Design of a period batch control planning system for cellular manufacturing

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Chapter 9 Conclusions and further research

The purpose of this study is to gain insight into the main factors that should be taken into account when designing a planning system for the co-ordination between cells in a cellular manufacturing system. The conclusions of this study will be presented and summarized in Section § 9.1 and Section § 9.2 will provide some recommendations for further research.

§ 9.1 Conclusions

The historical development of planning system design cannot be explained solely in terms of theoretical progress or information technology advancements. Redesigns of the planning system have also been initiated as a result of the influence of several stakeholders, including customers, shareholders, and labour force, as also as a result of a change in position and power of the planning function in the organization. We would therefore also expect a change in the planning systems of firms that have chosen to apply cellular manufacturing in their small batch production. These changes might be instigated either to avoid any negative consequences of such a change in the production system, or to provide opportunities that were not as easily obtainable with the former production system design.

In cellular manufacturing systems, several operations per work order are performed within one unit, the cell. The main benefits of such a system are substantial reductions in throughput time, lower work in progress, improved quality and accountability, and workers who are trained to carry out various operations. It should be noted that these benefits are particularly obvious if the production system has been using a functional organization. If they used formerly a line organization, the main benefits of a change to cellular manufacturing will be a more robust system, improved volume and mix flexibility, higher job satisfaction, and improved quality.

Literature on cellular manufacturing and socio-technical systems design often assumes that the delegation of planning tasks and responsibility to cells automatically results in an easy to accomplish overall co-ordination of the goods flow in the system. We conclude that this is a far too simple view of the co-ordination issue within multi-stage cellular manufacturing systems. It might be true for a specific type of cellular manufacturing systems, i.e., single-stage cellular systems, in which completely autonomous cells produce a whole product for a separate segment of the market. In multi-stage cellular manufacturing systems, where our study focuses on, relationships between cells generally do arise in the process of transforming customer demands into finished products. We conclude that there are valid reasons for the existence of these relationships between cells in such multi-stage systems, and hence they should be co-ordinated adequately. The relationships between cells that require co-ordination should not be restricted to material flow relationships. In some situations, the co-ordination of specific resource and information flows may also be important.

Our study provides a typology of relationships between cells. We make a distinction between sequential, simultaneous, and latent relationships between cells. The determination of the type of relationship provides information on the extent of the co-ordination requirements between these cells. The framework of relationships between cells and the analysis of the five case studies have revealed that the co-ordination issue within multi-stage cellular manufacturing systems is an important aspect of planning system design. We found a huge variation in co-ordination mechanisms applied by firms in order to cope with these co-ordination requirements. The specific relationships between the cells explained for a large part this variety, in addition to the system objectives, the available resources, and the planning and information systems used . The effect of planning system design choices on the possibility of effectively co-ordinating the sequential material flow relationships between cells should be considerd, as well as other sequential, simultaneous, and latent relationships between cells.

The second research question of this thesis concerns identifying the main factors that distinguish the basic unicycle period batch control system from other planning concepts in supporting the co-ordination requirements between cells. We conclude that the basic unicycle PBC system can be distinguished from other PBC systems and alternative planning concepts such as MRP and Kanban in the application of *three* principles: it is single cycle, both at programming and ordering level, single phase, and uses a single offset time. Furthermore, it uses a cycle time that is equal to the offset time and phase of the system. The combination of these principles results in a thorough cyclical planning system, which is able to provide central co-ordination of flows between cells in a multi-stage cellular manufacturing system.

The third research question addresses the design choices in this PBC system for appropriate co-ordination between cells and the effect of these choices on system performance. We conclude that the degree of control provided by central PBC co-ordination depends on three main factors: the period length P, the number of stages N, and the contents of these stages (the definition of the work orders). These three design choices in a basic unicycle PBC system are not always considered in comparative studies on planning system performance. This has resulted in these comparisons producing contradictory results. Hence, we need to improve our understanding of the main design choices of such systems and their effect on performance.

The design of the production system and the planning system are interrelated. This has consequences for the procedure for determining the parameters of PBC system design. We have shown that it can result in huge inefficiencies if the structure of the production system is designed independently of understanding about appropriate structures for planning systems. The decomposition of the production system into cells need not correspond with the decomposition of the planning system into stages. We developed a framework that identifies the various choices that should be made in order to determine an adequate division of the planning system into stages. This framework starts with formulating the desired mix of system objectives (speed, dependability, flexibility, quality, and costs). The central issue is to consider changes in either uncertainty or required accurateness of control between successive operations as indicating a need to introduce a stage decoupling point between these steps.

