Linking manufacturing strategy decisions on process choice with manufacturing planning and control systems

JAN OLHAGER†* and MARTIN RUDBERG†

For any manufacturing firm, theory suggests that the firm is better off if the manufacturing planning and control (MPC) system supports the market strategy as well as the manufacturing strategy. Typically, the strongest link between market requirements and manufacturing strategy concerns the process choice, i.e., choosing a manufacturing process that supports a firm’s competitive priorities. The general aim of this paper is to examine the role of the MPC system in a manufacturing strategy. More specifically, the purpose is to link market requirements, product characteristics, and the process choice to the MPC system. A special focus will be placed on the link between the process choice and the design of the MPC system. Two key factors are identified as major process-specific elements influencing the MPC system design: the number of planning points, and set-up times at individual resources. The process choice affects the lower planning levels of the MPC systems, where the physical reality of the plant becomes apparent. This is especially true for production activity control, but also for requirements planning (material and capacity). Concerning the MPC system design for longer-term planning, such as sales and operations planning and master scheduling, the impact from market requirements and product characteristics dominates.

1. Introduction

The content of manufacturing strategy is traditionally built around two broad groups: competitive priorities and decision categories. The competitive priorities are defined as a set of goals for manufacturing (Leong et al. 1990), which are used to align the business strategy and market requirements with the manufacturing task. When determining the manufacturing task, it is vital to define what the manufacturing function must accomplish in terms of providing competitive priorities. Consequently, it is obvious that the choice of manufacturing task will position a company relative to its competitors in terms of its competitive advantage. The decisions made to fulfill the manufacturing task are often grouped into a number of decision categories (Hayes and Wheelwright 1984). Wheelwright (1984) defines a manufacturing strategy by the patterns of decisions actually made within these categories. The more consistent the pattern of decisions is in supporting the competitive priorities and the manufacturing task, the more effective the manufacturing strategy.

Competitive priorities as means to structure and operate manufacturing have been used extensively in the manufacturing strategy literature (see, for example, Hayes and Wheelwright 1984, Miltenburg 1995, Hill 2000). The decision categories

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† Department of Production Economics, Linköping Institute of Technology, S-581 83 Linköping, Sweden.
* To whom correspondence should be addressed. e-mail: jan.olhager@ipe.liu.se
noted in a manufacturing strategy differ somewhat between authors, but there is an essential agreement on areas that really matter for manufacturing. The categories, generally ranging from six to ten in number, are usually divided into structural (related to long-term commitments and heavy investments) and infrastructural (related to support functions where changes may be incorporated in a shorter time perspective) decision categories, as proposed by Hayes and Wheelwright (1984). A typical set of decision categories includes process technology, capacity, facilities, and vertical integration as structural categories, and quality, organization, and a manufacturing planning and control (MPC) system as infrastructural categories (see, for example, Hayes and Wheelwright 1984, Leong et al. 1990, and Miltenburg 1995). Authors such as Skinner (1969) and Hill (2000) have developed frameworks for linking the business strategy, via market requirements and marketing, to the manufacturing strategy. Typically, the strongest link between market requirements and manufacturing strategy concerns the process choice (the major policy area regarding process technology), i.e. choosing a manufacturing process that supports the competitive priorities of the firm (see, for example, Hill 2000). It is, however, equally important to link the MPC system to the market requirements and the manufacturing environment.

The general aim of this paper is to examine the role of the MPC system in a manufacturing strategy. More specifically, the purpose is to link market requirements, product characteristics, and the process choice to the MPC system (see figure 1). A special focus will be placed on the link between the process choice and the design of the MPC system.

In the manufacturing strategy literature dealing with the relationship between market, manufacturing and MPC systems, there is not much on the relationship between process choice and MPC systems (see, for example, Skinner 1969, Hayes and Wheelwright 1984, Voss 1992, and Miltenburg 1995). Most researchers report that the MPC system design is strongly influenced by the market requirements and

![Figure 1](image-url)
the product features (see Kotha and Orne 1989, Bhattacharya and Coleman 1994, Vollmann et al. 1997, Olhager and Wikner 2000, and Hill 2000). Vollmann et al. (1997) state that there is some interdependency between the manufacturing process features and the MPC system. Grünwald et al. (1989) also indicate that there is a relationship between product, market, process, and control concept criteria. However, this link needs further investigation in order to clarify the properties involved in designing the MPC system. Market requirements and product characteristics are important inputs to the manufacturing strategy. Together they affect the decisions made within each decision category. In this paper, we focus on two decision categories, i.e. the process technology (here reduced to the choice of manufacturing process) and the manufacturing planning and control system.

