's work content.	Planners release jobs weekly, providing that materials are available. Department supervisor creates a plan for each week and can pull forward jobs from the next week, machines and people are planned. Shift foreman carries out dispatching based on due-date.	Due dates are set by the customer and backward scheduling generates planned release dates. The planner can release jobs with planned release-dates three weeks into the future. Releases are weekly. Department supervisor dispatches work twice a day.

Table 3.1: Basic company characteristics

The demand for parts originates both from stock replenishments and customer orders. Capacity checks are made for each job, to decide about outsourcing; jobs are always outsourced completely. Process planning provides the appropriate documentation for the jobs and creates routes for new parts. The shop supervisor maintains a steady work in progress level of about one week of work. Once released to the shop floor, the operators have a shared responsibility to ensure on-time job delivery. Hence, they decide at which machine they should work, and in what sequence the jobs are processed. They have access to a computerized shop floor control system, but they also benefit from their own observations of the shop status. Operators are allowed to cluster a half a day's work content to save set-up time between part families. Similar routines are used in assembly and testing. New routes are created by an experienced process planner on the basis of similar parts that have been manufactured before. Still there is a lot of variation, despite the effort from the sales department to phase out obsolete pump types and the involvement of parts manufacturing in product development.

3.4.2 Company B: Heracles

Heracles manufactures metal plate components and assemblies for cars, power tools and household appliances. Our study focused on the press and welding department. The company faces fierce competition from Eastern-European companies. Therefore it looks for possibilities to reduce throughput times and improve due date performance. The company also carries out the production engineering for new products (especially die development).

The company has about 100 work stations, including presses (hydraulic, mechanical, progressive die), spot welding machines and lots of peripheral machines for grinding, degreasing, sawing, etc. Altogether there are about 22 different operations. For all press operations a die is needed and spot welding often uses fixtures. All machines require operator attendance. All the press operations are machine paced, whereas at spot welding production output depends highly on the worker. Lot-sizes range from 160 to 3300 and are determined by the customers.

Most of the operations can be carried out at alternative machines, thereby providing potential for routing flexibility. However, in general, the production engineering department uniquely assigns each operation to a specific workstation. The shop layout is a functional one, with some complementary machines added to each department (i.e. grinders, degreasers etc.). Only some assembly and packaging occur in a cell. Some parts require multiple consecutive press strokes in different dies. In such a case, these dies are attached to adjacent machines simultaneously,

and mobile conveyors are placed in between them. Accordingly, a temporary single product flow cell is created. Some products, like gas heaters, are so bulky that they have to be transported in small batches anyway.

There are about 70 workers in the two departments, pressing and welding. Only, the expensive large hydraulic presses operate in two shifts. Most workers are multi-functional and master several work stations. There are only few workers able to operate the progressive dies presses. Substantial experience is needed for setting up these machines. Spot welding is relatively simple and workers with a work-related handicap are assigned to these operations. Each department is relatively independent, including its own technical experts and quality control. The company is actively seeking process improvements by means of Kaizen-events and SMED-projects.

The orders for parts and assemblies are usually stock replenishments for the customers. Many customers provide demand forecasts, and some even place orders for a whole year in advance. Based on the available capacity jobs are released two weeks in advance. The department supervisors create weekly schedules, involving machines, dies and workers. When a mobile conveyer belt is used, the subsequent operations are considered as one operation that requires multiple machines simultaneously. Occasionally, orders for the same part type are grouped into a larger process batch to save set-up time. Some jobs require an outsourced operation, after which the products return to Heracles to be processed further. The realization of short throughput times is an important goal of the company. This is especially difficult to realize for products that require processing in both the press and welding department. It is complex to balance the load over these departments.

3.4.3 Company C: Athena

Athena is part of an international group that manufactures high-tech defence equipment. The company performs production engineering and manufacturing of metal parts. Due to the low repeat frequency of end-items, parts manufacturing effectively boils down to one-of-a-kind production. Part manufacturing faces severe competition from other companies and is therefore eager to reduce manufacturing costs, mainly by reducing the excessive set-up times.

Athena's facilities consist of CNC machining centres and CNC lathes, complemented with quality control and some finishing. Actual production is machine paced and determined by the CNC program; most machines can run without operator attendance. Since lot-sizes often equal one and set-ups are lengthy, Athena is focussed on decreasing set-up times.