The length of the planning period P has important consequences for two operational issues relating to the PBC system. Both issues originate from the cyclical, periodical characteristics of the basic unicycle PBC system. We have called them the start/finish and set-up time effect.

The start/finish effect describes the utilization losses due to the unavailability of work at the start or finish of a period, because the work has to visit preceding or subsequent operations in the same period as well. The length of P influences the size of the batches and hence the start/finish effect. If P increases, it takes longer before a work order arrives from a preceding work station that has to be visited in the same period.

The set-up time effect describes the influence of set-ups on the net available capacity. It should be noted that the size of the set-up times does not depend on the size of the period length. However, the total number of set-ups in a year does depend on the length of period and hence a decrease in P reduces the net available capacity in the system.

Together, the size of P and the number of stages N determine the manufacturing throughput time $T=N\cdot P$, and hence the customer order lead time or the forecast horizon that has to be used in the planning system. The definition of the stages (both the number of stages and their contents) influences the performance of the system with respect to dependability. The use of overlapping production (transfer batches or subbatches) improves dependability. However, the introduction of overlapping production has important consequences for the operation of a cellular manufacturing system. The PBC design choices should therefore be made with care.

The mathematical models that we have developed show that the period length and a suitable batching policy both have an important effect on the costs of the system. This holds true both for production situations that allow only an equal number of subbatches per operation and for situations with a varying number of subbatches per operation. In the latter case, we show that co-ordination requirements between successive operations differ for nested, powered-nested, and non-nested batching policies. Hence, the specific variable batching policy used will affect the cost of co-ordination in the system.

In order to choose an appropriate value for the PBC system design parameters P, N, and the subbatch policy that should be used, we developed two heuristic solution approaches. In these heuristics, the number of stages N is a function of the ratio between the expected maximum total throughput time and the period length P. We firstly developed an enumerative search heuristic. For a specific period length P, this heuristic determines a suitable subbatch strategy that minimizes total costs. It should be noted that a subbatch strategy influences the total throughput time and hence the required number of stages in the system. The heuristic compares the costs of the configurations at the various period lengths P and chooses the configuration with the least costs. The other solution approach is the progressive search heuristic. This heuristic searches for both a variable subbatch strategy and a period length that results in minimal costs. The progressive search heuristic outperformed in 92% of the experiments the time-consuming enumerative search heuristic.

The results of search heuristics cannot be directly used for configuring a basic unicycle PBC system. The assumptions behind the mathematical model are not completely in accordance with the characteristics of this system. This holds especially true for the periodicity (single-phase principle) of the system. Furthermore, the heuristics do not take into account the effect of stochastic variety on system performance. We therefore firstly considered the effect of the periodicity of a PBC system under various circumstances and policies by simulation analysis.

Literature on PBC system design generally assumes that system performance improves if either the number of stages decreases or the period length. Such a decrease results in a smaller manufacturing throughput time T, which raises the question as to what extent the change in the PBC design factors N and P in itself contributes to a change in system performance.

We have studied the effect of varying N and P while their product T remained constant. We conclude that the trade-off between systems with large N and small P and systems with small N and large P is essential, as it has important consequences for both the performance (amount of overtime work and costs) and the operation of the PBC system. Simulation experiments have shown that a configuration with small N and large P result in less set-up time losses, but in higher amounts of overtime work. Configurations with large N and small P result in improved co-ordination and control, higher bottleneck utilization, smaller order lead times, but also in higher set-up and material handling costs.

The simulation study was performed for two production situations that differ in the degree of routing variety within the cells. The first production situation showed that the number of stages and the number of transfer batches are the most important experimental factors. The scheduling policy within the cell and the type of stage co-ordination has a much smaller influence on system performance. The introduction of routing variety has no effect on this conclusion, but it does have a substantial effect on system performance. The effect of introducing mix variety is also present, but its impact is smaller. The conclusions remain valid under various levels of system utilization.

The analysis also revealed that the determination of the contents of the stages is an important factor in the design of the PBC system, even if the length of period P and the number of stages N are known.

