Design of a period batch control planning system for cellular manufacturing

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Chapter 1 Introduction

This chapter introduces the problem of planning system design in the context of a dynamic environment. The changing demands of the environment will often lead to a redesign of the production system and a redistribution of planning tasks and responsibilities within the firm. We focus on batch manufacturing systems that have chosen to apply a cellular production structure and we examine the consequences of choosing this production structure for the design of the planning system. Section § 1.1 introduces the area of application and defines the notions of group technology and cellular manufacturing that we use in this thesis. Section § 1.2 focuses on the design of a planning system. The section shows that besides developments in information technology and planning theory, changes in the organization of production and planning system and their environment have also had a strong influence on planning system design. As the introduction of cellular manufacturing entails a change in the production system, we therefore have to expect some changes in the planning system as well. This brings us to the main research questions in Section § 1.3. Section § 1.4 presents an outline of this thesis and describes the research approach used.

§ 1.1 Definition of the area of application

Most batch manufacturing firms face the need to produce both efficiently and flexibly in small batches and with short throughput times in order to stay competitive. These requirements are fundamentally different compared with some decades ago. Traditional production organization structures were designed with the aim of producing high quality products in specialized departments. These departments could either be process oriented (functional) or product oriented (lines). Both structures enabled the production system to produce efficiently. Efficiency in production lines could be a matter of well organized supporting processes, such as material transfer, making it possible to produce high volumes of standardized products. Efficiency in functional structures could be a matter of high utilization of specialized processes, making it possible to produce a large variety of products.

These traditional production organization structures have a cost. Figure 1.1 shows that production line organization is able to realize very short throughput times, but is not very flexible. On the contrary, functional organizations are very flexible, but they often involve long throughput times and low dependability. However, in order to stay competitive, batch manufacturing systems have to be both flexible and attain short throughput times.

One way to achieve this combination of objectives is to redesign the production system according to group technology principles. *Group technology* aims at searching for similarity within the production system and product structure, and at using this similarity in order to simplify the method of production. Some firms have introduced cellular manufacturing as a consequence of the application of group technology to their production system. Others adopted cellular manufacturing as a consequence of a socio-technical redesign of the production system.

We define a *cellular manufacturing system* as a production system that is decomposed into cells, with cells being able to process several operations per work order. This set of operations per work order reduces the total number of different organizational units that are sequentially involved in producing a product. The result of a good system design is a simple but robust decomposition of the production system into cells. Cells are not over-specialized in one product only, as in traditional production lines, but are able to produce a family of parts that require the combining of processes available in the cell.

