The applicability of Cellular Manufacturing techniques: an exploration in industry

Gert Nomden*, Jannes Slomp

Production Systems Design Group, Faculty of Management and Organization
University of Groningen, P.O. Box 800, 9700 AV, GRONINGEN, The Netherlands.

* Corresponding author: Tel: +31(0)50 363 4693, Fax: +31(0)50 363 2032, E-mail: g.nomden@rug.nl

ABSTRACT

This study addresses the applicability of Cellular Manufacturing (CM) techniques in situations where such a configuration is not obvious. Over the years, the academic community has shown a wide interest in CM. Case studies of successful CM implementations and model-based research clearly indicate the merits of typical CM techniques, like set-up reduction, a flow layout, pull production, etc. However, industry surveys indicate that completely cellularized manufacturing systems are rare in practice. Apparently, CM techniques are only applicable to a limited extent. What keeps the non-user from implementing CM techniques is not clear from the literature. Our research forms an attempt to fill this knowledge gap by means of a multiple case study. Firstly, we address to what extent the techniques of CM are applicable in a number of non-cellular situations. Secondly, we identify the barriers and enablers determining the success or failure of CM techniques in these situations. Thirdly, we indicate promising issues for further research. The subjects of study are Dutch manufacturing companies, which do not, or only partially, apply CM techniques. The exploration and subsequent analysis of these cases lead to the identification of a number of factors influencing the applicability of CM techniques. Important are an organization’s arsenal of manufacturing technologies, as well as product and demand characteristics. Also the organization of manufacturing and the possibility to exert extensive control over jobs and resources seem important. Some benefits from links between different business functions have also been found. By confronting our findings with the current state of CM research we derive a number of promising directions for further study.

1. INTRODUCTION

During the last decades, the academic community has shown considerable interest in Group Technology (GT). This is a philosophy that builds on the recognition and exploitation of similarities between tasks. In manufacturing this has resulted in physical groupings of machines, or cells, each being dedicated to the manufacturing of a product family. This mode of operation—Cellular Manufacturing (CM)—benefits from similarities in manufacturing requirements between 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).

Despite the foreseeable advantages, the adoption of CM in practice remains limited. Prior empirical research provides some clues on the rationale behind this. The costs of organizational changes and technical problems seem barriers to putting machines into a cellular structure (Choi, 1996; Johnson and Wemmerlöv, 2004; Waterson, Clegg, Bolden, Pepper, Warr and Wall, 1999). Moreover, model-based studies indicate sensitivity of CM to stochastic demand and (temporary) changes of the product mix (Morris and Tersine, 1990; Suresh, 1994).

Virtual Cellular Manufacturing (VCM) has been proposed as an alternative to CM. Conceptually, VCM and CM share many similarities. VCM also assumes the application of GT principles to manufacturing operations. However, it does so within a functional layout setting, without a physical re-allocation of machines. VCM achieves many of the benefits associated with CM, while retaining and building on the routing flexibility of a functional layout, i.e., the possibility to choose from alternative machines to execute an operation. Research in this area—the application of GT principles within functional layout settings—is still at the outset. Nonetheless, in both CM and VCM research there is a need for empirical perspectives (Nomden, Slomp and Suresh, 2006a; Shambu, Suresh and Pegels., 1996).

This paper departs from the traditional conception of CM and VCM and takes the proposition made by Hyer and Brown (1999) as a starting point. Here, CM and VCM are viewed as part of a continuum, each with varying degrees to which typical CM techniques are applied. To this point, little is known about the applicability of CM techniques in situations where a cellular layout is not...
obvious. Therefore we employ the explorative strengths of a multiple case study (Yin, 1989). Our research focuses on three issues: i) to what extent CM techniques are applicable in non-cellular situations, ii) what the barriers and enablers for applying CM techniques are, and iii) where future research in this area should focus on.

This contribution is structured as follows. In section 2 we provide a concise overview of the relevant literature. In section 3 we explain the research methodology of this study. In section 4 we present the results of a cross-case analysis. We confront our findings with the current state of research in this field in section 5. Section 6 concludes the paper by summarizing our key findings.