Demand per part is small and it is difficult to distinguish clear-cut part families. The machines are organized functionally in an air-conditioned facility. The number of different routings is very high, involving many outsourced operations and backflow. Transfer batches are not used. At the manufacturing department of Athena jobs pass only one manufacturing stage, other types of operations occur in other parts of the facility or are outsourced.

The workers at Athena are cross-trained within their department, i.e. workers usually master all CNC machining centres or all CNC lathes. New workers undergo a period of on-the-job training before they also become responsible for quality checks. There are only two tool-setters for the whole shop. The company uses so-called performance teams to realise process improvements.

At Athena, parts are only produced to meet demand from confirmed orders. Sometimes parts can be batched and stocked long before they are needed at assembly since demand is well-known far in advance. Over the years many different process planners have worked there, without adherence to tooling standards. Meeting due dates is very important. Schedules are levelled on a weekly basis. In this stage it is difficult to recognize similarities between different jobs. The only exceptions are parts that are exactly the same, but require different finishing; these are clustered into a larger process batch. These are easily recognized as they share the same CNC program number. Once jobs are released, the shop supervisor allocates and dispatches jobs to the tool-setters twice per shift. This is done without considering tools that different jobs might share. Accessing the relevant information is difficult and there are no clear-cut tooling families. Moreover, the supervisor is responsible for the workflow of the entire shop and therefore lacks time to consider complex job assignment and sequencing decisions. After the tool-setting stage the jobs enter the shop floor. Effectively, the sequence initiated by the supervisor is also the sequence during production. On the floor there is little room for work in progress, which limits the possibility for operators to manipulate job sequences.

3.5 Results

In this section, we describe the results of our study, see Table 3.2. Subsection 3.5.1 is devoted to the current applications of GT-principles at the firms. Subsection 3.5.2 concerns the interest of managers in the firms to further apply GT-principles. Subsection 3.5.3 presents the limitations in each firm with respect to using GT-principles. Finally, subsection 3.5.4 summarizes all the findings by means of an extension of the conceptual model of Figure 3.1.

Principle	Practice	A: Poseidon		B: Heracles		C: Athena	
		Current	Future	Current	Future	Current	Future
I: Processing similarities	Process planning	++	++				++
	Family oriented lot- sizing		++				
	Order release	+	+	+	+		++
	Family-based dispatching	++	++	+	+		++
II: Routing similarities	Permanent, real manufacturing cells	+	++				
	Virtual manufacturing cells					+	
	Dynamic cells			+	+		
Legend:	Level of application: None , Restricted: +, Considerable: ++						

Table 3.2: Current and future application of GT-principles

3.5.1 Current application of GT-principles

The application of GT-principles is limited in the three companies. Poseidon has partly organized the manufacturing department in manufacturing cells. Jobs are released up to a workload of one week, but GT-principles do not play an explicit role here. However, the amount of work released to the shop floor gives some opportunities to sequence and process jobs family-wise. It is interesting to note that routing cards, created at the process planning department, only indicate one work station per operation, despite of the presence of alternative machines. This assignment to only one work station limits the flexibility at the shop floor, however, serves setup time savings. Set-up time considerations play a role at Poseidon when assigning operations to stations.

Heracles is, to a large extent, functionally organized. The production engineering department, however, uniquely assigns each operation to a specific workstation. This early and definite assignment of part types to machines is based upon quality considerations. The best press for a particular operation is selected and

all repetitive lots have to be performed at that press. Possible GT advantages play no role, since each die is unique and cannot be used for multiple jobs. Heracles applies temporary single product flow cells. Some part types require multiple consecutive press strokes in different dies. In such a case, these dies are attached to adjacent machines simultaneously, and mobile conveyors are placed in between them. Production planning considers these consecutive operations as one operation. The workload of the departments is controlled by means of a periodical release of orders, leaving some room at the scheduling stage to group various operations of different jobs. In the case of Heracles, only jobs for the same part type are grouped occasionally.

Athena is functionally organized. The firm does not apply any of the GT-principles. A major problem is the huge diversity of part types to be produced and the small lot sizes.

3.5.2 Future applications of GT-principles

All three firms are interested to extend the application of Group Technological principles. Poseidon studies the option to create more manufacturing cells at the shop floor. This will, in the firm's opinion, improve the controllability of the operations. Manufacturing cells support the workers to focus on the flow of jobs. Teams of workers can be made responsible for the complete manufacturing of part families. Subsequently, it may be possible to reduce manufacturing throughput times. Poseidon also wants to improve the way in which they implemented family-oriented planning. Currently, the family-oriented element of the planning is performed at the process planning department, where part types are grouped and assigned to machines on the basis of product sizes. The company is interested in adopting family-based lot-sizing. This not only changes the way in which lot-sizes are determined. It also means that manufacturing jobs which need similar set-ups at important machines will receive the same planned lead times and, therefore, will be released in the same period.