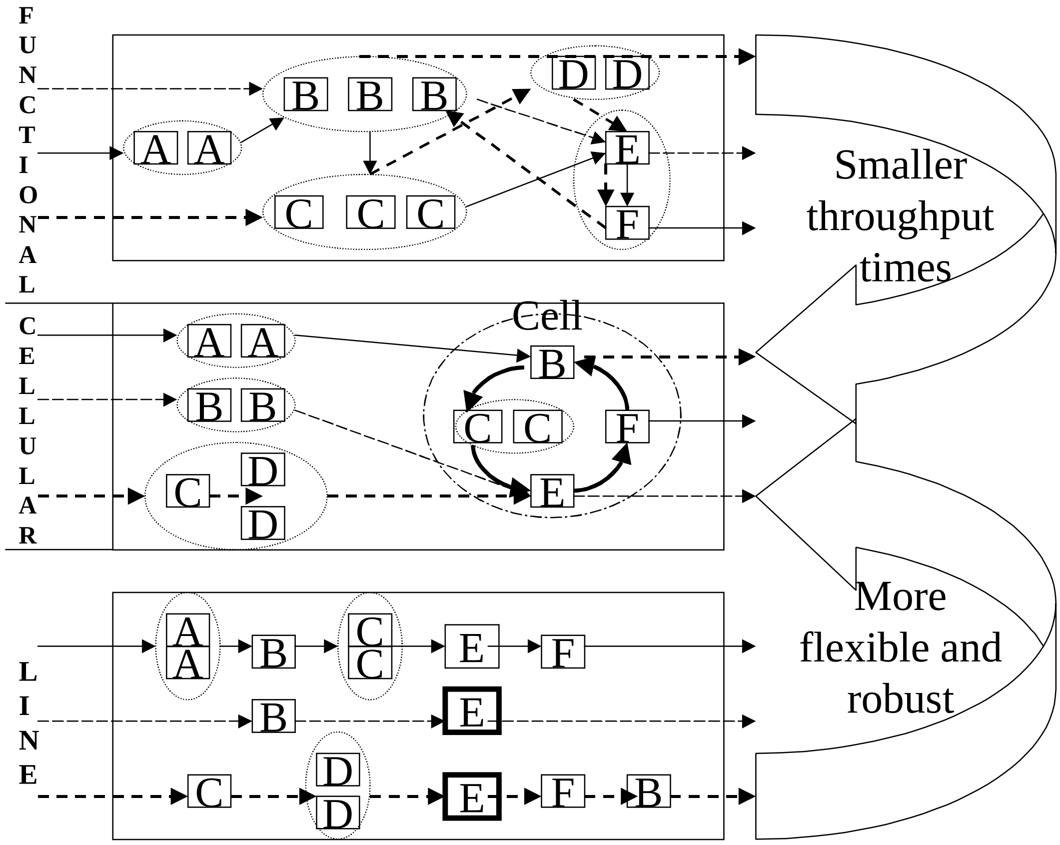

Figure 1.1 Pressures to change towards cellular manufacturing

Figure 1.1 shows an example of a cellular decomposition as an alternative for functional or line production. In functional organization, each product visits organizational units that are responsible for special processes (i.e., A or B). This results in a lot of material handling. The line organization uses different organizational units per product. The example in Figure 1.1 shows that this leads to extra investments in two machines that can perform process E. Furthermore, if changes occur in demand volume or mix, the capacity of a specific machine in the line may become a bottleneck, while the total amount of capacity of this machine type is still sufficient. The line production system is therefore not very flexible and the system design is less robust, as redesign has to be considered on a regular basis.

The cellular organization in Figure 1.1 shows a cell on the right side in which four different operations are combined. In this example, the routing direction within the cell is identical for all products. The operations are arranged in a circular routing, as work may enter from other parts of the system at any of the operations, and also may leave the cell after a number of operations, depending on the product. Due to mix variation, capacity imbalances for the machines within the cell will occur. Operators in a cellular manufacturing system are trained to process multiple operations within a cell in order to handle these fluctuations in machine utilization. We see that a cellular organization tries to combine several advantages of a production line system without facing the inherent weaknesses of this system.

Production planning is an important task within a manufacturing system. We define the *planning system* as that part of the manufacturing system that is responsible for regulating, co-ordinating, and monitoring the flow of work through the *production system.* The production system is that part of the manufacturing system that is responsible for performing the required transformation. The way the planning system accomplishes its function strongly influences the performance of the production system. Planning systems can differ in the way they distribute tasks and responsibilities over various organizational entities, and in the way they decompose the planning problem into subproblems (aggregation/disaggregation).

This thesis examines the changes that are required in the design of a planning system when cellular manufacturing is being applied. The study identifies the factors that have to be taken into account when designing a planning system in order to realize the desired benefits of a change towards cellular manufacturing.

§ 1.2 Relevant factors in the design of a planning system

Developments in the field of production planning during the last century have been substantial. There has been considerable progress with respect to the theoretical foundation of various aspects of production planning, such as scheduling, requirements planning, capacity planning, and so on. Another factor that has played an important role in the development of planning systems is the increase in technological possibilities for supporting the planning function, mainly through the use of computer technology. From these two factors, one can easily draw the *incorrect* conclusion that planning systems that incorporate more advanced theoretical methods and make more intensive use of computer technology are better suitable for providing support to the actual production planning task in a firm.

If we want to determine how the production planning task in cellular manufacturing should be supported, we have to understand the nature of the planning task itself and the position of the planning function within the firm. We will show the relevance of this approach through an exploration of historical developments in the field of production planning. This will help us to identify factors that must be considered when determining an adequate planning system.