APICS (1998) regards the MPC system decision category (referred to as a ‘production planning and control strategy’) as an element of manufacturing strategy that includes the design and development of MPC systems in relation to: market related criteria, consistency between the process type and the MPC system, and the organizational control levels (ranging from long-term to short-term planning). Due to the complexity of MPC decisions in large organizations, the latter relation normally requires a hierarchical division of the MPC system into different levels (see Vernadat 1996, Doumeingts et al. 1998). Hence, we will analyse the links to the different levels of a hierarchical MPC system.

The methodological approach in this paper is analytical and normative. Fine and Hax (1985) notice that a manufacturing strategy on the one hand has to be comprehensive, but on the other hand the complex web of decisions must be broken down into analysable pieces. Their statement underpins the analytical approach and explains the notion of the decision categories. Our results are normative, i.e. they explain how things should be, aiming at improved performance. In our search for a normative model, we investigate existing normative and descriptive research from an analytical perspective.

In the sections that follow, we first explore the linkage between market requirements and process choice. Secondly, the corresponding link between market requirements and MPC systems are analysed. Thirdly, we address the link between process choice and MPC systems. After analysing the three links in figure 1 separately, we bring them together and analyse the interrelations in section 5. We then discuss the possible consequences of not linking MPC systems to markets, products and processes.

2. Exploring the linkage between market requirements and process choice

It has been established that the market requirements strongly influence the choice of manufacturing process, see for example the product–process matrix by Hayes and Wheelwright (1979, 1984) and the product-profiling methodology by Hill (2000). These frameworks are the two most widely recognized approaches for choosing an appropriate process, taking into account the market and product features. The relationship between product issues—such as volume and mix—and the process choice is perhaps the strongest and most discussed link between market-related characteristics and a manufacturing strategy decision category.

Complementary approaches to the market–process interface are found in for example Kim and Lee (1993), Sheu (1994), Schroeder et al. (1995), and Bozarth and Berry (1997). Kim and Lee (1993) deal with a manufacturing strategy in two dimensions in accordance with Porter (1985), i.e. differentiation and cost efficiency.
They discuss process choice, in terms of ‘choice of equipment’, as a strategic variable and propose that special (dedicated) equipment should be used in a pure cost-leadership strategy, whereas general equipment could be used in a pure differentiation strategy. General equipment could, however, also be used in a combined cost and differentiation strategy.

Sheu (1994) presents a heuristic method for focus unit design in batch manufacturing facilities with minimum resource needs. Two alternative approaches are analysed. One is based on similarities regarding competitive priority weights, i.e. weighting the order-winning criteria. The other considers similarities in resource requirements. These two aspects are measured in terms of degree of focus (average degree of commonality with regard to the manufacturing task) and average resource similarity. As more emphasis is placed on resource similarity, the degree of focus is diluted and no predominant competitive criterion can be found. In terms of process choice, the resource similarity would typically lead to a flow line. The process choice for the focus design is not as straightforward; it depends on the number of resources and whether they can be split among a number of focused units, or if they have to be shared. Schroeder et al. (1995) present an empirically grounded study of the linkages between competitive strategy and manufacturing technology for 20 small to medium-sized manufacturers in three types of industries: job-shop machining, plastic injection moulding and metal cutting tools. High-performing firms with high volume products (large order sizes or repeat orders, and hence long production runs) tended to use computer-controlled technologies to a greater extent than high-performing firms producing small volume, high mix products (small lot-sizes or one-of-a-kind products). They also describe a few misalignments, supporting the relationship between the choice of technology process and product volume. They note that the strategy–technology alignment process has strong interactive effects in that once a technology is adopted, greater understanding develops, and the firm’s strategy must be adjusted to maximize its advantage.

Bozarth and Berry (1997) extend the product-profiling approach of Hill (2000) by offering a measurement methodology to evaluate the fit between market needs and manufacturing plant capabilities. This method uses available data and statistical techniques to derive a scalar measure of market-manufacturing congruence. It is not dependent on assumptions about ‘classic’ process choices. Instead, it builds on profile dimensions such as lead-time, order quantity and percentage of shared components.

3. Exploring the linkage between market requirements and MPC systems

The models for linking market requirements, via the manufacturing strategy, to the design of MPC systems can basically be reduced to one, first presented in Berry and Hill (1992). However, there are many scholars indicating that market requirements do play a major role when designing MPC systems, see for example Grünwald et al. (1989), Kochhar and McGarrie (1992), Bhattacharya and Coleman (1994), and Newman and Sridharan (1995).

