Production planning systems for cellular manufacturing

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SOM theme A: Intra-firm coordination and change

Abstract

The application of group technology to production systems has in many firms led to the introduction of cellular manufacturing. This paper studies the changes that are required in the organization of the planning and control systems when applying cellular manufacturing. We review existing frameworks for designing such a planning and control system and propose a new framework that gives attention to decisions with respect to the aggregation and abstraction of information on resources, orders, and time. We discuss various contributions from literature on the applicability of well known approaches of planning and control to cellular manufacturing , such as Material Requirements Planning, Kanban, and Hierarchical Production Planning. We give specific attention to Burbidge's contribution to production control, and to the use of Period Batch Control as a simple but often effective planning system for cellular manufacturing.

Keywords Production planning; Group technology; Cellular Manufacturing

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1. Introduction

The performance of a production system depends not only on the quality of the decomposition of the system in cells and departments, but also on the quality of the production planning system that is being used to plan and control the flow of work. However, the goodness of fit between both systems is of the greatest importance to take full advantage of the benefits of cellular manufacturing. The design of the production planning and control system should meet the requirements of the production system.

Cellular manufacturing creates coordination needs that cannot be tackled by existing planning systems (Rolstadås, 1988). These needs concern both the handling and determination of batches that contain families of parts and the consideration of the cell as one planning unit. Batch sizes cannot be determined in the traditional way, due to setup similarities of various parts within the same family and tooling constraints on the (automated) machines. Considering the cell as a planning unit affects the planning with respect to the cell loading procedure applied and the possibility to control production.

Rolstadås considered highly automated flow line cells, but even if other types of layouts within a cell are used, this would not solve the problems mentioned sofar. Therefore, we have to take a look at the design of production planning and control systems that can be applied in cellular manufacturing. A number of review articles on production control in cellular manufacturing have appeared, see e.g. Sinha and Hollier (1984), part of the study of Mosier and Taube (1985). We will not redo their work, but we aim to give an overview on the available systems and to identify important characteristics of them if they are applied to cellular manufacturing.

2. Production planning and control systems for CM

One of the first who noted that a redesign of the production planning and scheduling system is required when applying group technology principles to production organization was Petrov (1968). He considered various types of flowline cells that can be constructed using group technology and determined the planning conditions that are required to improve both the performance of these cells and the performance of the complete system, as this consists of interrelated cells. Dale and Russell (1983) report on typical production control problems in flow line cellular manufacturing systems. The load balancing problem in a cellular system is one of these problems. The cells consist of various types of machines and operators which often are not equally qualified. In such configurations it can become a problem to maintain a good balance between key machine utilization and operator utilization. Fluctuations in product mix and volume and introduction of new products can exaggerate these problems. Redesigning the production system itself to solve these problems is often not possible or acceptable, so the production control system has to deal with these problems. The same holds for the problems caused by the sharing of key machines between cells. In these cases the realisation of the full potential of cellular manufacturing depends mainly on the production planning and control system design. Dale and Russell state that many problems in firms that reorganised their shop floor layout along GT lines have been caused by still applying conventional control thinking which had worked in a functional organized production system.

This section is directed towards the design of a production planning and control system for cellular manufacturing (CM). We first present in section 2.1 a framework for production planning in CM. Next, section 2.2 describes some existing frameworks and points to their contribution in designing a production planning and control system for CM. Section 2.3 is directed towards the use of MRP in CM. Section 2.4 summarizes the view of Burbidge on production planning in CM and the use of Period batch Control. Finally, section 2.5 gives attention to other approaches to planning for CM.

2.1 A framework for production planning in CM

There are a lot of differences between firms in the way they plan their production. This can be caused by differences in product characteristics, market position, organization of the production system, capabilities of the planner, available information technology, etcetera. Therefore, designing a production planning system for a firm is a very specific activity. However, there are some guidelines which we can take into account in this design process. Frameworks for designing production planning systems specify what factors have to be taken into account in such a design process. A very useful approach to this design process can be found in Banerjee (1997). He applies his methodology for the design of an integrated manufacturing planning and control system to a real life cellular manufacturing system.

A framework for designing a production planning and control system for a specific production system should in our opinion specify both

the required planning functions and

the direction and contents of the relations between these functions.

A framework should give attention to the following three decision types:

determine what to produce	(orders)
determine when to produce	(time)
determine where to produce	(resources)

and specify the following information on the proposed decomposition of the planning process in phases:

hierarchical or heterarchical decomposition

aggregation levels per phase with respect to orders, time, and resources

abstraction levels per phase with respect to orders, time, and resources

frequency of (re)planning in the various phases

Note that a framework does not specify *how* the decisions are taken. Hence, the methods that will be appropriate in a specific production situation to determine what, when, and where to produce are still to be selected.