2. LITERATURE REVIEW

Several decades of research have lead to a considerable set of publication about Cellular Manufacturing and its appearance in well-defined techniques. Hyer and Brown (1999) define a "real manufacturing cell" as 1) consisting of resources that are dedicated to a coherent set or family of parts or products, and 2) a workflow that is closely linked in terms of time, space and information. The authors suggest that the time, space and information linkages are the result of a number of techniques. They provide examples of such CM techniques, as we call them. In this section we look at the implementation of CM in practice. We provide an overview of the techniques that constitute CM. Finally, we derive a set of research questions.

2.1 CELLULAR MANUFACTURING IN PRACTICE

Group Technology has received considerable attention in both the academic and industrial community. Its origins are in the manufacturing of discrete goods in small to medium volumes. Typical end-items are machinery and machine tools, electronic products, and medical equipment, just to name a few examples (Wemmerlöv and Hyer, 1989). Recognizing similarities has brought successes not only in manufacturing, but also in product design and process planning. As such, GT forms a step towards functional integration and automation (McLean, Bloom and Hopp, 1982). Perhaps the most recognizable and far-reaching implementation of GT is Cellular Manufacturing. The stereotypical CM plant is one where each resource is part of an independent group, neatly located together in its own part of the factory. This group bares responsibility for processing a clearly recognizable family of parts, or assembling products, from beginning to end. It includes quality control and support functions like process planning, material acquisition etc. Parts and products flow smoothly through the factory on an as needed basis. The planning and control of shop operations is unambiguous and seems almost straightforward (Burbidge, 1975). However, the stereotypical CM plant sketched above is a rarity. Moreover, it has been subject to some controversy right from its introduction (Rathmill and Leonard, 1977).

A number of industrial surveys that appeared in 1996 and later clearly show the limited adoption of CM in practice. Choi (1996) surveyed firms (presumably in Korea) that adopted some form of CM; most firms employed more than 1000 people. Of the responding firms, 39% produced more than 75% of their components in cells; the rest had a lower conversion scope. Choi reviews a number of causes for this, including the presence of financial constraints, product and demand characteristics and the production technologies in the firms. Waterson et al. (1999) conducted a large-scale industry-wide survey of firms in the United Kingdom, that each employed more than 150 people. In the amalgam of businesses addressed by the study, a superficial conclusion would be that CM hardly pays off. Of the companies 50% has not adopted CM at all, only 14% has adopted CM all-embracingly. Unfortunately, possible causes for this outcome are not given. The author’s claim that "... the use of practices, their year of introduction and their perceived success are not related to manufacturing sector, company size, extent of trade union membership, or the company’s country of ownership" (p. 2287) could not be deduced from the data provided in the paper. Also, the broad sample might hide companies that are—by the nature of their production process—not suited to CM, like process industries. Nonetheless, within the set of companies that did apply CM, more than 75% of the respondents claimed moderate to high successes with respect to improving quality, costs and responsiveness. Boughton and Ariokam (2000) surveyed firms manufacturing discrete goods in the region of Liverpool (UK). The adoption of CM was low, 25% for SMEs and 33% for the larger companies, despite great awareness of the concept. Interestingly, the authors provide clues about barriers to introduce CM. These relate especially to technical difficulties of re-locating machines and to the match between demand and capacity in eventual cells. Isa and Tsuru (2002) addressed the Japanese machinery industry, also using a survey and four additional case studies. The adoption of CM has a level comparable to those found in the other studies discussed above—despite the popularity of the Toyota Production System—but is on the rise. Though revealing by itself, the study only hints at possible causes of this low adoption rate. Johnson and Wemmerlöv (2004), finally, surveyed metal machining and fabrication companies employing more than 200 people, mainly based in the American Midwest. The study clearly aimed at CM adopters and indeed, 79% used some form of CM, though only 36% were more than 50% cellularized. The authors found a number of reasons why cell penetration stops. These relate to problems with finding product flows with enough volume and stability, the time and investments to implement more cells, the presence of “service processes” that are shared by many products, and simply the expectancy that CM would not result in performance improvements.

The studies suggest that the limited adoption of CM is not necessarily bounded to specific sectors or geographical regions. Although some of the studies addressed possible causes, they offer little perspective to
those firms marked by one or more of the implementation barriers. Hence, we should reconsider which companies our empirical research should focus on. For these companies it would be more interesting to learn what parts of CM are applicable to their situation. The imprecise nature of the surveys, however, generates difficulties in appraising the peculiarities of each business. We should consider alternative approaches in this respect.

