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Empirical Studies in Discrete Parts Manufacturing Management

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'De moderne tijd geeft een valse vorm van zekerheid door de grote hoeveelheid beschikbare informatie. Waar het om gaat is echter hoe we de informatiestromen leren beheersen.' **(uit Goethe's *Faust*, 1832)**

Voor Ellen,
Mart, Jop en Ties

Preface

Although this thesis succeeded by perseverance, the unpaved path was extremely instructive. The choice to accept the proposal of Steef van de Velde to start a Ph.D. research project at the former POM group of Henk Zijm, and additionally combine it with a proposal of Ben Wiggers to execute the work at Urenco Nederland BV was a good one. The stay at Urenco significantly contributed my self-development, especially the meetings with Harm Munneke, Marcel Damen, Gerrit Bouwhuis, Bas Timmermans, and Erjan Kelder. I am very grateful to them all. Furthermore, I like to thank various former employees of, and students at Add-Smart BV, in particular Paul Hentschke, Bart van Hezewijk, and Paco Koudstaal. Although only my name appears on the cover, I am very grateful to these and several other people (my supervisors, the M.Sc. students, and my colleagues) who jointly worked with me on this research project, or gave me the opportunity to do the research.

Real scientific contributions, and serious breakthroughs in particular, cannot be achieved independently by one research group, let alone by one researcher. Indeed, researchers are forced to collaborate in research projects from a multidisciplinary perspective. With the imminent disappearance of the discrete parts production function in The Netherlands because of the massive displacement of large batch production to low wage countries, production engineering and production management as a professional training and education seem to become superfluous. Indeed, mechanical and industrial engineers specialized in production engineering and production management are basically educated for an industry that generally is, perhaps not able, but certainly not willing to pay for these specialists. During the many visits to various discrete parts manufacturing firms during this Ph.D. trajectory, I was astonished over and over again of the low levels of OM/logistics-related sophistication at all organizational levels, and especially of production engineers and production managers. By no means innovate on OM/logistics-related business processes, but consider production to be a cost-driver which has to be displaced to foreign countries, abolish education and research on mechanical and industrial engineering and related management issues, preserve the trench warfare between various manufacturing related scientific disciplines, maintain a one-sidedly rationalist perspective on manufacturing operations management, and do certainly not accommodate positivistic and phenomenologistic empirical research. Anybody who disagrees with this statement is heartily invited to collaborate on future manufacturing operations management projects.

Abstract

Manufacturing firms are bound by the conditions of their environment. They have to fulfill the demands of various stakeholders (e.g., customers, suppliers, government, financiers, and employees) that provide the resources to perform their operations. The effectiveness of a manufacturing firm depends on the fit between the manufacturing system and the level of uncertainty in its environment. There must be consistency between numerous manufacturing dimensions, such as operations strategy, process choice, level of decentralization, production planning and control strategies, concepts, and tools, and the characteristics of the dominant Product/Market/Technology (PMT) combinations of the manufacturing firm. This thesis focuses on empirical studies that address the impact of PMT-uncertainty on various operations management issues in Dutch discrete parts manufacturing firms. The central research question of this thesis is, 'what is the impact of PMT-uncertainty on important discrete parts manufacturing management issues, such as the strategic focus on competitive priorities, the dominant type of manufacturing layout, the decentrality of the locus of production planning and control, the use of various production planning and control tools, and line management's attention for social issues like individual competence management?'

In Chapter 2, we discuss an in-depth exploratory longitudinal case study at Urenco Aerospace, a second-tier supplier in the aerospace industry. The objective of this case study is to gain insight into the problem domain and the various constructs that form the basis for answering the main research question of this thesis. In this chapter, we particularly aim to study the questions 'does a dedicated product-oriented cellular layout technically outperform a functional cellular layout?, and if not, 'why do discrete parts manufacturing organizations choose to implement dedicated product-oriented cells?', In either case, we like to explore the remaining production planning and control requirements and the type of production planning and control tools used. Based on an analysis of the expected performance measures, we found that for this manufacturing firm a dedicated product-oriented cellular layout would not outperform a pure functional layout with teams. In contrast with well-known socio-technical systems theory, it turned out that the manufacturing system with a dedicated product-oriented cellular layout has still considerable production planning and control requirements. What is more, these product-oriented cells are subsequently managed with the help of a low-end Advanced Planning and Scheduling (APS) system and a visual manufacturing control system, respectively. These different planning concepts are both supported by a central ERP system, SAP R/3; an Enterprise Planning System that centralizes data storage, but that had been implemented to support a decentralized manufacturing organization.