Production systems that use cellular manufacturing can often not be planned in the same way as a functional organized system. It is therefore important to give attention to the various layers of the production system when designing a planning system. We distinguish five layers of a production system: single resource layer, shift layer, cell or production unit layer, cluster layer, and system layer. Some planning functions that are specified may be required only for one layer. For example, loading procedures for a cluster of similar cells. In a functional organized system such a layer may be not necessary to take into account. Other planning functions may be required at various layers. For example, material requirements planning may be performed both at system layer and within a cell, as described by Love and Barekat (1989).

We will first specify the contents of the five layers of the production system:

The system layer comprises the total production system that is considered and its relation with the environment (e.g., subcontractors, suppliers, customers). Supporting departments, such as maintenance, expediting, purchasing, also belong to this layer.

The cluster layer consists of various clusters of production units within the production system, for example, assembly cluster, parts-producing cluster, sheet metal cluster, finishing cluster, remaining work cluster, etcetera.

The cell layer consists of the cells or production units within the cluster. The similarity between these cells can be used in designing the planning and control system. A large extent of the available flexibility in the system is concentrated in this layer. Examples are work load release choices (if more than one cell can perform the work) and flexibility of human resources (if these resources can be reallocated between these cells).

The shift layer consists of the shifts within the production unitl. Load balancing between the shifts is an example of a planning function that operates on this layer.

The single resource layer consists of the various resources within a single shift. Types of resources that can be distinghuished are, for example, machine, operator, tool, buffer place, transportation equipment, etcetera.

This five-layer system can be used to make a more explicit decision on the relations in the cellular manufacturing system that should be coordinated with the aid of a production control system. It is important to note that the decisions need not to be taken in the sequence of the distinguished layers. In that sence this layer system differs from the NBC-layer system and the architecture for decision making proposed by Jackson and Jones (1987), who apply a hierarchical approach according to this layer system.

The choice for an aggregation level is determined by the required level of detail of information for the decisions that have to be taken. The choice for an abstraction level can be based on the cost of timely acquisition of the required information versus the cost of omitting part of the information in the analysis.

Aggregation of *orders* can be done by considering product families, for example, all products of the same model, but with various colors. For the abstraction of *orders* the subset of orders that are placed by a customer can be considered, or the subset of orders that are generated by a reorder point system (forecasted demand), or the subset of orders that are generated to fill capacity, etc.

For the aggregation and abstraction of *resources* subsets can be constructed using combinations of resource types, such as machines, operators, transportation equipment, storage places, tools, fixtures, information, etcetera. Within these resource types further aggregation or abstraction is possible, for example, key machines, tools that are not duplicated, welding operators, etc.

The aggregation of time is determined by the length of the time bucket that is considerd; the abstraction of *time* by the length of the planning horizon that is considered.

In figure 1 we show an example of a planning framework for a CM situation that specifies relations between various elements in the production system, e.g., various production cells, and the remainder shop. However, the framework gives no information on the aggregation and abstraction levels applied.

For example, it specifies that coordination between production and sales has to take place (system level: the master production

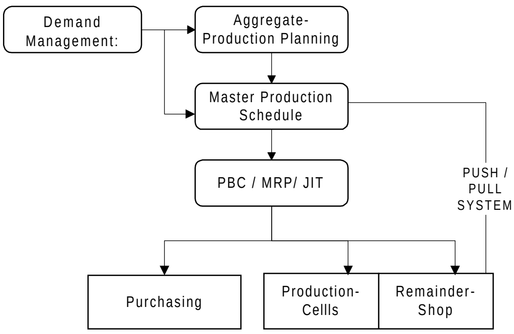

Figure 1 Framework for production planning and control in CM (Suresh, 1979)

schedule), but does not indicate if this coordination has to be performed at end item level or that it suffices to define some product families (higher aggregation level). Neither does it specify what abstraction levels are applied. For example, demand management has direct relations with both aggregate production planning and master production scheduling. For the latter planning function, information on demand of spare parts may be important, while this might be neglected in determining an aggregate production plan (higher abstraction level). The framework doesn't give information on the frequency planning functions are performed. The hierarchical decomposition is an indication for the distinction between a long term planning phase (APP), a medium term planning phase (MPS) and a short term planning phase (PBC/MRP/JIT) that plans and controls the procurement and transformation of materials in the production system.