§ 1.2.1 Historical developments in the field of production planning and control

Before the Industrial Revolution, which started around 1750, manufacturing activities were mainly domestic, taking place in small work shops in homes. These activities were often highly specialized, based on manual skills. The relationship between supplier and customer was based on merchandising finished products or ordering a new amount of these products that could be used as input for the customer's processes. The successive processes in the supply chain were decoupled through inventory.

The Industrial Revolution and, more specifically, Richards Arkwright's introduction of a fabric system into the textile industry (1769) reduced the geographical distance between the sites of successive processing stages. Workers, materials and machinery required for these processes were all concentrated at a site where power for the new machinery was available. It was therefore less necessary to decouple the successive processing steps through large amounts of inventory. The huge investments in new technology and the interdependency of labour and technology stimulated the development of control procedures for the availability of the various system inputs, such as raw materials, workers, water and power, in order to improve the return on investment of the new machinery. The concept of planning as an instrument for effectively coupling traditionally independent processes, i.e. a *controller point of view*[1], was born.

The concept of the 'interchangeability of parts' could be introduced into fabric systems due to the development of lathes and milling machines by Henry Maudsley (1794) and Eli Whitney (1818). This interchangeability became more essential because of the increased application of steam-powered machines, which resulted in a demand for spare parts. A kind of repetitiveness emerged that became a further subject of study. The attention of management changed from selecting and developing individual craftsmen in order to produce products with sufficient quality to the design of a system that was able to produce quality products efficiently in the amounts that were required by the market. This resulted in the development of cyclical planning systems that could use the repetitive character of demand, i.e. a development that originated from a *market point of view*[2].

Adam Smith pointed out the advantages of the division of labour and specialization for a nail-making operation. He noted that there was an increase in dexterity in every workman. This enabled time savings gained by less frequent passing from one species of work to another, and the invention of or improvement in tools, methods, or machines facilitating labour and making it more efficient. These effects were more likely to occur in case of specialization.

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1 The *controller point of view* indicates changes in the required internal performance of the production system that make changes in the planning and control system necessary. The increased demands in terms of return on investments and the increasing influence of share holders result in such changes.

2 A *market point of view* indicates the effect of changing market demands with respect to speed (lead time), dependability, flexibility, quality, and price on the design of the planning and control system.

Note that this type of worker specialization includes preparational, executionary, as well as regulatory aspects of the tasks. However, this further division of tasks made the co-ordination between the various tasks more complex. Charles Babbage (1832) noted:

'The constant repetition of the same process necessarily produces in the workman a degree of excellence and rapidity in his particular department, which is never possessed by one person who is obliged to execute many different processes. … Now the cost of keeping a stock of iron ore, or of coals above-ground, is just the same as that of keeping in a drawer, unemployed, its value in money (except, indeed, that the coal suffers a small deterioration by exposure to the elements). The interest of this sum must, therefore, be considered as the price of an insurance against the risk of combination amongst the workmen'

Babbage showed that co-operation between workers who have specialized in a certain process has a cost. If one chooses to strive for the benefits of such specialization, appropriate design of the co-ordination system may lower the extra costs that are incurred. Babbage noted that there was a possibility of reducing the risk of combining processes, as this reduces the costs of manufacturing. He showed that the co-ordination system, i.e., the master manufacturer who distributes the work, was an instrument to reduce total costs. These planning system developments originated from both a *systems point of view*[3] and a *controller point of view*[1].

The work of Taylor (1903) on shop management was a next step towards the development of production planning systems. He made a distinction between administrative and preparatory planning tasks and executionary planning tasks, and advocated the creation of a specialized planning function for the first set of tasks, so the foremen and workers could concentrate on the execution and realization of these plans. Furthermore, he abandoned the principle of 'unity of control', advocating a change from a strict hierarchical management control structure with one supervisor linking workers and management to a flatter control structure '*in which a worker receives his daily orders and help directly from eight different bosses, each of whom performs his own particular function*' (Taylor, [1903: 98-99]). His ideas instigated that the new production planning function owned a direct responsibility over the progress of work at the floor. The planner had to design the order release and control system such that the workers were able to work according to plan. Therefore, the system required that the output of the planning function -the plans- had to be very realistic. These developments led to a fundamental change from a *power balance point of view*[4].