Heracles focuses on further reducing the set-up times of the presses. Therefore they are busy to perform SMED-projects. There is limited opportunity to use GT-principles for the reduction of set-up times. Currently, jobs related to the same part type are, if possible, scheduled sequentially in order to save setup time. There are no clear families of part types which need the same machine set-up. As mentioned in section 3, the company has difficulties with controlling the throughput times of products that require processing in both the press and welding department. Large parts, large lot-sizes, and unbalanced cycle times at both departments regularly lead

to extreme amounts of work-in-process and, subsequently, blocking situations. The firm seeks an answer to this problem. The creation of temporary Virtual Manufacturing Cells, consisting of presses and welding equipment, may serve as a solution to this problem. Such a temporary cell can be assigned, during a certain period, to a particular job. This assignment, or dedication, has to be performed before job release, at the loading level. It ensures that sufficient welding capacity is available at the moment that the pressing operation starts.

Athena is very much interested in reducing set-up times. Managers see possibilities for family-oriented process planning, release and dispatching. Problem is the huge variety of part types and the lack of a supportive information and decision support system.

3.5.3 Limitations in the application of GT-principles

Several factors prevented the applicability of GT-principles. We identified the following barriers: *manufacturing technology, workflow characteristics, information technology, worker characteristics, market constraints, and organisational constraints.*

Manufacturing technology plays an important role in the application of both GT-principles (see also Collett and Spicer, 1993, and Prince and Kay, 2003). Some examples from our case studies may further clarify the importance of manufacturing technology. The lathes of Poseidon use a face plate that can easily be used for many different parts, as long as their diameter fits. Here the specific sequence of jobs does matter for the length of a set-up; the more similarities in size, shape and material, the shorter the required set-up effort between two jobs. Several cases from literature also illustrate sequence-based setup times (see for example Collett and Spicer 1995, Flower 1993). It is interesting to see in our study that different manufacturing technologies may ask for different groupings of jobs. Size, material, colour, tools, etc. may play different roles at different machines with respect to change-over times. Part families are not always there. There are, for instance, no part type families in the case of Heracles. The dies attached to the hydraulic presses of Heracles are each unique for a specific product. Therefore the length of set-up times is not affected by specific job sequences. Most set-up activities can be done externally, only die positioning and test runs require the availability of the machine. The possibility to apply the second GT-principle (exploiting routing similarities) is also limited by technological constraints. Sometimes machines are very difficult to move or can hardly be combined with other technologies. In all companies we found machines that require special facilities for their operation (foundation, air-conditioning,

overhead cranes). Sometimes, they are too large to move, or they generate noise or other harmful exhausts. These particular machines can frequently be found in a functional layout. Also capital-intensive equipment is often pooled so that operators can easily move from one machine to the other, in order to utilize the machines effectively. This is particularly the case in Heracles and Arena. Cellularized parts of the visited factories usually consist of small, conventional machines which do not generate harmful by-products.

Workflow characteristics inside a company play a role in the usefulness and applicability of both GT-principles. It is not always possible to define coherent part families of sufficient size. A great variety of jobs and many processing steps per part may complicate the grouping of machines. This is the reason that, in the case of Poseidon, grouping similar jobs is not done at the release stage. The release function only takes care of sufficient loading to enable family-based dispatching at the shop floor. Small lot sizes and a low repeatability of part type orders may further decrease the usefulness of introducing manufacturing cells (Athena). These characteristics limit the possible advantages of cellular manufacturing, such as the reduction of lot sizes and learning effects.

Information is an important element which limits the possibility to implement family-based planning. The required information (tools, and such) is, in most cases, not available in the firms ERP or MRP system. At Athena, information about tools used for each part is not available to the shop supervisor in such a way that it can be used to realise set-up savings. Operators at Poseidon benefit from their own observations of the shop status to make dispatching decisions. Visual inspection of a set of jobs and their work pieces are sufficient to group them into set-up families. At Hercules the realisation of a Virtual Manufacturing Cell is complicated since it requires substantial data processing.