In Chapter 3, we study the question 'how is PMT-uncertainty related to the locus of production planning and control, and the frequency of planning and control meetings, given a particular manufacturing system and environment specified by its dominant (set of) PMT combination(s)?' To answer this question we conducted survey research (i.e., questionnaire-based research) in the Dutch discrete parts manufacturing industry. Based on a sample of 206 respondents, we found that different dimensions of PMT-uncertainty affect the locus of production planning and control differently. Environmental complexity, and in particular customer order complexity, leads to a decentralization of the operational planning and control decision structure, but at the same time to a centralization of the customer-order processing (COP) decision structure. We found that firms with high levels of customer order complexity have a low frequency of production planning and control meetings and they have more centralized COP decision structures. In contrast, firms with high levels of end-product complexity have a high frequency of production planning and control meetings and they have more decentralized COP decision structures. In addition, the impact of the environmental rate of change and information deficiency on the level of decentrality of the locus of production planning and control is small. Another interesting finding with managerial implications is that firms with a high score on financial performance appeared to have a lower level of customer order complexity and decentralized COP decision structures than firms with a low score on financial performance. Hence, organizations that decentralize their structure to cope with PMT-uncertainty would be well-advised to reduce customer order complexity first. Furthermore, it turned out that the use of an ERP system negatively affects the locus of control; it leads to a more centralized locus of production planning and control.

With the help of the survey data, we explore the impact of information deficiency, rate of change, and complexity on the use of different production planning and control tools (i.e., kanban control, conventional plan board, spreadsheet, ERP, and APS) in Chapter 4. We found that the impact of PMT-uncertainty on the use of various production planning and control tools is only small; route complexity, for instance, does not discriminate users from non-users of different types of production planning and control tools at all. In addition, the only rate of change related factor with some impact, i.e., product change, is negatively related to the use of an APS system. Furthermore, it turned out that a lack of information forces firms to use spreadsheets. Finally, we found that size is negatively related to the use of a conventional plan board; however, it turned out to be a stronger predictor of the use of a kanban control system than PMT-uncertainty.

In Chapter 5, we extensively focus on organizational and innovation-related characteristics that affect the adoption of an APS system. Accordingly, Chapter 5 addresses the questions ‘what is the state-of-the-art of advanced planning and scheduling within the discrete parts manufacturing industry?’ and ‘what is the impact of innovation and organizational factors on APS adoption?’ Based on a second survey among Dutch discrete parts manufacturing firms, for which we obtained a sample of 136 respondents, we found that management support, purchase cost of an APS system, number of end-products, and other users’ opinions are factors that directly affect the adoption of APS systems. In addition, observability has an indirect effect on APS adoption via other users’ opinions. Thus, organizations that attach importance to the ease to demonstrate the results and advantages of an APS system also value other users’ opinions about the APS system important. It turned out that organizations with high scores on innovation experience have significantly lower means for other users’ opinions and observability compared to organizations with low scores on innovation experience. This indicates that organizations without much innovation experience perceive more uncertainty about a new technology, such as an APS system, have more negative attitudes towards the innovation, and attach greater importance to other users’ opinions and the observability of the APS system. However, Operations Management/logistics-related sophistication also indirectly affects APS adoption.