The introduction of separate planning departments and the application of scientific knowledge to the field of planning stimulated conceptualization of the relationship between efficiency, inventory, and production planning. Ford W. Harris (1913) was the first to publish a paper on

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3 A *systems point of view* indicates changes in the organization and integration of the technology in the production system that make it necessary to change the planning system as well.

4 A *power balance point of view* indicates changes in the position and power of the planning office and in the task of production planning and control itself, resulting in changes in the planning system.

this relationship. He suggested the use of a mathematical formula in which the most economic choice for the order quantity would depend on cost factors, such as the costs of releasing an order to the floor, including the set-up costs, and the costs of carrying a large stock. This formula did not include all relevant factors, he noted, so it should be used by managers to check their own insights, and apply some correction factors if required. His economic order quantity formula is also known as Camp's Formula (Camp, 1922), or as Wilson's Formula (Wilson, 1934). The intended audience of the journal in which Harris published his formula consisted of managers in manufacturing. At that time it had some 10,000 readers, which shows that the development and application of scientific management principles had attracted broad interest. Since then, the application of statistical and mathematical models in the area of production planning has grown rapidly, a development, originating from a *theoretical progress point of view*[5].

The next important step was made by Henry L. Gantt (1918), who developed charts for the detailed planning and monitoring of the production progress. The Gantt charts could be used in the planning room as a descriptive model of the controlled system. Such a model is one of the prerequisites for an effective control system, as noted by De Leeuw (1986). The development of these charts enabled the position of the planning room to change from mainly an administrative and preparatory one to a more proactive one in controlling the production system. The expected future loading of the resources in the system could be shown and this information could be used when deciding about the release of new work to the floor. The expected consequences of interventions by a manager in the production system (for example, if he planned to release a maintenance plan) could be visualized and communicated in advance to other parts of the system. This gave the production planning a central position in the operational control of the factory, and increased the power of the planners. Note that this development in the planning system originated from a *theoretical progress point of view*[5].

However, the increased dependency on information systems such as Gantt charts for the control of production made the planning system more sensitive to errors or time delays in the information. This led to the development of administrative procedures for monitoring the progress of jobs, the availability of the required input material, the accuracy of the estimated times for setting up the machine and processing the jobs, the control of process outcomes in terms of yield and product quality, and so on. Many of the advancements were oriented towards the reduction of uncertainty, and statistical methods were developed in order to forecast demand and test the quality of production and input. All these measures were oriented towards making the deterministic model of the controlled system (the Gantt chart) a more accurate representation of the real system. These developments were necessary in order to preserve the position of the planning function from *a power balance point of view*[4].

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[5] A *theoretical progress point of view* indicates changes in the availability of planning methods, resulting in changes in the design of the planning system.

In designing an accurate model, the problem of aggregation and abstraction with respect to capacity and products appeared for the first time. Questions had to be answered: what products have to be included, should they be aggregated into families that are planned as one group, how should capacity be modelled, would it be necessary to model each capacity source separately, and so on. The decisions that were then made have had an important impact on the design of planning systems from a *theoretical progress point of view*[5].

During this time, the period batch control system emerged, and it made use of the principle of parts explosion. This principle requires that products and parts be individually planned in order to generate balanced ordering sets. The enormous amount of data that had to be gathered and calculations that had to be performed forced the designers of the planning systems to search for stability in the overall plans, so plans would not have to be updated continuously.

As a consequence, planning efforts became hierarchically organized into several levels. In the first place, long term plans resulted that had to take into account such factors as seasonal demand, capacity changes, and so on. In the second place, short term plans resulted in which the actual production had to be planned. Here, the problem of aggregation with respect to time became apparent for the first time. For cyclical planning systems such as PBC, the length of the time bucket (the stable period) in both the long term and short term programs had to be determined. This choice had a direct impact on the amount of co-ordination effort required.

After the Second World War, the industrialized countries faced a steady increase in demand. Production facilities had to be rebuilt, as many had been destroyed, had deteriorated, or reconfigured during war time in order to supply the war industry. The modernization and rebuilding of society generated a multiplier effect that led to a strong increase in demand. At the same time, it was difficult to enlarge machine capacity by the required speed, due to scarce resources. The only way that production facilities could respond to the demand was to increase efficiency, enlarge batches instead of run frequencies, and provide longer throughput times. Buitenhuis and van het Nederend (1969) describe a cyclical planning system that in the early 1950s changed from a period length of one week to a period length of four months due to these market circumstances! This can be characterized as a development originating from both a *market point of view*[2] and a *resource point of view*[6].