Worker characteristics may complicate the use of the GT-principles. Two cases showed that multi-skilling has its limits. Hercules employs several people that work part-time and some people that have a work-related handicap (a physical or mental disability that limits the scope of work they can perform). The former limits the creation of a stable team of workers and both reduce the possibilities for multi-skilling. Some jobs require a lot of skills and dedication to perform them correctly, such as setting up progressive die machines. The role of worker characteristics is also reported in the cases study of Molleman et al. (2002).

Market constraints refer to characteristics of demands from customers. Stringent due dates of jobs, which occur frequently at the three companies in our

study, limit the possibility to produce according to part families. The level of customisation may limit the application of GT. Frequent changes in the demand mix may prevent permanent dedication of resources to part families (Heracles). Demand fluctuations may even require a redesign of cells (see for example Prickett 1994, Molleman et al. 2002).

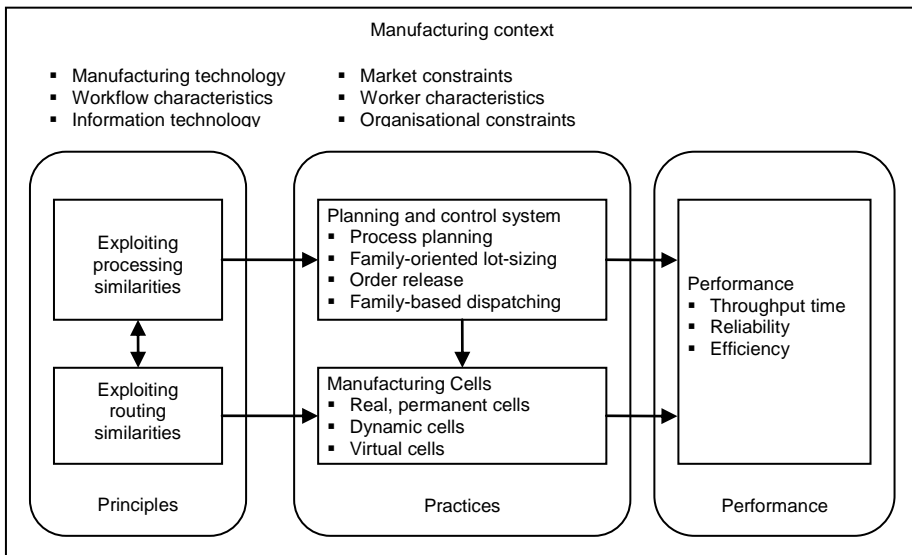


Figure 3.2: Refined conceptual model

3.5.4 Extension of the conceptual model

The previous subsections give some insight into the applicability of GT-principles in part manufacturing situations. Figure 3.2 summarizes the findings in the conceptual model which was the basis of our explorative case study research. Table 3.2 shows some outcomes of the case studies, using the framework of the conceptual model.

As can be seen, there are several contextual factors that set limits to the applicability of both GT-principles. The most dominant factor is *manufacturing technology*, which may be unsuitable for a cellular layout and family grouping (see also Johnson and Wemmerlöv 2004, Choi 1992). The *workflow characteristics* within a company should also allow for GT. The more uniform and stable the workflow is, the easier it is to use the GT-principles. *Information technology*, in a broad sense, is critical to make proper decisions. The lack of information may limit the possibility to integrate family-aspects in production planning and control. Although information itself may be available somewhere, it should be in an interpretable format and be processible as well. *Worker characteristics* may set

limits to the number of different skills they can develop. The *market* may set demands that conflict with GT, such as high levels of customisation, seasonality and strict due-dates. Finally, the *organisation* itself may be a constraining factor. Sometimes there is a lack of time to implement changes (see also Johnson and Wemmerlöv 2004) or it is undesirable to create independent worker teams or divide machine pools into cells (see also Molleman et al. 2002).

The first GT-principle is to exploit similarities in processing. The extended conceptual model shows that the principle can be embedded in several planning and control practices: (i) *process planning*, (ii) *family oriented lot-sizing*, (iii) *order release*, and (iv) *family-based dispatching*. The role of *process planning* is important because, in many cases, assignment decisions are taken at that level. This may limit and/or support the possibility to save set-up times by means of family-based dispatching. The fixed routing, determined in the process planning, may further frustrate the formation of manufacturing cells. In the assignment of operations to machines, GT aspects may deserve attention. *Family oriented lot-sizing* may be useful at the planning level where lot-sizes are determined. Jobs belonging to the same family will then be produced in the same period. Both *order release and dispatching may be family-oriented*, to realize set-up time savings.