In the Berry and Hill (1992) framework there are links and choices at three levels of the MPC system. At each level a set of market requirement attributes is used to make generic choices among a set of level-dependent MPC design variables. At the master scheduling level, the choices are reduced to three variables; make-to-order (MTO), assemble-to-order (ATO), or make-to-stock (MTS). At the materials planning level the choices are rate-based or time-phased. Finally, at the shop floor con-
Strategic variables

<table>
<thead>
<tr>
<th>Market requirements:</th>
<th>MTO (Time-phased)</th>
<th>ATO (Rate-based)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Push/MRP</td>
<td>Pull/JIT</td>
</tr>
<tr>
<td>Product: type range</td>
<td>Special, Wide</td>
<td>Standard, Narrow</td>
</tr>
<tr>
<td>Volume/(product and period)</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Accommodating demand versatility:</td>
<td>Easy, High</td>
<td>Difficult, Low</td>
</tr>
<tr>
<td>total volume product mix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delivery: speed reliability</td>
<td>Difficult, Easy</td>
<td>Easy</td>
</tr>
</tbody>
</table>

### Figure 2
The typical structure of linking the manufacturing strategy to the MPC design (based on three separate tables in Berry and Hill, 1992, here condensed into one).

trol level the choices are push or pull. The strategic attributes linking market to MPC are very much the same, irrespective of the actual hierarchical MPC level, therefore we have condensed the original three tables into only one (see figure 2). An example of the conformity of this framework is that firms with high-volume standardized products typically would choose MTS, rate-based, and pull, whereas firms with many low-volume, customized products would choose MTO, time-phased, and push. In ATO environments, both sets of MPC choices are applicable to different sections of the plant, i.e. before and after the order penetration point (OPP). The OPP is the point where an order is linked to a specific customer, typically through some customization features, or a specific mix of modules. In the case of ATO, volumes are typically sufficiently high before the OPP to make MTS/rate-based/pull possible, whereas MTO/time-phased/push is typically required after the OPP due to customized features and low volumes per product. Variants of the Berry and Hill (1992) framework are presented in Vollmann et al. (1997) and Hill (2000).

Although Berry and Hill (1992) present the basic model for the market–MPC link, other authors identify a link between market requirements and the design of MPC systems, see for example Grünwald et al. (1989), Kochhar and McGarrie (1992), Bhattacharya and Coleman (1994), and Newman and Sridharan (1995).

Grünwald et al. (1989) identify two major factors influencing the choice of production control concepts. The first factor is market-related and is concerned with the specificity of product, demand uncertainty and irregularity, product life cycle, commercial lead-time, and the market requirements’ heterogeneity within a company. The second factor is product/process related and comprises product and processing complexity, number of production stages, degree of convergence, diversity of products per department, average utilization, etc. Grünwald et al. (1989) reduce all variables to three: product/process complexity, stationary demand uncertainty, and non-stationary demand uncertainty, in a three-dimensional space to identify dominant regions for various production control concepts. The product/process complexity dimension is only concerned with product structure complexity, whereas market and product related variables solely form the basis for designing MPC systems.
Kochhar and McGarrie (1992) identify 41 key characteristics that put requirements on the manufacturing control system. The vast majority of these are market related, e.g. demand pattern, commercial lead-time, number of products, degree of customer specification, etc.

Bhattacharya and Coleman (1994) present another framework that addresses this link in a more thorough way. They use a similar approach to that of Berry and Hill (1992), but include a dimension of process complexity. However, they limit this dimension to discrete manufacturing ranging from highly complex (job shop or batch type) to low complexity (flow shop and large batch processing). Furthermore, they do not recognize any relationship between process complexity and the dimensions of market and product characteristics, which typically are tightly linked according to most manufacturing strategy literature. Olhager and Cimander (1998) modified this framework to allow for an alignment analysis (profile match) between, on the one hand, market, product and process complexities, and, on the other hand, MPC system design.

Finally, Newman and Sridharan (1995) recognize the link between MPC and the manufacturing environment. With 185 responses out of 1500 surveys mailed, they analyse the relationship between the manufacturing environment (reduced to only two variables: demand predictability and demand variability) and the choice of MPC system in use (reduced to the choice among the planning techniques ROP, MRP, kanban, or OPT). They find that no one single system dominates all the others, and that dependent on the manufacturing environment (i.e. the demand patterns) different MPC systems can be more or less appropriate.

4. Exploring the linkage between process choice and MPC systems

Some authors indicate that there is a linkage between process choice and the MPC system (see, for example, Berry and Hill 1992, Kochhar and McGarrie 1992, Bhattacharya and Coleman 1994, Newman and Sridharan 1995, Safizadeh and Ritzman 1997 and Vollmann et al. 1997). However, this link has not yet been as thoroughly investigated as the two previously described links, and there are no normative guidelines or models for establishing a link between process choice and the MPC system. Thus, in this section, we rely more on descriptive, rather than normative, information in our analysis. We will therefore use a number of case studies from the texts mentioned above.