The type of planning system modification that has been sketched above (period length increase) is quite illustrative for the way systems were designed or redesigned. There was much attention to partial insights, but the effects on other parts of the system (inventory management) or other objectives (flexibility) were overlooked. Systems theory and, more specifically, industrial dynamics, did focus on the interrelationship between parts of a system and time varying behaviour. Jay W. Forrester (1961) studied dynamic systems with time-

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[6] A *resource point of view* indicates changes in the availability of technology for the required transformation, which also requires a change in the way the system is being planned.

sequence relationships and showed the presence of amplification behaviour. He observed that the response of a part of a system to a certain change generally exaggerated the response that could reasonably be justified by the magnitude of the change. Such amplified changes could be observed in ordering behaviour in successive stages of the supply chain. The main causes for this nervous behaviour were found in (1) the length of the pipelines and hence the length of the time delay in the information feedback system, (2) the common but incorrect inventory policies that often were used, such as an upward tendency in the amount of safety stock if demand increased, and (3) the use of statistical forecasting techniques that assume that the historical demand patterns will prevail in the near future.

The literature on industrial dynamics has had an important impact on the design of planning systems from a *systems point of view*[3]. Monhemius (1989) notes that as a consequence, the old principles of period batch control, such as parts explosion, were reconsidered. These principles had resulted in '*one of the most sophisticated systems for goods flow control for complex products in the period before 1940*' [1989:2], as they led to an integral control of the supply chain by using the information of end product demand in the control of each manufacturing stage.

Another development after World War II originated from a *theoretical progress point of view*[5] due to the growth in the field of operations research. Both the deterministic and stochastic aspects of production planning became objects of study, mainly for academic researchers. The role of consultants (such as Harris) who had been both developing and using scientific instruments changed. They became expert users of new knowledge. Some examples of these developments are queuing theory, general systems theory, linear programming (the simplex method), inventory theory, and scheduling theory. These theoretical developments have resulted in a large number of alternative planning systems for different production situations. For example, network planning theory for the planning of research and development projects, with their inherent task-time uncertainty, resulted in PERT (Program Evaluation Research Task (PERT, 1958), later known as Program Evaluation and Review Technique. Construction projects, with their inherent trade-off between realizing time objectives and cost objectives and the consequences for the usage of resources, were supported using CPM/Cost (Critical Path Method, Kelley & Walker, 1959). Scheduling theory was developed for job shop as well as flow shop production situations (e.g. Johnson, 1954, Muth & Thompson, 1963, and Conway, Maxwell, & Miller, 1967). However the distance between the developers of new theory and the proposed users of this theory rapidly increased. Many planning system designers were primarily users of this new theory, so a gap with mainstream operations research literature started to develop during the 1960s.
The growing insight into the need for integral control, and the theoretical progress in the field of forecasting and inventory models were important prerequisites for a new step forward in planning system design, but the contribution of the computer technology that became available at the end of the 1960s has to be seen as being the trigger for these developments.

Applying the developments that originated from an *information technology point of view*[7] made it possible to compute the expected demand for parts, calculate the required amount of raw materials, and co-ordinate the timing of release of work orders such that a successive process was fed without making it necessary to use huge amounts of either decoupling or buffer inventory. The systems were named Material Requirements Planning (MRP) systems.

The development of these computerized information systems reduced both the required time for and the costs of integral control. The need for integral control was interpreted as a need for central planning. This centralization empowered the planning and information functions in firms, and the newly obtained status had to be preserved through the application of advanced planning instruments that were made available from theoretical advances. In MRP systems, various options became available, often not well understood by the people who implemented these systems in firms or used these systems for actually regulating the goods flow in manufacturing systems. Some examples of these options are advanced lot-sizing rules for discrete demand, capacity planning, and so on. The application of such instruments made the system nervous, or resulted in unrealistic tasks being given to the floor because of the inherent weaknesses of the model of the controlled system that was behind the MRP system.