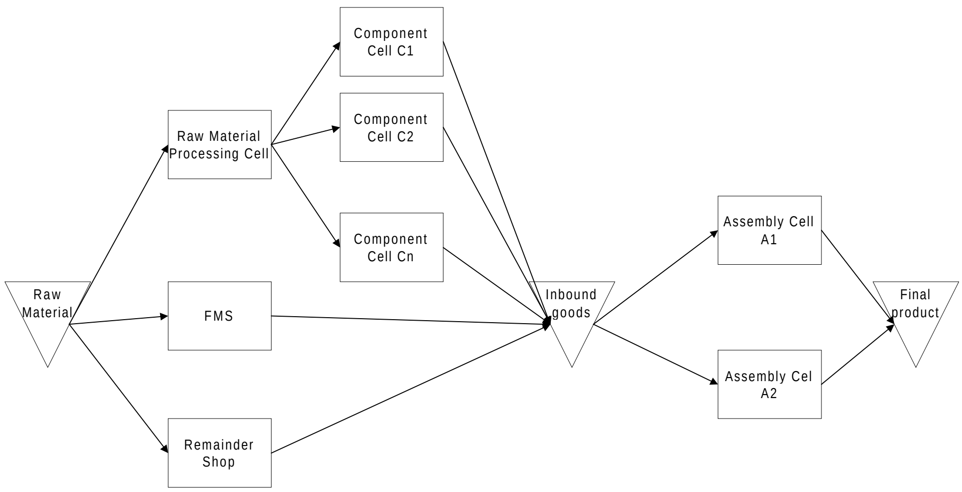

Figure 2 Goods flow in a cellular production system

Figure 2 shows a specific cellular manufacturing system. For this system figure 3 presents a more detailed framework for production planning and control. This framework consists of planning functions, represented in the boxes, relations

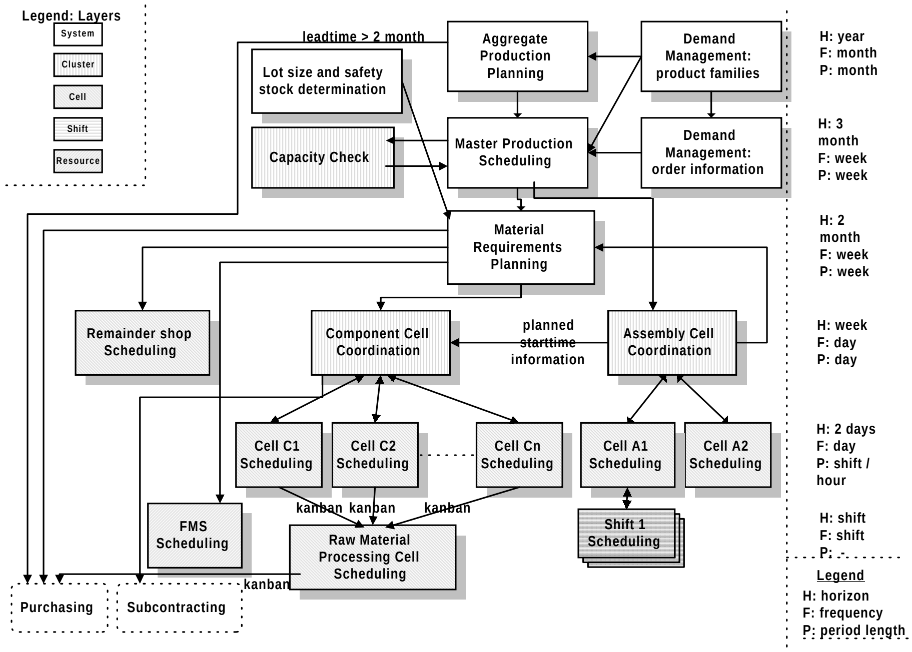

Figure 3 Proposed framework for production system of figure 2

between these functions, planning horizon, period length and replanning frequency applied to these functions, and the layer of the production system at which the function operates. Finally, the framework contains some information on abstraction levels for certain planning functions (e.g. demand management).

The proposed framework is a hierarchical framework. The highest level contains aggregate production planning and demand management. These functions can be performed at an aggregate order level: product families. This planning level initiates the purchase of common items with very long lead times, for example some metal castings. The next level consists of Master Production Scheduling. This planning function uses customer order information, hence no more aggregate order information, and performs a capacity check at cluster layer, so the available capacity of the various clusters (a rough measure) is compared with the capacity required by the master schedule. This schedule is weekly updated. Next, MRP uses information on the planned production of the end items (including, for example, spare parts) and the preferred lot sizes and safety stocks to time phase the requirements for the various clusters and production units, using the expected (standard) throughput times. The Remainder shop and the FMS construct schedules on the basis of this information. However, the component cells use also information of the assembly cell coordinator on the planned starttimes of the various assemblies to determine the actual priority of the various released work orders. The component cells daily obtain orders from the cell coordinator. The available capacity in these cells is controlled by the coordinator function, and reallocating work to one of the other cells or an (external) subcontractor is used to solve short term loading problems. Work order release to the cells is performed by the cell coordinator function. The component cells obtain new material from the raw material cell through a kanban system. This cell is therefore not controlled from the MRP planning function. MRP does present information on the expected amount of raw material needed to the suppliers. The flow of this material is also controlled through kanban. The framework also shows that the FMS schedule is being updated far more frequently than the remainder shop schedule.