The second GT-principle can be applied in several ways. Applying this principle may lead to physical, *real manufacturing cells* (see Hyer and Brown, 1999). It is also possible to form temporary, *dynamic cells*. The application of a mobile conveyer belt in Heracles is an example of a dynamic cell. Another possibility is the establishment of a *virtual cell*. Such a cell consists of machines of different departments which are only grouped (virtually) to produce some jobs during a particular period. Heracles (section 3.5.2) provides an example of a possible virtual cell. Manufacturing cells may give a company important advantages, such as a better product quality, more worker motivation and an improved control situation. Shorter throughput times can also be realized. Important is the setting of correct, and realizable, lead times in the planning and control system.

There is a potential conflict between the applications of the two GT-principles. The grouping of jobs based on processing similarities may be different from the grouping of jobs on the basis of routing similarities (e.g. at Poseidon). This implies that the application of one principle may decrease the effect of applying the other principle. The application of manufacturing cells at Poseidon, for example, may simplify the realization of performance advantages but may also lead to the inability of gaining full advantages from applying the first GT-principle. There is also a

potential conflict at Athena in the application of the two GT-principles. The implementation of Virtual Cellular Manufacturing (second GT-principle) will have an impact on the planning and control functions (i.e. release and scheduling) which, to a limited extent, also focus on gaining profits from applying the first GT-principle. In general, the correlation (positive or negative) between routing similarities and processing similarities determines whether full benefits of GT might be achieved or not. The conceptual model shows this potential conflict by means of an exclamation mark between the two GT-principles.

3.6 Discussion and future research

This section is meant to discuss the outcomes of our study and to give some suggestions for future research. We follow the structure of the conceptual model of Figure 3.2. Subsection 3.6.1 concerns the first GT-principle and discusses the complexity of family-based planning and dispatching. Subsection 3.6.2 is devoted to the second GT-principle and concerns critical issues related to Manufacturing Cells. Contextual factors are included in both sections. Section 3.6.3 discusses the generalizability of our findings.

3.6.1 Discussion and research need for the first GT-principle: processing similarities

The first GT-principle attempts to realize advantages by making use of processing similarities between part types. The cases presented in this paper show the importance and the opportunities to save set-up times by means of the first GT-principle. Set-up time reduction is important for many firms. It increases the efficiency and flexibility of the companies. SMED (Shingo, 1985) and family-based planning and dispatching are two different ways to reduce set-up times. It is interesting to note the different effects of these two different ways. SMED increases the flexibility of companies by making smaller lot sizes acceptable. It may also increase efficiency if some set-up tasks can be eliminated during the SMED stages. SMED, however, is mainly focused on reducing in-process changeover time. This implies that labour-constrained systems may achieve only limited gains from SMED, since it may not eliminate the required labour effort for set-up activities as does family-based planning and dispatching. Family-based planning and dispatching, on the other hand, may have a negative effect on throughput times of jobs because of the grouping of orders with different urgency. It is interesting to study empirically as well as analytically (models and simulation studies) the effects of applying different types of setup-time reduction. It may support firms to decide for a certain focus in setup-time reduction projects.

As indicated in the cases, process planning plays an important role in companies and determines the assignment of the jobs to particular machines in an early stage. It is questionable to what extent processing similarities (i.e. set-up savings) do, can and should play a role in the assignment of processing steps to machines. An early assignment based on processing similarities may support the realization of substantial cumulative set-up time saving. An early assignment, however, may also lead to undesirable pooling loss at the shop floor and, consequently, long throughput times. It is interesting to study the effect of an early assignment of jobs, based upon processing similarities, on manufacturing performance in different situations (e.g. different staffing levels, different number of different families, different setup time / processing time ratio's). Simulation is an appropriate methodology to study this issue. It may be informative to compare the outcomes of such a study with results of applying a Virtual Cell Manufacturing concept as described by Kannan and Gosh (1996a) or Suresh and Slomp (2005). Such a Virtual CM concept basically assumes the presence of an integrated process planning and production planning function; process plans can be generated Just-in-Time for those machines which are earliest available (see Gaalman et al., 1999). The studies proposed here support firms to make decisions with respect to the design of their process planning function.