The simulation model enabled us to test a configuration proposed by one of the search heuristics. Due to the differences in purpose and use of the simulation model and the mathematical model for determining a PBC configuration, we had to modify several elements of the heuristics in order to compare the results of the proposed configuration with already performed experiments. The procedure for proposing configurations had to be corrected for underestimation of the amount of overtime work needed. This is due to the characteristic flow-shop structure of the cellular manufacturing system that we tested. If the calculated throughput times were corrected with a small correction factor (95%), this resulted in configurations that are more realistic. These configurations resulted in a strong decrease in costs (at least 15% cost reduction was achieved) compared with the originally tested configurations. This was mainly due to the smaller throughput time that resulted from the proposed configurations.

We conclude that a search heuristic can provide valuable information on a suitable initial configuration of a PBC system. However, the deficiencies of these heuristics with respect to the characteristics of the basic unicycle PBC system have to be taken into account. Therefore, the configuration that is proposed by a search heuristic should not be considered as a blueprint for PBC system design, but may be used as a first step in a design process that consists of four steps. An integral design for a manufacturing system that uses cells and co-ordinates its production with a PBC system needs to take into account the interaction between production system design and planning system design.

Finally, we have considered the effect of PBC system design choices on the co-ordination between and within cells. We conclude that these choices affect the distribution of uncertainty in a cellular manufacturing system. We make a distinction between conversion uncertainty and boundary transaction uncertainty, either within or between cells. A change in the length of P causes a redistribution of uncertainty amongst the conversion uncertainty and the boundary transaction uncertainty between cells. A change in the number of stages N only affects the amount of conversion uncertainty within cells. Finally, a change in the allocation of operations to the stages has a most important effect on the redistribution of uncertainty in the system. If the allocation results in more cells becoming sequentially related within a stage, this causes an increase in conversion uncertainty and boundary transaction uncertainty between the cells. If the allocation results in more cell operations being performed in successive stages, this leads to a reduction of conversion uncertainty and boundary transaction uncertainty within the cell.

PBC system design choices not only affect the occurrence of sequential and simultaneous relationships between cells within a period, but also affect the possibility of exploiting latent relationships. A larger period length makes it more difficult to exploit these relationships. Stage definition affects the possibility of using latent relationships between cells.

In order to cope with the resulting distribution of uncertainty in the system, appropriate co-ordination mechanisms have to be designed. The PBC system provides only for the central co-ordination between stages. We introduced the notion of stage co-ordination in order to fill the gap between central PBC co-ordination and decentral cell co-ordination. Three functions were seen as belonging to the domain of stage co-ordination: (1) determining intermediate release and due dates for work orders that pass through various cells within a stage, (2) enabling transfer of material between cells, and (3) redirecting various types of flows between the cells. We further distinguish between off-line planning activities, on-line decision making, and monitoring. Finally, we conclude that the allocation of the tasks of stage co-ordination in the planning system to either cell co-ordinators or central planners depends on the characteristics and objectives of the manufacturing system.

The conclusions of our study with respect to the design choices in a basic unicycle period batch control system have implications for the design of other planning systems as well. Most MRP systems use time buckets, but the length of a time bucket is not often discussed in MRP literature. On the contrary, much attention has been paid in the last decade to the reduction of the number of levels in the Bill of Materials. This number of levels corresponds with the number of stages in a PBC system. Our study has revealed that for a basic unicycle PBC system, it is better to increase the number of stages and at the same time decrease the period length. This result is at odds with the path followed in redesigning MRP systems. However, it should be noted that we have not studied the effect of introducing multi-offset times, multi-cycles at programming level, and different lot-sizing rules on the performance of a PBC system. This may influence the implications of our conclusions for the design of related planning systems.

Our study has shown that a change towards cellular manufacturing has important consequences for planning system design. The design of a planning system has to resemble the inherent characteristics of the production system and vice versa. Nevertheless, the decomposition of the production system into cells need not correspond with the decomposition of the planning system into stages. Stage allocation should reflect the intrinsic uncertainty and required accurateness of control between successive operations. The cellular structure influences this decision about stage definition.

§ 9.2 Recommendations for further research

Our study identifies the mutual relationship between production system design and planning system design as an important element in manufacturing system design. Product and process design provides input for decisions with respect to planning system structure and decomposition of the production system. This raises questions about the quality and specifics of the decisions in the product and process design phase. The relationship between process planning and production planning should be reconsidered from the perspective of the ability to improve the design of both production and planning systems

Literature on cellular manufacturing system design provides many methods for production system decomposition. Most methods decompose a part/machine matrix into a block diagonal form. This approach is only applicable for single-stage cellular manufacturing systems. Decisions about appropriate segmentation of the production system have to be taken in advance. The methods that we have developed for planning system decomposition might also be useful for improving the production system decomposition algorithms. As the block diagonal form will not be suitable for these algorithms, this will also require further study towards appropriate measures of performance for cellular decompositions.