2.2 Review of frameworks for production planning in CM

Many authors propose to use an MRP II framework (Manufacturing Resource Planning) in a cellular production system, see for example Singh (1996). However, note that an MRPII framework specifies what planning modules are required and how they are related, but does not give attention to the contents of the relation between the planning modules and the configuration of the production system that has to be controlled. The information contents of such a framework is restricted.

Hyer and Wemmerlöv (1982) propose a general framework for production planning and control and apply this to cellular manufacture in the components parts manufacturing. Their framework is a hierarchical decision process that consists of three levels:

1. determine when and in what quantities final products are to be produced
2. determine what parts are to be produced during a specific time period and in what quantities
3. determine when and in what order jobs should be processed at various workstations

At each level capacity checks are required to ensure feasibility of a particular decision. The hierarchical levels specify the sequence of decision making. Feedback loops between the levels are not considered. Note that their framework does not help to determine a suitable time period in level 2 and that the type of coordination between clusters, cells, or shifts is not determined in this framework.

Bauer et all (1991) develop a manufacturing controls systems hierarchy for a batch oriented discrete parts manufacturing environment. Their hierarchical framework represents a hybrid approach to production planning, e.g., it is said to be based on ideas from materials requirements planning, optimized production technology, and just in time. Production activities that require planning can be strategic, tactical, or operational in nature. Strategic activities relate to the products to be manufactured, and the design of the production system. These strategic activities have to result in a realizable master production schedule. The tools that can be used to generate such schedules can as well be obtained from JIT planning techniques as from MPS scheduling techniques (Vollmann, Berry, and Whybark, 1997). It depends on the specific situation which of these techniques is appropriate and what level of detail in modelling the production system is required.

The tactical planning level consists of a requirements planning function, which is considered to translate the master schedule into weekly or daily requirements of parts and components in the system. The operational planning consists of cell controllers (production activity control) and a factory coordination level, which coordinates activities of the various cells. Factory coordination can be divided into a production environment design task (short term redesign of the production system and the product routings) and an inter cell goods flow control task. The main contribution of this framework for planning in cellular manufacturing is the recognition that a direct translation from tactical requirements planning, based on planned operation lead times, to operational detail planning of the production process is problematic. The characteristics of the cells can vary, for example with respect to the degree of autonomy, multi-functionality of employees, presence of bottlenecks, shared resources, etcetera. Therefore, each cell has to be planned and controlled seperately (the PAC planning function), while at the same time another planning function is required for coordinating activities between cells (Factory Coordination). If cells are totally independent, both with respect to goods flow and use of resources, this latter function can be omitted.

This approach to consider cells as autonomous organizational units in the design of a production planning system is further elaborated upon in German literature. Rohloff (1993) developed a framework that decentralizes planning to the autonomous units (e.g., cells) as much as possible. The framework places a strong emphasize on the horizontal coordination level, e.g., the direct coordination between various autonomous units. The vertical coordination levels can be considered as an attempt to solve certain remaining planning problems using a hierarchical approach. The planning hierarchy has to take explicit notice of the available capacity in the cell within a certain time frame. This can be accomplished by a load oriented order release planning function (Bechte, 1994).

Habich (1989) developed a production planning framework that recognizes the essential planning problem resulting from giving planning autonomy to cells that are interrelated in their primary production process. He views the essential problem of the central planning level to generate an overall optimum from the various local optima that were generated by the decentralized planning of the cells. His approach to this central planning is to consider the set of orders that require subsequent processing in various cells, determine for these orders appropriate sequences between the cells and planned throughput times per cell (e.g. order due dates), such that the cells will be able to finish these orders within their due dates while at the same time enough flexibility is available to optimize the planning within the cell.

2.3 MRP in Cellular Manufacturing

One of the questions that Hyer and Wemmerlöv (1982) raised is whether an MRP II system is compatible with the production planning and control requirements of production cells. They explore this question within their framework of the trilevel hierarchical decision-making process (see section 2.2). They conclude that MPS generation (level 1) would be unchanged and performing rough cut capacity checks will be easier. The impact on the second level is highly significant. Lead times will be shorter and more predictable as queue times, setup times and transfer times are smaller due to the proximity of machines in a cell. This results in modifications of some parameters in the MRP system. The same holds for the lot sizes that are used, as the product families in cellular manufacturing require similar set ups of the machines in the cell. Short throughput times in a cell, and the possibility of applying lot streaming, make it often not necessary to monitor the status of production orders within the cells. This could make it difficult to use CRP in its standard form. If the manufacturing lead time for a released batch exceeds the planning period that is used in the CRP profiles, the problem of allocation capacity requirements to the individual machines over time arises. Finally, according to Hyer and Wemmerlöv, the third level of their hierarchical framework is not important in cellular manufacturing. They state it will suffice to monitor and record only order releases and order completions for a cell. That means the cell is considered as black box and is unit for planning.