Berry and Hill (1992) state that, to be successful, companies have to link market requirements to processes to MPC systems, and that they must recognize the different decision-making levels within MPC systems. Although the process choice is one of the manufacturing variables linked to the MPC levels, Berry and Hill (1992) mainly focus on the link between market and MPC (see section 3). It is difficult to determine, based on their charts, the extent to which the process choice affects the MPC system relative to the extent of the effect from markets and products. Berry and Hill (1992) provide some case examples, but only a few show that the process choice affects the MPC design. The case of Company B in Berry and Hill (1992), uses an MRP system for the control of a broad range of complex internal processes, i.e. a range of batch processes and final assembly lines. Company F undertook a series of manufacturing investments with regard to set-up reductions, cellular layout, etc, which resulted in a simplified shop-floor control system with a pull system and manufacturing in small order quantities. Finally, Company I installed manufacturing cells to produce high volume, standard components and supported this process
with a rate-based material planning and a pull-type shop-floor control system. The other case companies do not address the process-MPC link explicitly.

Of the 41 key characteristics mentioned by Kochhar and McGarrie (1992) that put requirements on the manufacturing control system, three are related to the process. These are the number of manufacturing operations, the degree of cellular manufacturing, and set-up time. As discussed in section 3, the remaining characteristics deal with market requirements and product characteristics.

Bhattacharya and Coleman (1994) have noticed the diverse requirements on today’s MPC systems, and the corresponding need for hybrid solutions customized to the need of each firm. They notice that the market puts requirements on the MPC system, which in turn is constrained by the product and process dimension. They do not identify any unique relationship between process choice and MPC. Still, Bhattacharya and Coleman (1994) provide examples of manufacturing process variables, such as routings, importance of capacity utilization, and tracking/monitoring that are important for the shop-floor control system. In their case B, they show that complex batch manufacturing goes hand in hand with a push-type shop-floor control system. Case D incorporates both dedicated line flow and manufacturing with complex and flexible routings. In the former situation, pull control is judged appropriate, whereas a push-type system is preferable in the latter situation. Cases A and C do not address the process-MPC link.

Newman and Sridharan (1995), stating that MPC should support the manufacturing process selected for a specific environment, empirically explore the linkages between alternative MPC systems, the manufacturing environment, and performance. More specifically, they contrast the MPC techniques, MRP, kanban, OPT and ROP relative to environmental factors, such as product mix, nature of demand, manufacturing process, etc. However, their survey demonstrates neither whether the MPC system should fit the market, the process, or both, nor does it investigate the reasons for the choice of MPC system in terms of MPC option variables. Still, they make some indications as to where these systems are found; MRP in batch manufacturing and functional layouts, kanban in product layout and cellular manufacturing, OPT in the batch process industry, and ROP in stable demand pattern—without any indication as to process.

Safizadeh and Ritzman (1997) study the relationship between process choice and performance drivers in production planning and inventory control through a survey of 400 companies with 144 respondents. They found that job and batch shops are relatively better at managing uncertainty and complexity, whereas line flow and continuous flow are better at capacity utilization and elimination of excess inventory—results that agree with theoretical expectations. However, they do not take market and product characteristics into account, issues that are hidden behind the choice of process. Thus, they are unable to distinguish between market/product issues and process choice as the driver of the design of MPC systems.

Finally, Vollmann et al. (1997) make it clear that the MPC design must match the needs of the market, the manufacturing task, and the manufacturing process. Furthermore, they state that any of these three areas can mandate a change in the MPC design, and that there is interdependency between MPC option choices and process choice features. This is exemplified with the following situation: ‘…installing a JIT process with cellular manufacturing and short production lead times means rate-based detailed material planning approaches may be much more appropriate than time-phased approaches’ (Vollmann et al. 1997, p. 363). One may
still question whether such a relationship is dependent specifically upon the choice of process or rather dependent upon the presumed underlying demand volume, product mix, and market requirements. Their approach to MPC system design follows the same structure as the Berry and Hill (1992) paper. Nevertheless, Vollmann et al. (1997) do provide some additional examples in their case studies. Moog Inc. uses batch manufacturing in a more or less functional layout with high process uncertainty, which leads to it being most suitable to use MRP-based systems for both material planning and shop-floor control. In another case, Applicon replaced its functional layout with a more streamlined process, including flow manufacturing. This shift called for a change in MPC procedures, wherefore Applicon abandoned its time-phased system with push-type control in favour of a JIT-based system with pull-type control.

The review of the descriptive literature in this section is summarized in table 1, showing the specific examples where the process choice affects the MPC system design. No specific cases are found in Kochhar and McGarrie (1992), Newman and Sridharan (1995) and Safizadeh and Ritzman (1997), although they do indicate a link between process choice and MPC system. Adapting a hierarchical view of the MPC structure, it is important to notice that, from table 1, it seems that the manufacturing process mainly affects the lower levels of the MPC system. This issue is discussed in more detail in section 5.