Based on the findings at Urenco Aerospace, we address the question ‘whether the dominant type of manufacturing layout, and in particular the functional layout and the cellular layout, is correlated to the adoption of an APS system’ in Chapter 6: are APS systems predominantly more adopted by traditionally organized discrete parts manufacturers than by discrete parts manufacturers that are organized in groups? Furthermore, we address the issues of OM/logistics-related sophistication, as well as communication channels in relation to APS adoption within both cellular layout adopters and non-adopters. Do firms that work in a cellular layout solely focus on control complexity reduction and corresponding socio-technical management issues, or do they also develop a clear understanding of the recent developments in commercial and theoretical OM concepts and APS applications? Based on the data obtained from the ‘second’ survey discussed in Chapter 5, we found that APS systems are predominantly more adopted by firms that work in a cellular layout than ‘traditionally’ organized firms. This also holds for the adoption of ERP systems. In addition, we found that firms with a cellular layout have significant higher OM/logistics-related sophistication levels and external communication channels than firms with a functional layout. We also found that firms that had adopted APS and simultaneously work in a cellular layout indicated to have, on average, the best competitive position. Based on the findings of this chapter, we postulate that firms with a cellular layout are more developed on OM issues than traditionally organized discrete parts manufacturing firms.

Chapter 7 explores the differences on PMT-uncertainty, the extent of customer influence on the productmix, customer’s vendor-switching possibilities, and the focus on competitive priorities between firms with a cellular layout and firms with a functional layout. Based on the data obtained from the first survey discussed in Chapter 3, we found that there are no significant differences on all external environment related constructs used in this research project. Put differently, firms with a cellular layout do not differ on the PMT-related factors complexity and rate of change. However, we found that firms with a functional layout have higher levels of customer-related hostility in that their customers have more influence on the product-mix and more vendor-switching possibilities, than firms with a cellular layout. This concurs with the general point of view that firms with a functional layout generally sell capacity, and that these firms produce a large variety of products in various batch sizes or even one-of-a-kind production. In contrast, we found that firms with a cellular layout are more focused on both quality and delivery performance. It turned out that these firms have higher levels of strategic focus on quality and simultaneously higher levels of strategic focus on delivery performance than firms with a functional layout.

In Chapter 8, we address the question ‘whether firms in which line management values individual competencies outperform firms in which this is not the case’. In addition, we aim to explore whether line management’s support of individual competencies relates to a firm’s strategic focus on agility. Based on the data obtained from the survey discussed in Chapter 3, this research provides evidence that firms where line management values individual competencies obtain higher financial performance. Accordingly, firms that are capable of incorporating a strategic perspective on human capital throughout the management structure outperform competitors that do not. In addition, line management’s support of individual competencies is positively related to the focus on agility-related strategic priorities, as firms that value individual competencies have higher levels of strategic focus on flexibility than firms that do not value individual competencies. Manufacturing flexibility can provide a competitive advantage if there is a proper fit between variables, such as competitive environment, strategy, organizational attributes, technology, and human capital. Furthermore, these findings concur with the objective of agility, that is, to allow an organization to thrive in an environment of constant and unpredictable change, with the workforce as a key source of agility.

Chapter 9 concludes this thesis with a brief overview of the results. In addition, we briefly discuss the status of a complementary research project aiming for the development of a prototype manufacturing planning and control system for decentralized manufacturing environments, which is based on multi-agent coordination, resource loading, and the generalized kanban control system to combine the advantages of both push and pull (i.e., workload control).

Contents

1 Introduction and problem statement

Competing in today's dynamic organizational environments proceeds by new rules, from corporate management to individual self-management, and from the process and content of strategy to day-to-day operations. Consequently, contemporary business perspectives have emerged, with corresponding streams of research. One such perspective is agile management and agile manufacturing [2][7][86]. Agile manufacturing is the capability to reconfigure a manufacturing system for the efficient production of new products rapidly [110], and is about reacting quickly to changing markets, producing high quality products, reducing lead-times, and providing a superior customer service. As agile manufacturing has it origins in large mixed-model repetitive automotive manufacturing environments, agility is often equated with rapid response manufacturing and mass customization; these concepts all share a produce-to-order strategy to produce exactly what customers want. So, agile manufacturing seems to be appropriate for small and medium sized discrete parts manufacturing firms too. Indeed, cutting manufacturing lead-times and quoting reliable due dates have become crucial for any type of manufacturing environment [211].