Wemmerlöv (1988) gives more attention to the choice of the cell as the basic planning unit. He identifies a number of relevant factors that have to be taken into account in the decision what layer of the production system to consider as the basic planning unit. Factors he mentioned are the appropriate level of delegation of planning decisions to cells, the nature of the production process in the cell, the length and variability of throughput times, and the internal flow patterns in the cell. His thinking can be summarized by stating that the more unpredictable the flow within the cell is, the more problematic a black box approach to the cell in the production planning system of the firm will be.

Wemmerlöv (1988) also addresses the problem how to utilize the advantages of cellular manufacturing in an MRP planning system. The advantage of producing similar parts in one cell should be recognized and handled by the MRP system in order to obtain the benefits of cellular manufacturing. However, the nature of MRP is to convert independent (end item) demand to dependent demand of parts and components. This process does not count for similarities between parts. Lot sizing rules that can be used in MRP try to find a suitable number of subsequent period requirements that can be combined in one order.

Shtub (1990) discussed many of these lot sizing rules and concluded that they do not consider common set-ups required for a family of components and therefore are not suitable for the MRP/Group Technology lot sizing problem. At the other hand, Wemmerlöv (1988) states that he does not see family lot-sizing during the MRP explosion process as a realistic approach for most cellular systems, because of the implementation costs and the inflexibility in execution.

Sum and Hill (1993) criticise the MRPII framework with respect to the tactical planning level, e.g. the basic MRP I requirements planning function. Their critique is that MRP does not apply finite scheduling in generating the requirements plan. MRP uses fixed planned order lead times that are based on static planned operation lead times, and these parameters are usually determined independently of order sizes, work centre loads, and capacities. In many production situations, e.g., cellular manufacturing, this may not result in realistic plans.

Suresh (1979) describes an example of using an MRP approach within Group Technology. Compared with a functional organized production system, the operation of MRP affects:

- the length of the planned manufacturing lead times, which could be shortened;
- lot sizing, resulting in economical justification of the lot for lot ordering rule;
- production control effort, which could be reduced, resulting in less documentation and expediting;
- inventory, which could be reduced for both finished goods and work in process, partly due to more accurate inventory records.

New (1977) argues that MRP is well equipped to determine the component requirements to meet assembly needs, but that it is not suitable for detailed production control. The problem is that the MRP model of how the production system operates differs too much from the actual situation at the shop floor. Updated priority lists for already released work orders are often not used at all at the floor, making the outcome of the system less predictable. Through reducing the planned lead times, reducing the fluctuations in the workload of cells over time, and improving the possibility of using set-up similarities, cellular systems can benefit from MRP. However, this requires fundamental modifications of the basic MRP I approach. Adding a standard CRP analysis is not sufficient in CM.

Chamberlain and Thomas (1995) discuss the required modifications of MRP systems. They stress the importance of building information systems that can easily be modified with respect to the organization of the production system. Flow-line cells are sometimes formed for a period of 3 months, and after this period production will again be performed in other cells. This requires MRP systems that are very flexible in modelling the available capacities and their allocation to cells.

Restructuring the Planning Bill of Materials should be made very easy. In general, the number of levels in the BOM can be reduced, as there is less need to control production progress, due to the reduced throughput times. The number of parts that have to be controlled using MRP can also be reduced, as simple two bin systems with short cycle shipments often function very well in practice. However, MRP is still considered to be usefull as a tactical planning instrument.

To summarize, there are a number of problems if MRP is used in Cellular Manufacturing, for example:

- MRP is found to treat the part family lot sizing problem inadequately;
- MRP does not give enough support for finding a balanced loading of the cells;
- MRP is not flexible with respect to the restructuring of the routing of products;
- MRP does not consider actual information on the production progress in determining due dates and planned lead times;
- MRP is not suitable for detailed production control, as it uses an inadequate model of how the production system operates.

In order to obtain the benefits from a conversion from a functional organized system to cellular manufacturing, several parameters in the MRP system have to be changed, for example:

- Number of levels in the BoM
- Planned lead times
- Safety stocks and safety lead times
- Capacity and Labor bills