2.2 (Virtual) Cellular Manufacturing: A Set of Techniques

In this paper we view (V)CM as a set of techniques that a company can incorporate in its operations. A completely cellularized factory is one where all CM techniques are applied to all areas. It is up to a company to choose which techniques to apply, and where. This allows for many variations, as to provide a fit with each company’s characteristics. For example, applying CM techniques but without a cellular layout qualifies as Virtual Cellular Manufacturing (Hyer and Brown, 1999).

We define something as a CM technique when it has been subject of study in literature that positioned itself as CM research (Hyer and Wemmerlöv, 2002; Johnson and Wemmerlöv; 1996; Olorunniwo, 1996; Suresh and Meredith, 1994). We divided CM techniques into four distinct categories (Slack, Chambers and Johnston, 2004): process technology, layout and flow, job design and work organization, and production planning and control. The first set of CM techniques is directly related to the jobs or batches flowing through a manufacturing system, and the techniques used for processing them, i.e. process technology. They consist of direct reductions of set-up time, processing time and material handling time. This category also contains efforts to reduce lot-sizes, transfer batches and balance losses. An example of reducing set-ups directly is streamlining them by means of a SMED analysis (Shingo, 1985). These techniques have been addressed in many model-based studies and case studies. For an explanation of the underlying principles and their performance influences we refer to Hopp and Spearman (2000) and Johnson (2003). The second set of CM techniques relates to the layout and flow of a manufacturing system. They consist of dedicating resources, a cellular layout, and sequentially organized equipment. These techniques are mentioned mostly in relation to CM, however, they do not automatically materialize into performance benefits. For example, dedicating resources results in a loss of pooling synergy. This should be compensated by other benefits like less variable flows, set-up reductions etc. (Suresh and Meredith, 1994). CM techniques in the area of job design and work organization are cross-trained workers and cross-functional teams. The third set of CM techniques relates to the planning and control of operations. We consider family-oriented planning and dispatching, pull-production and workload control, treating a cell as a black box, and laying the locus of control down at the shop floor.

These CM techniques have received considerable attention from researchers, especially in simulation studies and analytical models. Their performance influences and, sometimes complex, interactions have been established quite well. Nonetheless, transferring these insights to practice remains difficult due to the peculiarities of each individual situation.

2.3 Research Questions

The current state of CM research shows a somewhat confusing picture when it comes to the applicability of CM. Whole-hearted CM applications are rare, even among likely users. However, many CM techniques might very well be applicable to non-cellular manufacturing systems. Next to this, research has hardly paid attention to non-cellular situations. This leads us to the following research questions:

- Which CM-techniques are applied, or intended to be applied, by the non-CM companies?
- What are the barriers and enablers for the applicability of CM-techniques in non-CM situations? What are promising issues for further research, considering the findings of this and other past studies?

3. Research Design

This section presents the research design to tackle the questions that were developed in the previous section. The choice for the case research method will be justified. Further details about data collection are given with special attention to quality assurances.

In the discussion in the previous section we concluded that research has paid little attention to the situations we are interested in. Prior empirical studies have been surveys of (likely) users of CM and exemplary cases often reporting successful implementations. These do not provide details on non-users and reasons why they did not adopt CM. For this reason our sampling strategy is aimed at selecting non-users of CM. Industry-wide surveys offer too little detail to have explanatory power at the aggregation level we are interested in. The lack of a sound empirical basis creates difficulties for model-based studies to pick the right combination of variables. We need a research method that is able to capture the complexities of reality, and an aid in determining future research directions. This lead to a choice for case research, above the narrowly focused (and therefore difficult to generalize) and time-consuming action-research instrument.

Multiple cases were selected for this study. We sought companies active in small batch discrete parts manufacturing, but still in different sectors. We pursued variety among cases by selecting for differences in terms of end-items, manufacturing technology, size, vertical integration etc. They were all part of the university’s network; often students had carried out their thesis projects at these companies. Peers were consulted to
suggest companies (or business units) that did not, or only partially, apply CM.