Agility can be considered as a successor to lean manufacturing [61] that considers the workforce to be a key source of agility. Indeed, agile manufacturing is largely dependent on the capabilities and competencies of a firm's people, both managers and workers, to learn and evolve with change, but also on the interactions between the technological capabilities of the manufacturing system and the capabilities of the employees working with the operations technology [110].

An effective strategy to gain flexibility and agility is to decentralize the manufacturing system and corresponding decision structure by implementing empowered cells, preferably in a product-oriented manufacturing setting [212]. This way, problems can immediately be solved locally, within and by the specific cell, when the problem arises [141][164] as it facilitates personal mutual adjustments and face-to-face interactions (i.e., production planning and control meetings).

Such cells are designed by the socio-technical systems design principle [143], or by a technical design principle [43] aimed for the reduction of the complexity of production planning and control. However, in this thesis we show that there is still quite some need of coordination in and among cells. What is more, an intelligent production planning and control system that simultaneously supports material planning and coordination and the (overall) planning and coordination of scarce resource capacity to achieve performance improvement is still important.

Enterprise Resource Planning (ERP) systems, the dominant production planning and control systems, are based on a traditional rigid hierarchical production planning and control framework [233]. ERP systems are centralized systems in which information is stored centrally [56][147]. Indeed, MRP-II lies at the heart of most ERP systems, although it ignores fundamental production planning aspects, such as limited capacity and variability, which is so characteristic of discrete parts manufacturing [110]. This is indeed remarkable: it is well known that the use of MRP-II leads to longer and longer planned lead-times, because interactions between work-in-process, capacity, variability, and lead-time are ignored. This phenomenon is known as the *lead-time syndrome* or *planning loop* [110][216][251]. Hence, we question whether an ERP system is suitable as a production planning and control system in a decentralized discrete parts manufacturing setting.

Various software vendors have responded to the deficiencies of MRP-based ERP systems by developing so-called *Advanced Planning Systems* (APS). The current state of the art shows the integration of hierarchical planning architectures with Linear Programming tools for aggregate production and capacity planning, and sometimes advanced shop floor scheduling systems at a low level in make-to-order production environments [254]. Since these APS systems are still centralized control systems [210] they are not suitable for decentralized cellular manufacturers. Indeed, in view of the social design principles, decentralized cellular manufacturers do not need detailed scheduling systems that prescribe exactly when operations have to be carried out.

Before we state the problem statement, the research question, the research domain, and the research method to answer the research subquestions in Section 1.4, we first briefly explore the main constructs of this thesis: *discrete parts manufacturing environments* in Section 1.1, *decentralized manufacturing and social issues* in Section 1.2, and *production planning and control issues* in Section 1.3; the latter is partly based on Van Assen, Van de Velde, and Zijm [9]. Finally, we conclude this chapter with an outline of the thesis in Section 1.5.

1.1 Discrete parts manufacturing environments

Manufacturing firms are bound by the conditions of their environment. They have to fulfill the demands of other parties (e.g., customers, suppliers, government, financiers, and labor) that provide them the resources to perform their operations. Fulfilling these demands leads to a fit with the environment [107]. Indeed, the effectiveness of any manufacturing firm depends on the fit between the manufacturing system and its uncertain environment [112]. There must be consistency between numerous manufacturing dimensions, such as operations strategy, process choice, level of decentralization, production planning and control strategies, –concepts, and –tools and the characteristics of the dominant Product/Market/Technology (PMT) combinations of the manufacturing firm.

However, before we proceed, we have to clarify our terminology. We refer to discrete parts manufacturing as the generic term for any combination of engineering, production, and assembly tasks involving discrete parts. Accordingly, a discrete parts manufacturer may range from an engineering factory, via an engineer-to-order factory, a 'jobber' to an assemble-to-order factory. All tasks of the same type take place in a stage; hence, a discrete parts manufacturer may consist of an engineering, a production, and an assembly stage. A stage may consist of sub-stages, e.g., several functional and/or product-oriented cells; for instance, a functional-oriented production stage may consist of a sawing, a machining, and a welding cell.