The developers of these systems (information system engineers) reacted by modifying the MRP concept into Closed Loop MRP and MRPII. However, modelling the control system in terms of important design parameters such as the offset lead time, bill of material structure, safety stocks, lot-sizes, was not paid the required attention by the information system engineers. The effect was that the quality of models of the controlled systems deteriorated, while the technical possibilities of more detailed control of the manufacturing system increased. In many applications, the combination of both effects made the industry very depressed about the competence of modern production planning systems. The result was a tendency to use the system only for administrative purposes, such as tracking and tracing, ordering materials, and so on. The role of such planning systems in actually controlling progress on the work floor is still limited, although no manufacturing system can nowadays operate without such a registrative and administrative ERP system.

In recent years, several important developments have taken place. The huge ERP systems are integrated with computerized graphical detailed scheduling systems (in Germany called *Leitstand systeme*) to improve the utilization of available system information in controlling the work flow. These systems are connected with systems for time measurement as well as simulation modelling tools in order to maintain an accurate model of the actual situation.
The increased popularity of cyclical planning systems and visual control systems such as Kanban in recent years is a movement in the opposite direction. These systems are easier to describe, understand, and therefore better communicate the objectives and tasks to which the manufacturing system has to direct its attention. However, they do not rely heavily on

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[7] An *information technology point of view* indicates changes in the availabilility of technology for supporting the required planning task, which enables a change in the planning system.

computer technology in controlling the work flow. Special attention has to be paid to the release of work to the production system and to the accurateness of the estimated throughput times and capabilities of the system. In repetitive production situations, level production schedules have been developed. For less predictive production and market situations, developments in the area of work load control systems have improved our understanding of the consequences of order release for system performance.

There are a number of parallel developments in the field of production organization that also have had important consequences for the design of planning systems.

The labour force has changed dramatically. There has been a strong increase in the education level of the work force, increase in their multi-flexibility, a tendency to temporarily use shift work as an instrument for increasing the flexibility of the firm, reduced working times per worker, an increase in part-time workers, higher participation of woman in production processes, the increased possibility of changing labour capacity in the short term by using employment agencies, and so on. All these developments have made it necessary to modify the production organization and its planning from a *labour force point of view*[8].

At the same time, the increased automation of machinery and computerization of process control has changed the role of other parts of the system towards a more direct-service oriented one. The interrelationships between several parts of the system have changed as well as the demands that are placed upon the system in terms of efficiency, flexibility, dependability, and other types of performance. The decomposition of the planning system according to the (rather functionally defined) processing stages in the production system is hence not as appropriate as it was before from a *systems point of view*[3].

Changes in machinery and set-up procedures have resulted in a change in the way capacity has to be planned. Conventional machinery would not take long to set up, but for newer machines, set-up activities have to be planned in a different way. The required precision and the availability of machine specific tools become more important in planning these set-ups. From a *resource point of view*[6], planning systems had to take into account the co-ordination of these additional preparatory activities as well, besides the procurement of required materials.

Market forces have resulted in a demand for more variety, less repetition, smaller lead times, higher quality, and lower costs. From a *market point of view*[2], this requires a better co-ordination of the activities that are involved both in translating the actual demands from a customer to the production organization, and in providing these demands.

Many production organizations have reacted to these demands from different viewpoints by delegating responsibility and authority to the work force, and redesigning the organizational

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[8] A *labour force point of view* indicates changes in the composition and characteristics of the labour market.

units on the floor into cells or teams. The consequences of the increased autonomy of these units for the distribution of planning tasks in the production system are not clear. Some firms only allocate the detailed planning tasks to the units, other firms give units the authority to refuse work order packages that are proposed by the central planning, and so on.

The role and power of central planning probably changes because of these changes in responsibility and authority. From a *power balance point of view*[4], we expect central planning to want to stay involved in determining the work order release packages, capacity analysis, and the co-ordination of the flows over the more or less autonomous units. However, the changing position and role of central planning puts other demands on the quality of the model they use to control the production system. This may have consequences for the required accuracy of data, and the degree of detailed knowledge about actual work order progress. The focus of the central planning systems may change, and this has important consequences for the architecture of production planning systems.