2.4 Burbidge's view on production planning in CM: PBC

The thinking of Burbidge on production planning and control is closely related to his view on the organization of the production system (e.g., see Burbidge, 1989a). In fact, he considered production organization as one of the factors that affects the flow of materials, and hence an element of production control in its widest sence (Burbidge, 1962). One of the basic skills used in production control is scheduling, e.g. planning the start times for tasks. Scheduling takes place progressively at three levels: programming (master schedule), ordering (requirements planning) and dispatching (shop floor control) (Burbidge, 1990). The programming level has to translate a sales programme into a realistic production programme that states the required production quantities in future periods of time. Short periods are preferred, as this results in less nervous plans and the possibility of using a chase demand strategy, which prevents from unnecessary stock building and product obsolence. At the ordering level several methods can be used at the same time. Parts that have a very irregular demand can be produced to order. In case of more repetitive demand, other ordering methods can be used. These methods can be classified as either *stock based* or *flow control* ordering systems. Stock based ordering systems, for example reorder level systems and kanban systems, function independent of the programming level in the generation of actual production orders, while flow control systems translate the production programme in parts requirements which, after applying a lot sizing rule, can result in production orders for these parts. Examples of such flow control systems are period batch control (PBC), material requirements planning (MRP),. and optimized production technology (OPT). The available ordering methods can also be classified as either *single* or *multi cycle.* In single cylce systems like PBC orders have identical frequency of occurence, while this may vary in multi cycle systems, such as MRP. The use of single cycle systems can cause uneconomical usage of setups for the production of some parts, while multi cycle systems can result in uneconomical usage of system capacity due to fluctuations in the loading of the system. Cellular manufacturing decomposes system capacity in several independent units (cells), which causes an increased sensitivity for fluctuations in the loading of the system. However, cellular manufacturing overall simplifies the production control and improves the performance of the system in terms of throughput time and inventory costs. Hence, Burbidge prefers the use of single cycle flow control ordering methods in combination with cellular manufacturing. Finally, at the dispatching level the required operations are planned, organized and prepared.

The PBC system can be characterized as a single cycle flow control ordering system (Burbdige, 1988). Like MRP, it uses time phased planning of the goods flow between stages and applies explosion of the end item demand to determine parts requirements. The essential feature of PBC is the periodicity with which this system operates, causing a synchronization of the goods flow within the production system. All products have equal throughput time T, determined by the product of the number of stages N in the production system and the length of the period P, see figure 4. The selection of suitable values for N and P is hence an important design problem in PBC (Riezebos, 1997). If there is little variation in the loading of the cells over time, the dispatching level can accomplish high quality schedules that make use of similar set ups within part families and transfer batches that are smaller than process batches. In that sence, the use of PBC can easily be combined with insights from just-in-time (JIT) (Burbidge, 1987, 1989b) and OPT (Burbidge, 1990).

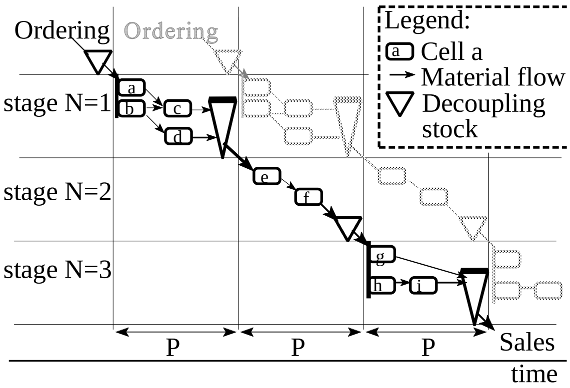

Figure 4: Stages and period length in PBC

The number of firms known to apply PBC is restricted. Burbidge, Falster and Riis (1991) reported that it would be difficult to find 30 companies in the UK which use PBC. Zelenovic and Tesic (1988) reported on several applications in Yugoslavia, Whybark (1984) described an application of a related concept in Finland. More recently, a renewed interest in the performance, design, and characteristics of PBC systems has evolved, see for example Yang and Jacobs (1992), Kaku and Krajewski (1995), Steele and Malhotra (1994), Steele, Berry, and Chapman (1995), Rachamadugu and Tu (1997), and Steele and Malhotra (1997). It is worth mentioning that PBC performs remarkably well in the various tests compared with well known systems as MRP and Kanban.

2.5 Other approaches to planning for cellular manufacturing

Wemmerlöv and Johnson (1997) report in an emprical study that 80% of the firms indicated that production planning and control had become simplified with cells. Olarunniwo (1996) reports on the changes in production planning and control systems when cellular manufacturing is implemented in a firm. Most firms he studied were only partly cellularized, e.g., there existed a remaining shop in more than 90% of the firms. The most remarkable results he found were that almost all firms that used MRP before the implementation of cellular manufacturing continued with this after cellularization took place. However, the number of firms that combined the use of MRP with a kanban system increased from 3.6% to 32.7%. After cellularization, 30.9% of the firms operated MRP alone, while 12.7% only used kanban. The popularity of kanban therefore increases rapidly (more than 50% of the firms) after implementation of cellular manufacturing. His survey makes clear that a lot of firms not simply choose between various production planning and control (PPC) systems, but apply a hybrid approach to planning.