Operations strategy 'Operations strategy' and 'focus' are two general concepts that have emerged to convey the need of the internal consistency and unity of purpose among operations decisions [99][107][205]. The accepted model for gaining focus begins with decisions on key competitive priorities (cost, flexibility, delivery performance, and quality), which in turn guide decisions on the manufacturing system. Competitive priorities denote the strategic emphasis on developing certain manufacturing capabilities that may enhance a plant's position in the marketplace. Such emphasis may guide decisions regarding production process, capacity, technology, and production planning and control [98][205][235]. Swink and Way [220] state that competitive priorities have become an increasingly important factor in empirical studies on operations strategy.

Many see process choice as a pivotal element in operations strategy and in achieving focus. Process choice determines whether the production system is organized by grouping resources around the process, or by grouping around the product. *Process-focused* plants, such as job-shops, place similar machines and operations together to handle the same function for all products. A process focus is suitable for producing low-volume, customized products. *Product-focused* plants, such as continuous flow shops, group together all the machines and operations that are needed for manufacturing each product. A product focus is suitable for producing high-volume, standardized products.

Hill [107] distinguishes six pure process designs for manufacturing, of which three are typical for discrete parts manufacturing: flow shop, job shop, and fixed site. However, because pure production process designs are rarely found in practice, these three production process designs are better represented as extremes between which a continuum represents hybrid process designs; on which firms can define their exact position.

	Low volume High variety	Medium volume Moderate variety	High volume Low variety	High volume Standard
Fixed site	**Group 1**			
Job shop	**Group 2**			
Batch flow		**Group 3**		
Mixed-model repetitive			Group 4	
Dedicated repetitive			Group 5	
Continuous				Group 6

	Group 1 and 2	Group 3 and 4	Group 5 and 6
Order winner	High quality	High quality	Competitive cost
Variety	High flexibility	Some flexibility	Low flexibility
Implication	High cost	High/medium cost	Some automation
Machinery	General purpose	General/specific purpose	Specific purpose
Product position	Engineer- and Make-to-order	Assemble-to-order	Make-to-stock

Table 1-1: Traditional product positioning-process choice [99].

Various hybrid structures, like functional resource groups and product-oriented cells, are possible. Nevertheless, the dominant process design determines the basic positioning strategy. Table 1-1 identifies a matrix of the traditional product and process relationships. The product continuum is shown at the top with several further descriptors, including volume and degree of standardization. The production process continuum is at the bottom, ranging from flexibility/quality to delivery/cost. Although manufacturing firms are somewhat constrained by the type of product and the state of product development, they can define their position within the framework of the matrix to strive for consistency with their environments. Discrete parts manufacturers can typically been classified within groups 1, 2, and 3.

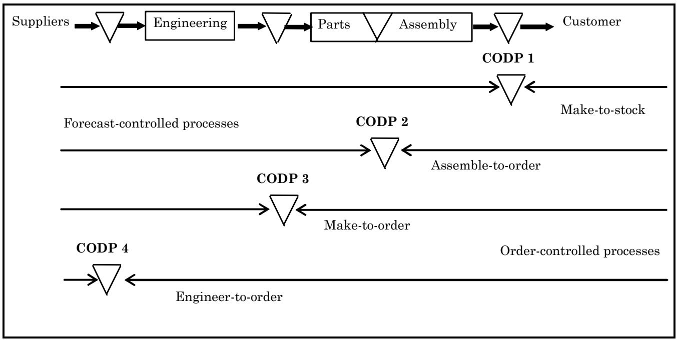


Figure 1-1: Positions of the customer order decoupling point (adapted from Hoekstra et al. [108]).

The effectiveness of a manufacturing system strongly depends on the requirements of its environment. These requirements are partly reflected by the product positioning strategy (which is also known as the order penetration point or the customer order decoupling point [108]). This point identifies the extent by which customer orders penetrate the production system. Downstream of this point, manufacturing is based on real customer orders; i.e., no anonymous stock of end-products is kept after this point. Upstream the material flow is controlled by forecasting and planned orders; see Figure 1-1.