§ 1.2.2 Summary

We conclude that, besides changes from a theoretical progress point of view[5] and information technology point of view[7], other factors have led to developments in the design of planning systems. An historical overview of developments in the field of planning systems design shows that there have been the following driving forces:

- The changing demands of customers with respect to speed (lead time), dependability, flexibility, quality, and price. The required external performance has led to changes in the planning system from a *market point of view*[2].
- Changing internal performance requirements on the production system from a *controller point of view*[1]. Demands in terms of return on investments, and the increasing influence of share holders on the performance records have resulted in changes in the planning system.
- Changes in the labour market (the *labour force point of view*[8]), in the availability of transformation technology (the *resource point of view*[6]), and in the organization and integration of the technology in the production system (the *systems point of view*[3]), all have resulted in other demands on the planning system.
- Changes in the position and power of the planning office and in the task of production planning and control itself have led to changes from a *power balance point of view*[4].

Changes in the design of a planning system should therefore not only reflect progress in information technology or planning theory, but also changes in organization and environment.

§ 1.3 Research questions

In the past, development of planning systems was strongly related to general organizational and technological development processes. We wonder to what extent the application of cellular manufacturing affects the design of production planning systems in organizations. The change towards cellular manufacturing is not primarily a technological change, but more an organizational change. Such a change has implications, and we ought to consider both the consequences and opportunities for planning system design.

Due to the introduction of cells, changes will occur with respect to the power of the planners in the organization, their relationship with cell leaders, communication and negotiating patterns, and so on. However, apart from these, we expect that the introduction of cells will have even more impact on the planning systems in firms, due to the change in the flows that will occur within the production system. In order to plan and co-ordinate these flows, we make a distinction between two levels of planning in a cellular manufacturing system: planning within cells and planning between cells. In this study, we direct our attention primarily to that part of the planning system that is responsible for the regulation of the various flows between cells in the production system.

The objective of this study is:

to gain insight into the main factors that must be taken into account when designing a planning system for the co-ordination of flows between cells and their effect on system performance.

The study will reveal what characteristics of a planning system should be taken into consideration for appropriate co-ordination between cells in a cellular organized production system. The relationship between production system design and planning system design affects the performance of the whole system. If we gain insight into the main design choices in planning system design and understand their relationship to production system design choices, we will be able to improve the performance of cellular manufacturing systems.

There is a huge variety in cellular manufacturing systems and planning system design choices. This variety has forced us to focus our attention on a specific type of cellular manufacturing system and also on a specific type of planning system.

We have chosen to restrict our attention to multi-stage cellular manufacturing systems, as we will examine the co-ordination between cells. Single-stage cellular manufacturing systems do not encounter intercellular flows. Our understanding of the main factors in planning system design for multi-stage systems will increase if we consider actual policies that are applied to planning and co-ordinating these cellular manufacturing systems. The practical situations that we consider in our study are mainly found in the discrete fabrication industry, especially in metal ware fabrication. The desired multi-stage characteristics were found in these situations.

Furthermore, we have restricted ourselves to one well-defined planning system that may be suitable for these cellular manufacturing systems. We examine which main factors should be considered when designing this planning system in the context of a multi-stage cellular manufacturing system. The choice for a specific planning system constrains the search process to suitable parameters for this system.

We have found one planning system that is both specifically proposed (Burbidge, 1971, 1996) and criticized (Hyer & Wemmerlöv, 1982) in literature for its suitability for supporting the overall planning in these multi-stage cellular manufacturing systems. Burbidge propagated the use of the *Period Batch Control* (PBC) system for these production situations because of the predictable throughput times, short lead times, low work in progress, and the clear distribution of responsibility. Hyer and Wemmerlöv criticized the PBC system for being too rigid and unsophisticated, but noted the influence of PBC system design choices on its effectiveness in multi-stage cellular manufacturing systems.

We require a well-defined planning system, but there are several variants of the PBC system described in literature. We have therefore decided to focus our study on a specific variant of this cyclical planning system, the *basic unicycle period batch control* system. The essential characteristic of this particular PBC system is its periodic, cyclical nature, where each work order has an identical lead time. It provides central co-ordination of the goods flow in a cellular system and synchronizes the transfer of work at fixed moments in time. It results in an intermittent, but predictable goods flow within the organization and in a transparent production plan.