Each company was visited, including a factory tour and interviews with multiple persons from multiple functions. All companies provided manufacturing data from their ERP-system, and for each company one or more relevant theses were available. Repeated visits, as well as keeping interviews rather informal, allowed us to gain the confidence of the interviewees. The semi-structured nature of the interviews allowed for exploring topics that were triggered by surprising events, spontaneous remarks, etc. The thus obtained data were tabulated, which facilitated finding patterns and building explanations.

The quality of the research project was safeguarded in several ways, according to guidelines set by Yin (1989). Firstly, we used data from multiple sources, and interviews were held with people from different functions (construct validity). Secondly, each case was analyzed by itself and explanations for the observed phenomena were given. These were compared to the other cases, in an attempt to refute these ad hoc hypotheses (internal validity). Thirdly, the selected companies possess a certain variety, for example in terms of manufacturing technologies, size, types of products, etc. (external validity). Finally, we used a case protocol that specifies 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 (reliability).

4. RESULTS

In this section we present the results from our multiple case study. For each set of CM techniques we will discuss the barriers and enablers. Extensive descriptions of our cases can be found in the appendix.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Barriers</th>
<th>Company</th>
<th>Enablers</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set-up reduction</td>
<td>Extensive tool proliferation</td>
<td>C</td>
<td>Possibility to externalise set-ups</td>
<td>B</td>
</tr>
<tr>
<td>Processing reduction</td>
<td>Risk of tool breakage and scrap</td>
<td>A</td>
<td>Active role of product development to reduce costs</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Machine paced operation</td>
<td>B</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Handling reduction</td>
<td>Customer sets lot-sizes</td>
<td>B</td>
<td>Adjacent machines for consecutive operations</td>
<td>A</td>
</tr>
<tr>
<td>Lot-size reduction</td>
<td>One of a kind jobs</td>
<td>A</td>
<td>Make-to-stock situation</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Small lot-sizes</td>
<td>A</td>
<td>Bulky products produced in series</td>
<td>B</td>
</tr>
<tr>
<td>Transfer batch reduction</td>
<td>Machines for consecutive operations are far apart</td>
<td>B</td>
<td>Large lot-sizes</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Flow passes multiple authorities</td>
<td>B</td>
<td>Adjacent machines for consecutive operations</td>
<td>A</td>
</tr>
<tr>
<td>Balance loss reduction</td>
<td>Difficulties to switch operations between processing steps</td>
<td>A</td>
<td>Possibility to deploy multiple resources for a job</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Mix of manufacturing technologies</td>
<td>B</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Mix of batching types</td>
<td>B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1 PROCESS TECHNOLOGY

The results for CM techniques related to process technology are shown in table 1. Most CM techniques are subject to one or more barriers and enablers. These do not only relate to the manufacturing technologies, but also to product characteristics and the organizational context of manufacturing.

The influence of manufacturing technology is most notable in the different types of set-ups. These vary with respect to uniqueness and the possibility to carry out parts of a set-up off-line, without stopping a machine. The dies attached to the hydraulic presses of company B are each unique for a specific product. Therefore the length of a set-up 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 lathes of company A constitute a different set-up type. They often 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 set-up effort between two jobs. Only the preparation of tools can be done externally, nearly all other set-up activities require the machine to be stopped.

Creating a balanced flow proved difficult, except for company B. This was the only company with lot-sizes large enough to justify overlapping production. Still, the mix of different technologies and the required organizational efforts prevent an all out implementation of transfer batches.

The differences between the cases are striking. Especially company C lacks enablers, but abounds with barriers. Nonetheless, this company also is eager to increase the application of CM techniques.

4.2 LAYOUT AND FLOW

The relation between layout and flow, and their
barriers and enablers are shown in table 2. These CM techniques are largely dominated by the manufacturing technologies of each company.

In all companies we found machines that required special facilities for their operation (foundation, air-conditioning, overhead cranes), were too large to move, or generated noise or other harmful exhausts. Such machines were always found in a functional layout. Also capital intensive equipment was often pooled so that operators could easily be shifted between them, to ensure a proper machine utilization. Cellularized parts of the visited factories usually consisted of rather the opposite: here machines were small, conventional, and did not generate harmful by-products. The dominance of manufacturing technology is clearly expressed in the number of enablers. Company A has a lot of them, whereas B and C experience a severe lack of enablers. For company B and C, dedicating equipment would hardly yield any benefit. It would not reduce set-ups, nor result in more regular product flows. Only company A might benefit a little from dedication. Moreover, the benefits might be larger because it is a highly labor constrained situation. Benefits realized in one part of the factory also benefit the rest, as this results in a greater availability of workers.