In table 1 a few elements that are process-specific can be identified. These are routing complexity, degree of flow orientation (e.g. cellular manufacturing) and set-ups. Monahan and Smunt (1999) identify four characteristics of a process that may influence its performance in a batch processing environment. Their characteristics are flow dominance, number of machines in each department, set-up time, and operation-time variance. Thus, they arrive at a similar set of key variables although their problem is different.

At this point, we would like to introduce the concept of a planning point. A planning point is a manufacturing resource or a set of manufacturing resources such as a work-centre or a work cell that can be regarded as one entity from a production and capacity planning point of view. We will now show that the process-related issues mentioned above can be condensed to two: the number of planning points and set-up time. Set-up time is regarded by, for example, Kochhar and McGarrie (1992) and Monahan and Smunt (1999) as a key characteristic of a process in itself. The other key characteristics in table 1, Kochhar and McGarrie (1992), and Monahan and Smunt (1999) can be reduced to one, i.e. the number of planning points. Routing complexity and degree of flow orientation (table 1) as well as the number of manufacturing operations and the degree of cellular manufacturing (Kochhar and McGarrie 1992) can be interpreted in terms of the number of planning points. Monahan and Smunt (1999) relate flow dominance to the number of potential bottlenecks, and this is thus related to the number of planning points. The number of machines in each department depicts the level of multiplicity of resources (Monahan and Smunt 1999) that can be interpreted as the number of planning points, if these are planned actively as independent resources. Otherwise the number of planning points would tend to correspond to the number of departments. Operation-time variance is created by, for example, defective component parts (Monahan and Smunt 1999) and is therefore not entirely process-dependent.

Thus, set-up time is considered a major process-specific characteristic, whereas the other process-related issues in Kochhar and McGarrie (1992), Monahan and
<table>
<thead>
<tr>
<th>Process issues</th>
<th>MPC system issues</th>
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<tbody>
<tr>
<td>Berry and Hill (1992)</td>
<td></td>
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<tr>
<td>Set-up reduction, cellular layout</td>
<td>Pull-type shop-floor system (company F)</td>
</tr>
<tr>
<td>Batch process, complex routings</td>
<td>Time-phased MRP-system (company B)</td>
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<tr>
<td>High volume cell manufacturing</td>
<td>Rate-based material planning, pull-type shop-floor system (company I)</td>
</tr>
<tr>
<td>Bhattacharya and Coleman (1994)</td>
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<tr>
<td>Complex batch manufacturing process</td>
<td>Push-type shop-floor system (case B)</td>
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<tr>
<td>Dedicated line flow</td>
<td>Pull control (case D)</td>
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<tr>
<td>Complex, flexible routings</td>
<td>Push control (case D)</td>
</tr>
<tr>
<td>Vollmann et al. (1997)</td>
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<tr>
<td>Cellular layout with short production lead times</td>
<td>Rate-based more appropriate than time-phased</td>
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<tr>
<td>Batch manufacturing, high process uncertainty</td>
<td>MRP-based materials planning and shop control (Moog Inc.)</td>
</tr>
<tr>
<td>Functional layout with batch manufacturing</td>
<td>Time-phased system with push-type shop-floor control (Appicon)</td>
</tr>
<tr>
<td>Streamlined process with flow manufacturing</td>
<td>JIT-based scheduling and control system (Appicon)</td>
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</tbody>
</table>

Table 1. Specific examples on the link between process choice and MPC system.
Smunt (1999) and table 1 can fundamentally be reduced to one, i.e. the number of planning points in the process. These two characteristics are regarded as the key process variables and can be used to describe the impact of the process choice on the MPC system design in the following way.

- The number of planning points, which affects routing complexity. A functional layout such as a job shop typically has many planning points, potentially one per machine. In such a manufacturing environment a time-phased planning approach is needed. An increasing degree of flow orientation, i.e. flow shops and lines, reduces the number of planning points, increasing the potential for using a rate-based planning approach.

- Set-up time of individual resources, especially those that are critical to the throughput of the manufacturing process. If set-up times are short enough not to influence lot-sizing decisions (i.e. allowing for small lots) a rate-based approach can be used, whereas a time-phased approach is required if set-up times need to be accounted for (resulting in large lots).

We have now explored the linkages shown in figure 1, with reference to how they are treated in the literature. In the next section we structure the linkages to MPC system design, with respect to a four-level hierarchical MPC system.