The insights that we gain from examining this particular planning system will also be useful for designing other planning systems, whether cyclical or not. Characteristics of the PBC planning system do also appear in related planning systems such as MRP and Kanban. However, the latter systems require some additional design choices (e.g., lot-sizing decisions, internal lead times, container size, and capacity planning). These choices may distract attention from the main design choices in a planning system for cellular manufacturing. This makes these systems less suitable for our analysis.

There are three questions that we want to answer in this study:

- *What characterizes co-ordination between cells in a cellular manufacturing system?*
- *What are the main factors that distinguish the basic unicycle Period Batch Control system from other planning concepts in supporting these co-ordination requirements?*
- *What choices have to be made when designing a basic unicycle Period Batch Control system for the co-ordination between cells and how do they affect performance?*

The study aims at a specialist audience of people involved in the design or redesign of planning systems, both from academic institutions and from industry. It supposes elementary knowledge of logistics and production planning at APICS CPIM level, which can be obtained by studying, for example, the introductory text of Vollmann, Berry and Whybark (1997). However, the results of this study should also convince other people involved in the redesign of production systems of the relevance of considering a suitable reconfiguration of planning systems in order to obtain the benefits that are aimed at in the redesign project.

Ultimately, the study wants to show that in the redesign of both production organization and planning system a careful trade-off should be made in order to realize a higher performance by the system as a whole.

§ 1.4 Outline of thesis

Our study focuses on that part of the planning system that is responsible for regulating the co-ordination between cells. It is therefore directed towards logistical co-ordination requirements in the system.

Chapter Two examines the first research question. It describes the impact of an organizational change towards cellular manufacturing on the logistical co-ordination requirements between cells. We present an instrument to describe the various relationships between cells that may occur. This instrument is used to analyse five case studies involving Dutch firms that use cellular manufacturing in their small-batch metal ware fabrication. We identify various types of relationships between cells and show how these firms co-ordinated these relationships. Finally, we discuss the implications for planning system design.

Chapter Three studies the second research question. It analyses the basic unicycle period batch control system and addresses the essential principles of such a system that distinguish it from other planning concepts. It discusses the major differences with other PBC systems as well as other planning approaches, such as material requirements planning and Kanban. Finally, it introduces our last research question on the design choices in such a system.

The third research question is answered in Chapters Four to Eight.

Firstly, Chapter Four discusses the relationship between the structure of the production system and the design of the basic unicycle period batch control system. We examine the influence of both the definition of stages and the length of the period on the performance of the manufacturing system. This will reveal whether the application of a cellular manufacturing system can be more successful if combined with an appropriate design for a period batch control system.

Chapter Five provides support in the determination of a period length in such a period batch control system. For this purpose, it develops mathematical models and several heuristic solution approaches.

In Chapter Six, the effect of the design of a PBC system on performance is further elaborated through a trade-off analysis with respect to PBC design parameters: period length, number of stages, stage contents, and number of transfer batches. We apply simulation analysis to determine the effect of various combinations of design parameters on the performance of a PBC system, and test the sensitivity of this performance for changes in product structure and market characteristics. We perform this analysis for a cellular manufacturing system that has been described in literature.

Chapter Seven explores the applicability of the solution methods of Chapter Five for PBC system design parameters in the simulated system of Chapter Six. It provides a design approach for the integral design of the production and PBC planning system.

Finally, Chapter Eight studies the relationship between PBC design and the required co-ordination in the cellular manufacturing system. If an organization applies cellular manufacturing and uses PBC as an overall planning system, the design of the PBC system influences the distribution of co-ordination requirements in the system. In order to analyse this distribution, it makes a distinction between co-ordination within and between cells. Finally, for specific PBC system design choices, it proposes an intermediate hierarchical planning level between the central co-ordination performed by the PBC system and the decentral co-ordination that is performed within cells. This intermediate hierarchical planning level is denoted 'stage co-ordination'.

Chapter Nine recapitulates the conclusions of this study and provides suggestions for further research.