4.3 JOB DESIGN AND WORK ORGANIZATION

The results for job design and work organization are represented in table 3. The number of workers and their specializations as well as their learning capabilities constituted an important factor. This seems to be related to decisions about the size of the labour force and personal characteristics.

Company A is a highly labor constrained system—there are twice as much machines as there are workers in a shift. It is therefore necessary that workers are cross-trained to master multiple machines. The number of technical experts is also limited, and they provide services to the entire factory. It is therefore difficult to allocate them a certain part or product family. This is in contrast to company B. Labor is less constrained, but there also seemed less potential for cross-training for some workers. Here each department had a dedicated technical expert. Here one could more easily consider the workers to be part of a team, containing all the necessary capabilities and constituting a clearly identifiable manufacturing unit.

4.4 PRODUCTION PLANNING AND CONTROL

The barriers and enabler for production planning and control are shown in table 4. The differences between the three companies are striking.

In all three companies jobs possessed overlapping set-up requirements, allowing for family-oriented planning and dispatching at some machines. This was most easily at company A, and most difficult at company C. Difficulties to realize larger process batches of similar jobs mainly relate to the relevant information not being available in an easily usable format, and the lack of freedom to tamper with job sequences. Concerted efforts to reduce product variety seem to increase the usability of family-based dispatching. Principles of workload control were applied in all cases, whereas pull production was not. Apparently, in these cases the repeat of individual products is too low to keep any buffer stock. Workload control benefited from information about future demand.
Table 4: Barriers and enablers for production planning and control

<table>
<thead>
<tr>
<th>Technique</th>
<th>Company</th>
<th>Enablers</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family-oriented planning and dispatching</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure from due-dates</td>
<td>A</td>
<td>C Repeat of same or similar jobs</td>
<td>A B</td>
</tr>
<tr>
<td>Low in-process inventory</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty to recognize job similarities</td>
<td>C</td>
<td>Clear similarities among jobs</td>
<td>A</td>
</tr>
<tr>
<td>No time to scrutinize job sequences</td>
<td></td>
<td>Dominant set-up factors</td>
<td>A B</td>
</tr>
<tr>
<td>Limited overlap of machine set-ups</td>
<td>B</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Pull production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot of different end-items</td>
<td>A B C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customized parts or products</td>
<td>A</td>
<td>C Limited number of products</td>
<td>B</td>
</tr>
<tr>
<td>Seasonal demand</td>
<td>C</td>
<td>Continuous and regular demand</td>
<td>B</td>
</tr>
<tr>
<td>Workload control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short planning horizon</td>
<td>A</td>
<td>Demand is well-known in advance</td>
<td>B C</td>
</tr>
<tr>
<td>Limited space on the shop floor</td>
<td>C</td>
<td>Jobs are stock replenishments</td>
<td>A B</td>
</tr>
<tr>
<td>Cell as black box</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outsourced operations within route</td>
<td>B</td>
<td>C High volume demand</td>
<td>B</td>
</tr>
<tr>
<td>No independent sub-units</td>
<td>A</td>
<td>C Physically coupled machines</td>
<td>A B</td>
</tr>
<tr>
<td>Greater control over jobs and resources is possible</td>
<td>B</td>
<td>Unambiguous job priorities</td>
<td>A B C</td>
</tr>
<tr>
<td>Locus of control to the shop floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult access to relevant information</td>
<td>C</td>
<td>Easy access to relevant information</td>
<td>A</td>
</tr>
<tr>
<td>Limited overview on the manufacturing process</td>
<td>B C</td>
<td>Multiple jobs to choose from</td>
<td>A</td>
</tr>
<tr>
<td>Standardized process planning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lots of different products</td>
<td>A B C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Many different process planners</td>
<td>C</td>
<td>Information loops between product design and process planning</td>
<td>A B</td>
</tr>
<tr>
<td>No process planning standards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Many outdated parts or products</td>
<td>A</td>
<td>C Concentrated efforts to phase out obsolete products</td>
<td>A</td>
</tr>
</tbody>
</table>

Each company had a different organization of planning and control. In case B, the department supervisor would plan jobs, machines, workers and secondary resources ahead for an entire week. In the other shops, where supervisors had a considerable larger span of control, such detailed planning was not achieved. The delegation of planning and control decisions to the operators was beneficial for company A. They have an information position that extends beyond computerized dispatch lists. Being able to actually see the pending jobs at multiple work stations allows for more thought-out decisions.