5. Linking the MPC system to markets, products and processes

Since we expected that there might be different relationships at different hierarchical levels in typical MPC systems, we mapped our findings relative four levels of a hierarchical MPC system (see table 2). Along with the three levels in Berry and Hill (1992), we include sales and operations planning (S&OP) as a fourth, upper level. S&OP can be seen as partly strategic and partly tactical, thereby facilitating the link to structural categories (Ling and Goddard 1988). In recent years the term S&OP has been more frequently used in articles and textbooks, mostly related to authors discussing MRPII (manufacturing resource planning) or similar systems (see, for example, Higgins et al. 1996, Vollmann et al. 1997, APICS 1998). It is important to distinguish S&OP from the term aggregate planning. The former is the long-term planning of not only production but also of sales relative to the forecasted demand and the complementary resource capacity planning, whereas the latter is sometimes used to denote mathematical programming methods to solve the production planning problem within S&OP (Vollmann et al. 1997). Additionally, it is important that S&OP and master production scheduling (MPS) are not viewed as one single process, but rather as two distinct but connected processes (Stahl 1995). S&OP fundamentally concerns volume planning, while the MPS is concerned with product mix planning within this volume.

As seen in section 4, the choice of manufacturing process has a low impact at higher planning levels, but there is a stronger link at lower levels. This is because the physical reality of the factory influences the way that day-to-day operations are planned, controlled and run. Safizadeh and Ritzman (1997), although not discussing in terms of market requirements, provide some support that the higher levels of MPC are more related to market, whereas the lower levels are more related to the choice of manufacturing process. In table 2 we summarize the linkages to MPC system design from markets, products, and processes, at each respective MPC level.
<table>
<thead>
<tr>
<th>MPC system level</th>
<th>Major decision areas and issues</th>
<th>Sample MPC system linkages</th>
</tr>
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<tbody>
<tr>
<td>Sales and operations planning</td>
<td>Aggregate data (product groups)</td>
<td>—</td>
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<tr>
<td></td>
<td>Planning strategy: Level, chase or mix</td>
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<td></td>
<td>Aggregate capacity at plant or production system level (production volume)</td>
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<td>Resource capacity changes</td>
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<td>Master scheduling</td>
<td>Products, delivery objects</td>
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<td></td>
<td>Production mix</td>
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<td></td>
<td>Capacity planning at (potential) bottlenecks</td>
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<td></td>
<td>Setting delivery lead times</td>
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<td>Demand information source:</td>
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<td></td>
<td>MTS—ATO—MTO</td>
<td>—</td>
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<tr>
<td>Requirements planning</td>
<td>Individual items</td>
<td>Cellular layout with flow manufacturing, short set-up and production lead-time lead to rate-based planning.</td>
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<tr>
<td>(material and capacity)</td>
<td>Individual resources (work centres or work groups)</td>
<td>Functional layout with batch manufacturing, complex routings and high process uncertainty lead to time-phased</td>
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<tr>
<td></td>
<td>Set-up times and costs</td>
<td>planning.</td>
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<td></td>
<td>BOM complexity</td>
<td>—</td>
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<td></td>
<td>Requirements/rate explosion</td>
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<tr>
<td></td>
<td>Degree of repetitiveness</td>
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<tr>
<td></td>
<td>Routing complexity</td>
<td>—</td>
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<tr>
<td></td>
<td>Number of planning points</td>
<td>—</td>
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<tr>
<td>Production activity control (shop-floor</td>
<td>Individual items (operations)</td>
<td>Cellular flow manufacturing or dedicated line flow with short set-ups leads to a pull-type control system.</td>
</tr>
<tr>
<td>control)</td>
<td>Individual resources (work centres or work groups)</td>
<td>Functional layout and batch manufacturing with complex, flexible routings and high process uncertainty lead to</td>
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<tr>
<td></td>
<td>Set-up times and costs</td>
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<td></td>
<td>Decentralized planning in work centres</td>
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<td></td>
<td>Routing complexity</td>
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<td>Number of planning points</td>
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<td>Execution of schedules</td>
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<td></td>
<td>Performance feedback</td>
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Table 2. MPC system levels, their respective decision areas and issues, and linkages to process issues. The examples are restructured and generalized from section 4 and table 1.
5.1. **Sales and operations planning**

At the sales and operations planning level, the use of aggregate data (also for resources) makes the actual process choice somewhat invisible. Still, it has been noticed that different planning strategies at the S&OP level (namely, level, chase and mix) support different order-winners and thereby indirectly different process choices (Olhager et al. 2001). This is also supported by Safizadeh and Ritzman (1997), who find that line flow and continuous flow plants use more of a *level* operations planning strategy, whereas job and batch shops use more of a *chase* operations planning strategy. Still, the choice of planning strategy is fundamentally based on the market and product characteristics. Market related variables affecting the MPC system design can be found in, for example, Kochhar and McGarrie (1992) and Vollmann et al. (1997). Examples of variables affecting the S&OP level are demand patterns, product variety, commercial lead-time, etc. Fundamental decisions to be made at this level are concerned with the groupings of product families, choice of planning strategy, and aggregate production volumes.