The results of this study were obtained from a rather rigid planning system. This has enabled us to focus on a number of elementary design choices that also appear in other planning systems with more degrees of freedom. For example, in MRP systems, we have to determine the size of the time bucket (period length), replanning frequency, work orders, and planned lead times as well. Megens (1999) confirms our experience in respect of the parameterisation of such systems.

Academic researchers have published a lot on more ‘advanced’ planning features, such as discrete lot sizing and the relationship to capacity analysis. Implementation consultants have primarily directed their attention to the speed and dependability aspects of the implementation process instead of the quality of the implementation. This may be no real problem in functional organized production systems, as in these cases the structuring of the BOM is quite evident and the estimation of the planned lead time of a work order is considered to be a consequence of the former decision.

However, cellular manufacturing systems are more sensitive to these planning system design choices, because of the loss of pooling synergy (Meredith & Suresh, 1994). If the parameterisation of the planning systems they use is not carefully undertaken, this may put achieving the desired benefits of cellular systems under threat. We should therefore pay explicit attention to the quality of planning system design choices in respect of cellular manufacturing systems. Further research should focus on providing implementation consultants with instruments to improve the quality of these decisions on planning system design. This will require modification of the reference models that they use in the parameterisation of the system. It also will require the development of simulation tools that they can use in making trade-offs between the various design choices. The tools provided by this study have to be further developed in order to make them suitable for application in realistic settings.

Our study has revealed that in basic unicycle PBC systems, the dependability of the system improves if one reduces the length of the time bucket and increases the number of levels in the BOM. Studies on MRP system design can benefit from the insights that this study provides on the length of the time bucket and structure of the Bill Of Materials. However, MRP systems are generally multi-cycle and multi offset time, and nowadays many are also multi-phased. Further research should therefore reveal the validity of these results for multi-cycle, multi offset time, and multi-phase systems. Our simulation model can easily be modified to perform such an analysis.

The system that has been described by Steele, Berry and Chapman (1995) uses such a multi-phase loading. They consider the effect of various positions of a weak cell, and conclude that the impact of a weak cell at the final stage has most impact on the dependability. We expect that these conclusions will not remain valid for single-phase systems as well. Our simulation model can be used to test these conclusions for single-phase loading.

We have experimented with two types of multi-stage cellular manufacturing systems, either with or without routing variety in the cells. Our results indicate that design choices for basic unicycle PBC systems in both cases significantly affect system performance. Further research should reveal if these results also hold true for other multi-stage cellular production situations.

The mathematical model for determining a suitable configuration of the PBC system (Chapter Five) can be combined with the mathematical model for determining a suitable stage allocation (see Appendix B). Combining both models enables the determination of a PBC configuration that reflects the single-phase principle, which improves the design of the PBC system. A new heuristic solution approach has to be developed for such an extended model.

Further research should make it possible to improve the accuracy of finding a suitable value for the lowerbound correction factor in both the mathematical model and solution approaches presented in Chapter Five. Estimation of the total throughput time in the system has important consequences for the dependability and costs of the system. These make it worthwhile to consider such improvements.

In addition, future research should address the problem of allocating tasks, responsibility and authority within the planning system. Our study has addressed the need for an intermediate level of stage co-ordination between central PBC co-ordination and decentral cell co-ordination. However, this distinction in levels does not imply that the planning tasks at these levels should be performed by different persons within different organizational units. The factors that have to be considered in designing these aspects of the planning system should be identified in future research. If this results in extended rules for stage co-ordination, our simulation model can be used to determine the effect on system performance.

In this study, the problem of planning system design has been considered mainly from a theoretical point of view. Future research should attempt to test the proposed design approach in practice. We expect that such an attempt will reveal additional insights into the factors that should be taken into account in designing a planning system for cellular manufacturing systems. From our contacts with firms that apply variants of PBC systems, we know that the technical parameter choices (period length, number of transfer batches, work order definition, and number of stages) do not remain constant for a long time. The determination of these parameters affects the possibilities there are for the system to improve its performance. This effect should be taken into consideration in successive studies on the design of planning systems for cellular manufacturing.