5. DISCUSSION AND FUTURE RESEARCH

Our descriptions and analysis of three cases has revealed a number of factors that hamper the application of CM techniques. By confronting the three cases and their application of CM techniques with the current literature, we obtain a number of topics for further research. For this purpose, we drew from Johnson and Wemmerlöv (1996), Shambu et al. (1996) and Nomden et al. (2006a).

The nature of set-ups differed between the various manufacturing technologies in our cases. Differences occurred in their length, possibilities of sharing set-ups between jobs and the possibility to carry out parts of a set-up externally. Principles of SMED and family-based dispatching may therefore have to be considered together. The omnipresence of labor-constrained systems may achieve only limited gains from SMED, since it may not eliminate the required labor effort for set-up activities as does family-based dispatching. Different manufacturing technologies had different job characteristics causing set-up activities. Hence, a sequence that saves set-ups at one machine may be detrimental to potential set-up savings at another machine. Material handling has received limited attention in previous CM studies, which by itself may be an argument to include this as a research issue. One of the cases showed potential for lot-size reductions and the use of transfer batches in their functional layout. The effects on material handling are hardly known here. Batching strategies for material handling jobs might be necessary to keep it from becoming a bottleneck operation. At this same company, an interesting topic was the design of a virtual cell for one product family with discontinuous demand in order to achieve short throughput times. The consideration of resource and work in progress constraints, set-ups, capacity deployment and differing output rates of consecutive operations form a challenging issue.

There has been some interest in new layout types that have the potential to combine the robustness of a functional layout and the short handling distances of a cellular layout. Simulation seems particularly suitable to study the effects of transfer batches, set-ups, lot-sizes, and eventual losses from imbalances and reduced pooling synergy in this context. Dynamic cells are another issue worth studying. Dynamic cells are real cells, but their configuration changes with current workload requirements. The notion of a set-up is extended here to that of repositioning equipment. Obviously, the trade-off is between the required repositioning efforts against the advantages from the reduced handling distances and possible adjacent machines.

In all our cases labor was a constraining factor, enforcing the cross-training of workers. This trait has received little attention in the context of VCM. Learning and forgetting curves may offset advantages of increased labor pooling. Hence, more labor flexibility may not
necessarily be an improvement and may even deteriorate shop performance. Next there is also the issue of times for workers to move between work stations. However, an attempt to reap the benefits from routing flexibility may be off-set by additional machine set-ups. Hence, this brings us to the question whether manufacturing flexibility should result from routing alternatives, labor mobility or perhaps both.

A number of issues regarding the planning and control of production emerged from our study. One interesting issue is that of the effects of family-based dispatching. Though the literature seems to favor exhaustive rules, practitioners used non-exhaustive rules to safeguard due date performance. Presumably, family-based dispatching has some side-effects related to its behavior in terms of queuing theory. It is a challenge to find analytical approaches that provide accurate flow time estimate, but that also generate insight into the variability of the job departures. A second issue is the locus where set-up savings are realized. This can occur off-line by applying a lot-sizing technique, but also prior to job release by combining jobs into larger process batches, or on the shop floor by means of family-based dispatching. The shop performance may be influenced by, for example, the variability of job routings, and the duration of product-specific and family-specific set-ups. Once we have obtained such insight, it is relatively easy to predict the performance of family-based dispatching in larger manufacturing systems. Finally, in a number of cases we observed that dispatchers had a much richer information position than just the computerized shop floor control system and paper shop orders. They also had information on the status of other work stations and could benefit from it by incorporating this information into their own dispatching decisions. This may very well be an explanation for the success of CM systems as reported in case reports. An interesting issue is therefore to look at the information that is used for planning and dispatching decisions. The information position may be a crucial difference between cells and a functional layout. A possible form is look-ahead information, where a dispatcher can count with jobs about to arrive in the very near future (Nomden, Zee, D.J. v.d., Slomp, 2006b).