Schonberger (1983) already pointed to the possibility of combining several elements from JIT in MRP, amongst which the so called Synchro-MRP approach that was applied by Yamaha. Flapper, Miltenburg and Wijngaard (1991) further discuss how to embed JIT into MRP. Kanban is only one of the available JIT techniques. To use MRP for planning raw material and component deliveries and for looking forward, while kanban is used to control the actual assembly process, is therefore only one of the possibilities of embedding JIT into MRP. Klein (1989) reports on the effect of kanban on the stress of the human system. She concludes that JIT eliminates the ability of workers to control their own work pace, but kanban makes workers to react on each other rather than answering a computer printout or a supervisor. Kanban therefore leads to a *perception* of increased control over the flow of production, although the reality may be otherwise. In literature we find many contributions that theoretically compare the effectiveness of a JIT approach to other production control strategies for various types of layout in a batch manufacturing environment, see e.g. Wainwright, Harrison, and Leonard (1993), Krajewski, King, Ritzman, and Wong (1987). Buzacott and Shanthikumar (1992) describe a general approach for inter-cell goods flow coordination that can be used for a more systematic comparisson of several approaches, such as kanban, conwip and MRP. However, their framework assumes that a multi cell production system is used and gives only attention to the sequential coordination between cells.

Another interesting approach to planning for cellular manufacturing originated from the work of Hax and Meal (1975). The hierarchical production planning framework they developped has been applied to group technology manufacturing in Kistner (1992). In this approach a strong focus exists on capacity allocation to various layers of production units. Much effort is given to the disaggregation of the complex production planning problem in several less complex subproblems and the description of the interfaces between these subproblems. The type of disaggregation that should be applied strongly depends on the specific characteristics of the cellular manufacturing system, e.g., relations between the cells and flexibility of the system.

3. Conclusion

This study has shown that there exist various approaches to planning and controlling cellular manufacturing systems. We have offered a new framework to determine essential characteristics of such planning systems in terms of decisions on aggregation and abstraction of infromation on resources, orders, and time. We want to stress that there does not exist one best approach of planning cellular manufacturing systems. The characteristics of the cellular system, such as the decomposition in cells, the degree of autonomy of the cells, etcetera, have to be studied in detail before a suitable planning system can be designed. Much work remains to be done in this area using analytical, simulation, and empirical research. This should result in selecting and designing a planning system that gives credit both to the physical structure and the operational conditions of the cellularized system.

References

Banerjee, S.K., 1997, Methodology for integrated manufacturing planning and control systems design, 54-88, in: Artiba, A., Elmaghraby, S.E., (eds), *The planning and scheduling of production systems, methodologies and applications*, Chapman & Hall.

Bauer, A., Bowden, R., Browne, J., Duggan, J., Lyons, G., 1991, *Shop floor control systems, from design to implementation*, Chapman & Hall.

Bechte, W., 1994, Load-oriented manufacturing control, just-in-time production for job shops, *Production planning and control*, 5 (3), 292-307.

Burbidge, J.L., 1962, *The principles of production control*, MacDonald and Evans.

Burbidge, J.L., 1987, JIT for batch production using period batch control, 163-174, in: *Proceedings 4th european conference on automated manufacturing*, 12-14 May 1987, IFS (conferences) Ltd., Birmingham.

Burbidge, J.L., 1988, Operation scheduling with GT and PBC, *Int. J. Prod. Res.*, 26(3), 429-442.

Burbidge, J.L., 1989a, A synthesis for success, *Manufacturing engineer*, nov 1989, 99-102.

Burbidge, J.L., 1989b, *Production flow analysis for planning group technology*, Claredon Press, Oxford.

Burbidge, J.L., 1990, Production control: a universal conceptual framework, *Production planning and control*, 1(1), 3-16.

Burbidge, J.L., Falster, P., Riis, J.O., 1991, Why is it difficult to sell GT and JIT to industry?, *Production planning and control*, 2(2), 160-166.

Buzacott, J.A., Shanthikumar, J.G., 1992, A general approach for coordinating production in multiple-cell manufacturing systems, *Production and operations management Society*, 1(1), 34-52.

Chamberlain, W., Thomas, G., 1995, The future of MRP II: headed for the scrap heap or rising from the ashes, *IIE Solutions*, 27(7), 32-35.

Dale, B.G., Russell, D., 1983, Production Control Systems for Small Group Production, *Omega*, 11(2), 175-185.

Flapper, S.D.P., Miltenburg, G.J., Wijngaard, J., 1991, Embedding JIT into MRP, *Int. J. Prod. Res.*, 29 (2), 329-341.

Habich, M., 1989, Koordination autonomer Fertigungsinseln durch ein adaptiertes PPS-Konzept, *Zeitschrift für wirtschaftliche Fertigung*, 84(2), 74-77.

Hax, A.C., Meal, H.C., 1975, Hierarchical integration of production planning and scheduling, 53-69, in:Geisler, M.A., (ed), *Studies in management sciences: logistics*, vol 1, Elsevier.

Hyer, N.L., Wemmerlöv, U., 1982, MRP/GT: A framework for production planning and control of cellular manufacturing, *Decision sciences*, 13, 681-701.