Family-based planning and dispatching may give a firm important efficiency advantages with respect to efficiency and, probably, lot size reductions. Family-based planning and dispatching, however, has to deal with the particular technological characteristics within a company. Different manufacturing technologies may have different characteristics causing set-up activities. A sequence that saves set-ups at one machine may be detrimental to potential set-up savings at another machine. Bokhorst et al. (2008) show that family-based dispatching at one particular machine, may lead to a negative effect on the throughput times of jobs at subsequent machines, even if set-ups do not play any role at these machines. Routing similarities of jobs play an important role here. It is interesting and worth to investigate further the relation between family-based dispatching and routing similarities in environments where machines have different characteristics.

The three cases showed different options to deal with family characteristics during planning and dispatching. Poseidon applied a non-exhaustive family-based dispatching at the shop floor: operators were allowed to group a limited amount of jobs to safeguard due-date performance. Hercules scheduled jobs on a weekly basis and decided in advance about the number of set-ups to be done. It was even allowed to pull some jobs forward from the next period. The literature has focused on family-based dispatching with exhaustive rules (see Nomden et al., 2008). It is

interesting to study the other practices as well and consider the results with respect to throughput time, efficiency and due-date performance.

3.6.2 Discussion and research need for the second GT-principle: routing similarities

Survey research shows the limited application of CM, see section 3.1 of this paper. Our paper gives some further information about the reasons why companies do not or cannot adopt GT-principles (see section 3.5.3). Regrettably, there is no indication which obstacles are dominant in the different types of the manufacturing industry. It would be worth to perform a survey research among non- or partial adopters of CM to gain more insight in the presence of obstacles in various manufacturing environments. Also the relation between the two GT-principles could be studied in the survey. Many companies are probably able to realise important family-based advantages easier by means of the first GT-principle than by means of the second GT-principle. If this is the case, then there may be less incentive to implement cells.

The application second GT-principle does not necessarily imply the establishment of real manufacturing cells. Our research indicates that concepts like dynamic cells and virtual cells can also be applied to gain GT advantages. It is interesting to integrate these options in design-oriented studies.

3.6.3 Generalisation of findings

This study involved three case studies of manufacturing companies. Truly small companies were not studied though. It has been claimed that CM is not applicable for small companies, since they constitute a cell on their own (Burbidge 1975). As we show GT is more than just CM. The first GT-principle may therefore still be applicable for small firms. This leads to the question how (re-)designs of processes occur in such organisations. The access to relevant knowledge (such as in-house experts, universities, consulting firms) may separate small from medium and large firms. Small firms have less process innovations than larger firms (Vaona and Pianta 2008). Additional research should be specifically targeted at the application of GT for small businesses.

Manufacturing technology was a dominant factor in the applicability of GT-principles. Our study has not addressed the full range of manufacturing technology. One aspect of technology requires further attention though: its batching behaviour. Most of the equipment we found was of a serial batching type, as opposed to parallel batching (Hopp and Spearman 2000). Additional cases should involve the latter type, like heat treatment and foundries, and combinations of both batching types.

Model-based studies are essential for generalizing the applicability and usefulness of GT-principles. We want to stress the importance of integrating real-world characteristics into simulation or analytical models. An important characteristic of all the cases studied in this paper is that the capacity of the part manufacturing departments is Dual Resource Constrained (DRC, labour and machine constrained). Most simulation studies do not model labour at all. Furthermore, in all the cases due date performance was the most important performance metric. Throughput time and costs were emphasized less but nonetheless considered important. We hope that these observations may lead to relevant model-based studies that may further generalize the applicability and usefulness of the GT-principles.

3.7 Conclusion

This study addresses the applicability of GT-principles in part manufacturing. The basic outcome of this research is a conceptual model that indicates how the principles can be applied in manufacturing companies and what major barriers are for implementation.

We show that the principle of ‘exploiting processing similarities’ can be integrated in the process planning function (assigning similar jobs to the same machine), in lot sizing decisions (grouping jobs in order to save setup times and to decrease lot sizes), in the release of jobs (releasing identical jobs with identical operations and/or creating sufficient load to enable family-based grouping) and family-based dispatching. The principle of ‘exploiting routing similarities’ can be realized though the establishment of permanent real cell, dynamic cells, and/or virtual cells.

We discuss several important barriers for applying GT-principles. These barriers may refer to manufacturing technology, workflow characteristics, information technology, worker characteristics, market constraints, and organizational constraints. The conceptual model, presented in Figure 3.2, can be used as a reference for new studies on the application of GT-principles. Our study indicates several topics for further research. The conceptual model may also support practitioners to assess the potential benefits of GT-principles in their specific situation.

P A R T I I :

Development and testing
of family-based
dispatching heuristics