Next to topics for research, it is also important to know what the settings of real world manufacturing systems are, in order to carry out valid model-based studies. One important characteristic is that all cases were labor constrained, while most simulation studies do not model labor at all. In all the cases due date performance was the most important performance metric, through time and costs were emphasized less but nonetheless considered important. We suggest that one should always provide multiple performance measures that represent throughput times, delivery reliability and costs. The chosen cases seem to represent a more variable environment than has been assumed so far. Product variety is generally higher—considering the number of part families found in each case—and set-up times may also be considerably higher—we found set-ups that easily exceeded twice the job processing time. A further issue is the information position of planners. In two of the three cases demand was well-known far in advance. This allows a pro-active treatment of capacity decisions, while capacity was considered fixed in many studies.

In future research it seems crucial to consider the degrees of freedom that firms have to change their layout and operating policies. For practical relevance it may be more useful to study improvement options within a functional layout itself, rather than comparing its performance to that of a cell system.

6. CONCLUSIONS

This study addresses the applicability of CM techniques in non-cellular layout situations. Over the years, numerous success stories of companies that implemented CM have appeared. However, surveys show that complete adoptions of CM in practice are rare. Nonetheless, many principles of CM, like set-up reductions, flow production etc., may still be applicable in a context where a complete conversion to CM is not obvious. This paper addresses this issue in a three-phase approach, by means of a multiple case study of three companies. In the first phase, each company is studied in detail. As a result we obtained barriers and enablers for the application of CM techniques. In the second phase, we discussed the enablers and barriers in more detail. In the third phase, we confronted the findings with the current state of CM research.

Manufacturing technology constituted an important factor. CM techniques are more likely to be applied when machines are easily moved and cheap, combinable with any other technology without the need for special facilities, having set-ups based on the same criteria, and operating at similar paces. Next, also the product and demand characteristics play an important role. Ideally there is a single product, or a coherent family of products, that has a large and steady demand, as well as a similar routing; this may justify dedication of equipment and workers. Lot-sizes and product size are sufficiently large to apply overlapping production. A number of organizational aspects showed their relevance. There should be enough room and proper information to make well thought-out planning and dispatching decisions. The labor force should be large enough to constitute complementary teams with room for cross-training of workers. Each company seemed to benefit from feedback and feedforward loops between various business functions.

By confronting the findings in our study with the current state of CM research we obtained a number of suggestions for further research. The nature of set-ups and the ways to deal with them—SMED, family-based planning and dispatching, dedicated equipment, etc.—deserve more attention. Also the layout of a manufacturing system and material handling aspects require more attention, especially in the light of new layout types. The inclusion of labor in CM studies could
bring more realism, and may very well reveal an important source of CM benefits that cannot easily be derived from model-based studies. Analytical discussions of CM techniques, especially family-based dispatching, are needed to predict the performance of various CM techniques. Altogether, CM techniques and their application still offer a number of interesting research issues.

**ADDITIONAL DATA**

Due to restrictions set to the length of the paper we were not able to provide all the information we would have liked to. Therefore, additional data on the case companies can be obtained by contacting the corresponding author: g.nomden@rug.nl.

**REFERENCES**


**APPENDIX: CASE DESCRIPTIONS**

**COMPANY A**

The company designs, manufactures and sells centrifugal pumps for the (petro)chemical industry, horticulture market, and shipbuilding industry. Our study 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 customization, 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 pumps have a high level of customization.

Company A houses a set of 14 typical cutting operations (e.g. turning, milling, drilling, grinding, etc.) are performed with about 40 machines (both CNC and conventional). Notable operations are drilling (a bottleneck operation) and balancing (a unique process). Most operations require secondary resources, i.e. tools and fixtures. The set-ups are mostly sequence-dependent, their length depends on the differences in diameter and material of parts. For each material type, different cutting materials are used to obtain the greatest cutting speed. Product development is also involved in realizing manufacturing cost reduction. Material handling is done using a fork truck and pallets. Lot-sizes are small, one to
tenfolds; about 40% are customer specific parts and this number is likely to increase in the future. Transfer batches are not used, expediting occurs rarely. Each part requires three operations on average of a different type (for example turning, milling and benchwork). Therefore it is difficult to shift part operations between processing steps.