Jackson, R.H.F., Jones, A.W.T., 1987, An Architecture for Decision Making in the Factory of the Future, *Interfaces*, 17, 15-28.

Kaku, B.K., Krajewski, L.J., 1995, Period Batch Control in group technology, *Int. J. Prod. Res.*, 33(1), 79-99.

Kistner, K-P., Schumacher, S., Steven, M., 1992, Hierarchical production planning in group technologies, 60-74, in: Fandel, G., Gulledge, Th., Jones, A., (eds), *New directions for* *operations research in manufacturing*, Springer Verlag.

Klein, J.A., 1989, The human costs of manufacturing reform, greater employee responsibility does not mean greater discretion over time and work, *Harvard business review*, 67(march-april), 60-66.

Krajewski, , L.J., King, B.E., Ritzman, L.P., Wong, D.S., 1987, Kanban, MRP and shaping the manufacturing environment, *Management science*, 31, 39-57.

Love, D., Barekat, M.M., 1989, Decentralized, distributed MRP: solving control problems in cellular manufacturing, *Production and inventory management journal*, 30(3), 78-84.

Mosier, C., Taube, L., 1985, The facets of group technology and their impacts on implementation - a state of the art survey, *Omega*, 13(5), 381-391.

New, C.C., 1977, *Managing the manufacture of complex products: coordinating multi-component assembly*, Business books communica europe, London.

Olarunniwo, F.O., 1996, Changes in production planning and control systems with implementation of cellular manufacturing, *Production and inventory management journal*, 37(1), 65-69.

Petrov, V., 1968, *Flow line group production planning*, Business publications, London.

Rachamadugu, R., Tu, Q., 1997, Period batch control for group technology - an improved procedure, *Computers industrial engineering*, 32(1), 1-7.

Riezebos, J., 1997, On the determination of the period length in a period batch control system, *Matador conference proceedings*, vol. 32, MacMillan Press Ltd., 131-136.

Rohloff, M., 1993, Decentralized production planning and design of a production management system based on an object-oriented architecture, *International journal of production economics*, 30-31, 365-383.

Rolstadås, A., 1988, Flexible design of production planning systems, *Int. J. Prod. Res.*, 26(3), 507-520.

Schonberger, R. J., 1983, Selecting the right manufacturing inventory system: western and japanese approaches, *Production and inventory management journal*, 24 (2), 33-44.

Shtub, A., 1990, Lot sizing in MRP/GT systems, *Production planning & control*, 1(1), 40-44.

Singh, N., 1996, Production planning in cellular manufacturing, 212-245, in: Singh, N., Rajamani, D., (eds), *Cellular manufacturing systems, design, planning and control*, Chapman & Hall.

Sinha, R.K., Hollier, R.H., 1984, A review of production control problems in cellular manufacture, *Int. J. Prod. Res.*, 22(5), 773-789.

Steele, D.C., Malhotra, M.K., 1994, Operating characteristics of period batch control, *Proceedings DSI 20-22 November 1994*, vol 3, 1699-1701.

Steele, D.C., Berry, W.L., Chapman, S.N., 1995, Planning and control in multi-cell manufacturing, *Decision sciences*, 26(1), 1-34.

Steele, D.C., Malhotra, M.K., 1997, Factors affecting performance of period batch control systems in cellular manufacturing, *Int. J. Prod. Res.*, 35(2), 421-446.

Sum, C-C., Hill, A.V., 1993, A New Framework for Manufacturing Planning and Control Systems, *Decision sciences*, 24(4), 739-760.

Suresh, N.C., 1979, Optimizing intermittent production systems through group technology and an MRP system, *Production and inventory management journal*, 20(4), 77-84.

Vollmann, T.E., Berry, W.L., Whybark, D.C., 1997, *Manufacturing planning and control systems*, 4th edition, Irwin/McGraw-Hill, NewYork.

Wainwright, C.E.R., Harrison, D.K., Leonard, R., 1993, Production control startegies within multi-product batch manufacturing companies, *Int. J. Prod. Res.*, 31(2), 365-380.

Wemmerlöv, U., 1988, *Production planning and control procedures for cellular manufacturing*, American production and inventory control society, Falls Church.

Wemmerlöv, U., Johnson, D.J., 1997, Cellular manufacturing at 46 user plants: implementation experiences and performance improvements, *Int. J. Prod. Res.*, 35(1), 29-49.

Whybark, D.C., 1984, Production planning and control at Kumera Oy, *Production and inventory management journal*, 25(1), 71-82.

Yang, K.K., Jacobs, F.R., 1992, Comparison of make-to-order job shops with different machine layouts and production control systems, *Int. J. Prod. Res.*, 30(6), 1269-1283.

Zelenovic, D.M., Tesic, Z.M., 1988, Period batch control and group technology, *Int. J. Prod. Res.*, 26(4), 539-552.