5.2. **Master scheduling**

Master scheduling is concerned with the effective use of available capacity, irrespective of the manufacturing process. All processes have limited capacity, whereas this issue is relevant to any manufacturing environment. However, the number of potential bottlenecks may differ between process choices. The more flow-oriented the process is, the fewer the number of distinguishable, discrete manufacturing steps. Therefore, the complexity of identifying and focusing the bottleneck(s) may differ between process choices. Still, the fundamental issue is the principle to take the bottleneck into consideration at this planning level, irrespective of process type. Thus, the ways in which bottleneck resources are taken into account do not differ between process types in general. Market related variables affecting the MPC design can also be found at this level, e.g. degree of product customization, production and delivery lead-time, etc. (see, for example, Kochhar and McGarrie 1992, Berry and Hill 1992, Bhattacharya and Coleman 1994, and Safizadeh and Ritzman 1997). Decisions to be made at this level include which end items to produce (product mix within the given volume) and when to produce them (with respect to delivery lead-times and capacity constraints).

5.3. **Requirements planning**

At the two lower levels, the factory physics become more real. Requirements planning deals with acquiring the components needed to fulfil the master schedule, either purchased or manufactured, and the capacity in the internal and external supply system. The product structure is used for exploding the master production schedule in terms of time-phased or rate-based requirements. The complexity of this procedure is very much determined by the product structure, but also dependent upon the actual manufacturing process in use. At this level, routings as well as set-up and run times are introduced for all items and resources when the plan is checked for capacity feasibility. The complexity of the manufacturing process becomes obvious with the number of planning points and consequently the complexity of routings. A similar result is derived from a VAT characterization of plants, indicating that a V-plant has fewer operations to plan than A- or T-plants, leading to another set of planning problems than for the other plant types (Umble and Srikanth 1990).
With a higher number of planning points per item and diverse routings among products, the more difficult it is to execute a rate-based schedule. Instead, time-phased planning and execution is required. On the other hand, for manufacturing systems with few planning points and similar routings, the potential use of rate-based schedules increases. Take, for example, the extreme situation where the whole manufacturing system can be regarded as one planning point. Then, the choice of planning procedure is not restricted in any sense by the complexity of the manufacturing system, but can be designed based on other issues, such as product volumes and the product mix. Thereby, the option to use a rate-based scheduling approach may become more interesting. The degree of repetitiveness is also an important factor for determining the level of detail in the explosion procedure and the number of planning points (see Spencer and Cox 1996). Thereby, it seems that the manufacturing process and the product structure are more important than the market requirements for designing appropriate requirements planning procedures. Berry and Hill (1992) provide examples where a change in process choice affects the design of the material planning method and so do Vollmann et al. (1997), cf. table 1. In addition, if set-up times and set-up costs need to be taken into account in lot sizing decisions, time-phased approaches may be necessary since batching occurs. In such circumstances, net requirements are often calculated. A basic assumption for applying rate-based approaches is that set-ups are negligible. Requirements planning in rate-based environments is typically reduced to gross requirements calculations as an input to longer-term purchasing agreements with suppliers.

5.4. Production activity control

Production activity control (PAC) is the layer of the MPC system that lies closest to the production process and plays an important role in linking the factory floor with the other elements of the MPC system (Browne et al. 1996). PAC, also called shop-floor control, deals mainly with the execution of the schedules, control of the execution, and feedback on the manufacturing performance. Process related variables, such as the number of planning points needed (routing complexity), and set-up times influence the design of the PAC level. Set-ups cause interruptions in the processing of orders. If set-ups are non-negligible, MRP/push-type approaches based on batch manufacturing are typically employed, cf. Berry and Hill (1992). In JIT/kanban environments, set-up time is one of the first elements to be addressed, reduced and minimized, and a key ingredient for JIT/kanban to work properly (Shingo 1981, 1985). Vollmann et al. (1997) provide examples where the manufacturing process affects the choice of shop-floor system used, as indicated in table 1.

5.5. Linking markets, products, processes and systems

The discussion throughout this paper shows that it is important to distinguish between market-related, product-related, and process-related issues when designing MPC systems. Market requirements have a major impact on the higher levels of the MPC system hierarchy, i.e. S&OP and master scheduling. It is also clear that the product characteristics, or complexity, affect the design of the MPC system (e.g. product structure, degree of standardization and modularization, etc). Product characteristics have to be taken into account at the master scheduling and requirements planning levels. Furthermore, it has been shown that the choice of manufacturing process is important for the design of the lower MPC levels, i.e. requirements planning and PAC. Hence, we have three distinct areas affecting the MPC system
design. These areas consist of market-related variables, product-related variables, and process-related variables. In figure 3 we have indicated the main issues and variables that affect each respective MPC level.