The part mix can be divided into around 10 natural part families, with a common base part type and routing for each part family. However, within such a part family, sub-families can be distinguished based on part size and material type. Within a route, none of the operations is outsourced. 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. Due to the low demand per part family, dedicating equipment to a single part family is difficult. Based on product size there is some dedication, which helps to save set-up time. 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). Nonetheless, shaft production is not operated as such. The functional layout exists because a number of machines can hardly be moved. Only part of the factory is covered by overhead cranes, which limits the possible locations to manufacture the heaviest parts. Assembly is organized in several cells. Painting and testing each have their own facility, i.e. would constitute a single cell on their own.

Within the mechanical processing department, there are 18 machine-operators in a single shift. The highly skilled workers master multiple machines and operation types. When machines have the same controls this is particularly easy. 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. The operators described the current level of cross-training as near the maximum of the attainable. Assembly workers are also skilled to assemble different pump types, and they can take over warehouse operations. Shop personnel are supported by a small number of technical experts. In the current situation it is difficult to distinguish smaller units within parts manufacturing—i.e. groups of workers and their machines.

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. Make-to-order jobs are prioritized above stock replenishments, within these two sets priorities are set by the order due date. Operators are allowed to cluster a half a day’s work content to save set-up time between part families. This rule is supposed to balance set-up savings against meeting due dates. New routes are created by an experienced process planner on the basis of similar parts that have been manufactured before. Still there are a lot of variations, despite the effort from the sales department to phase out obsolete pump types and the involvement of product development in parts manufacturing.

COMPANY B

Company B manufactures metal plate components and assemblies for cars, power tools and household appliances. Volumes range from weekly repeat orders to products that are only manufactured a few a times year. Our study focused on the press and welding departments, with extra focus on the gas heater product family. 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. At the presses and spot welding the set-ups times do not change with the job sequence. The only exceptions are the press brakes, these only use a few different stamps. The company actively seeks set-up reductions by means of Kaizen-events and SMED-analyses. 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. Transfer batches are often possible when a job requires adjacent machines; some products, like the gas heater, are so bulky that they have to be transported in small batches anyway. Between departments transfer batches are difficult to realize, because they come under different supervisors. The various work stations have different output rates; the presses are generally much faster than the spot welders. Moreover, spot welding cannot start until all the required parts are present completely. On the other hand, it is possible to deploy multiple spot welding stations for the same job.

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. They fear to lose the traceability of product quality problems when doing otherwise. Also, dedication does not yield set-up efficiencies. The shop layout is a functional one, with some complementary
machines added to each department (i.e. grinders, degreasers etc.). The presses are very large and difficult to move, they need special foundations to support their enormous weight. Moreover, presses can be very noisy during their operation. Welding needs special facilities because of smoke and light production. 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 dynamic single product flow cell is created.

There are about 70 workers in the two departments; the expensive large hydraulic presses are operated in two shifts. Most workers are multi-functional and can operate many work stations. Exceptions are the progressive dies presses and spot welding. While the former require lots experience for setting up the machines, the latter has many workers with a work-related handicap. Each department is relatively independent, including its own technical experts and quality control.

The demand for parts are usually stock replenishments for the customers. Many customers provide demand forecasts, and some even order 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. Jobs that require a conveyor belt (i.e. constitute a dynamic cell) are considered as one operation that requires multiple machines simultaneously. Occasionally, orders for the same part are grouped into a larger process batch to save set-up time. Some jobs require an outsourced operation, after which the products return to company B to be processed further. Foremen realize actual job execution. On-time delivery is the most important goal. The company has the most difficulties with products that require processing in both press and welding departments, especially the gas heaters. Since company B also carries on-the-job training before they also become responsible for quality checks. There are only two tool-setters for the whole shop. The smallest clearly recognizable sub-units are the respective machining and turning departments.

At company C, parts are only produced to meet demand from confirmed orders. Sometimes parts can be batched and stocked long before they are needed for assembly since demand is well-known far in advance. Company C has been the main part producer for the group’s end-items. This has resulted in a huge variety of parts. Over the years many different process planners have worked there, without adherence to tooling standards. Meeting due dates is very important. Schedules are leveled on a weekly basis. In this stage it is difficult to recognize similarities between different jobs. The only exception 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, therefore not allowing for cumbersome 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.