As we move down in the MPC hierarchy from S&OP to PAC in figure 3, the physical reality of the manufacturing process becomes successively more influential. At the S&OP level, the use of aggregate data makes the actual process choice somewhat invisible. Hence, the volume planning at the S&OP level makes no difference as to the product characteristics or the process choice. At the master scheduling level (with mix planning) product issues are introduced, especially with respect to differences among the various products that are to be delivered. Still, it really does not matter how these products are produced, i.e. how the processes are designed. When capacity is taken into account, the number of actual bottlenecks at a given point in time does not depend on the choice of manufacturing process. Although delivery lead-times and process capacities are considered, the process choice itself does not affect the choice of planning approach employed. However, at the requirements planning and PAC levels, where the factory physics become more real, the number of planning points, the routings and process resource specific issues (such as set-up times) are needed in the planning process.

Thus, the planning system can be described such that higher-level planning, which does not need to consider the physical process, creates market and product related plans (i.e. how to supply the market with products). The job of the lower-level planning activities is then to transform these higher-level plans into reality and to execute the plans in the manufacturing processes available. Performance measures and process characteristics, such as delivery lead-times and process capacities, need to be taken into account at higher levels. However, this is needed for all types of processes.

6. **Consequences of not linking the MPC system to markets, products and processes**

If there is a match (or alignment) between market requirements and process choice, then the task of the MPC system is simpler than should there be a mismatch. In the latter case, the MPC systems would need to work around this mismatch and
still deliver good plans and schedules in order to support the corporate objectives of customer service, manufacturing efficiency and inventory investments. In an empirical study of 213 business units, Ward et al. (1988) report that the MPC system is perceived by managers as having the capability to help them address problems in a wide variety of areas that fall into both structure and infrastructure decision categories. This suggests that the MPC system might be used for overcoming a mismatch between the marketing and manufacturing strategies.

Berry and Hill (1992) describe a situation where there are substantial mismatches between MPC and manufacturing (i.e. process choice), as well as between MPC and market. After a substantial drop in sales volume, a firm responded with a variety of new products offering a broad range of options produced in low volume to specific customer orders. To support the shift in marketing strategy, new investments were made in a functionally oriented batch manufacturing processes. The firm decided to retain its previous MPC system, which was designed to support the standard products on a repetitive, line production process. Substantial difficulties were encountered, which resulted in lengthy manufacturing cycles, simultaneous shortages, excesses inventory, and poor customer service. Thus, this case describes a situation where there is a match between marketing and manufacturing strategies but the MPC system does not support either one. Also, Schroeder et al. (1995) describe a few cases with clear misalignments between market requirements and process characteristics (level of automation and batch sizes), affecting the performance of the manufacturing firm. Thus, the link between market requirements and process choice heavily influences the role of the MPC system, as well as the performance of the manufacturing system. Therefore, the relationship between market and process needs to be addressed before designing the MPC system.

7. Concluding remarks

Traditionally, the design factors for MPC systems have been known to be a mix of market, product and process issues. However, there have been no decisive guidelines for making distinctions among these issues. The aim of this paper is to examine the role of the MPC system in a manufacturing strategy. More specifically, the purpose is to link market requirements, product characteristics, and the process choice to the MPC system, highlighting the link between manufacturing strategy decisions on process choice and MPC systems. Based on the literature survey, primarily drawing on empirical findings and case studies, we have used a structured normative and analytical approach to establish a conceptual model that identifies the various sources of influence, see figure 3.

This research suggests that there are differences between the influences by market, product and process characteristics on the MPC system. It is indicated that the impact of the process choice on the design of MPC systems is present only at lower planning levels. This is especially true for production activity control, but also for requirements planning (material and capacity). Two key factors are identified as major process elements influencing the MPC system design. First, the number of planning points, and second, set-up times at individual resources. These two factors greatly influence the choice between rate-based and time-phased MPC approaches. Concerning the MPC system design for longer-term planning, such as sales and operations planning and master scheduling, the impact from market requirements and product characteristics dominates completely. Based on our findings we have structured the link between the choice of manufacturing process and the
preferable design of a hierarchical four-level MPC system. In doing so, we have established a conceptual model linking market requirements, product and process characteristics to manufacturing planning and control systems, suggesting that consistency between market, product, process, and MPC system leads to better performance. The main contributions of this research are the identification of planning points and set-up times as key process choice factors, and the model in figure 3, structuring the dominating issues from the market, product and process perspectives vis-à-vis the MPC systems design.

To test this model further, more case studies, longitudinal studies, and path analytic modelling can be used. The literature so far contains a number of case studies, but a larger cumulative effort could provide thorough support for the model. Such case studies should include the aspect of the effect on performance. Longitudinal studies would be helpful in substantiating cause-effect relationships within the model and whether a higher level of consistency leads to better performance. A path analytic approach using a field study or survey would allow for a larger sample and statistical testing of the conceptual model.

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