Engineer-to-order Engineer-to-order (ETO) firms engineer, produce, and assemble complex products to order, such as machines and systems. Each order usually concerns a single machine or system that has seldom been engineered or produced before. Such a product consists of a huge number of components and parts characterized by a variety of dimensions and technical specifications, and as a result, the bill-of-material is generally large. In addition, these components and parts generally involve various types of materials. Except for standard components, it is therefore not sensible to produce to stock to anticipate future demand. The expertise of these firms lies mainly in the upstream stages, in the integration of the engineering and production phase [32].

Some firms have a full-blown part production department, others, typically the smaller firms, have one that produces simple parts only; more sophisticated parts are then outsourced. The lead-time is mainly dictated by the coordination between the engineering department and the production department, i.e., the job shop, and in the latter case between the engineering department and the assembly shop. In case of a full-blown parts production department, there is also a need of coordination between the different work centers, as these manufacturing shops generally have functional layouts.

Engineer-to-order discrete parts manufacturing environments are generally very *dynamic* and *hostile*, in that customers require high-quality unique complex systems at competitive prices. Furthermore, because of the fierce competition, customers have much freedom to choose among suppliers (i.e., customers can easily switch between vendors) and, as a result, an ETO firm usually receives many requests for quotations (RFQs). This leads to a low predictability of the workload and work content as well as the specific types of resources and quantities of capacity to be used. Indeed, the quotations are often due for quite a while, and as a result, it is very difficult to forecast the total product mix. This leads to high product diversity and fluctuations in capacity requirements. Finally, if a quotation is converted into a hard customer order, a short delivery time is expected.

Make-to-order A Make-to-order (MTO) discrete parts manufacturing environment is basically an ETO manufacturing environment, in which the engineering tasks already have been performed. MTO manufacturers generally sell capacity. They generally have a full-blown part production and assembly department, in which they produce and assemble a high diversity of end-products in small and medium-sized batches, often in a functional organizational manufacturing setting, such as job shops. The difficulty of production planning and control is due to the big fluctuations in capacity requirements and the high diversity of products that have to be made; from one product to another, there are usually big differences in resource requirements. Second, the size of the orders in hand may also vary greatly from time to time, which is inherent to producing solely to order. Hence, the value proposition of make-to-order is to provide capacity to produce components and subassemblies, or even finished assemblies to customer specifications.

Assemble-to-order In response to decreasing product life cycles and increasing pressure from customers for fast delivery, and mass customization, many high-tech firms have adopted an *assemble-to-order* (ATO) strategy instead of the more traditional make-to-stock (MTS) strategy. In contrast to MTS, which keeps inventory at the end-product level, ATO keeps inventory at the component level. When a customer order is received, the required components are pulled from inventory and the end-product is assembled and delivered to the customer. The ATO strategy postpones the point of commitment of components to specific products, and thus, increases the probability of meeting a customized demand in a timely manner and at low cost [152]. Furthermore, by using common components and modules in the final assembly, firms operating under an ATO strategy are better protected against demand variability, because of risk pooling, than firms operating under a make-to-stock strategy.

The positioning strategy of assemble-to-order is to offer a large variety of high quality, competitively priced, end-products with standard components and subassemblies within a short lead-time. By stocking a small supply of parts, components, and subassemblies, the manufacturer can quickly assemble a huge number of possible configurations. The customer enjoys the benefit of customization, yet faces generally a short wait for delivery. As a result, ATO firms have a hybrid production planning and control approach and are often forced by intense competition, to provide a wide range of products with short customer delivery time. In addition, the capability to speed-up customer-order controlled manufacturing processes by intelligent on-time adjustment of available capacity is also a key issue in this type of manufacturing environments that management has to address.

Make-to-stock The positioning strategy of make-to-stock emphasizes immediate delivery of good quality, reasonably priced, off-the-shelf, standard items. In this environment, a customer is not willing to accept a delay in the delivery of the product. Management is required to maintain a stock of finished goods.

Make-to-stock characterizes the manufacture of products based on a well-known and relatively predictable demand.

1.2 Decentralized manufacturing and social issues

For efficiency reasons, customer-order-driven discrete parts manufacturers generally do not have a pure product-oriented organization; dedicated manufacturing lines would often lead to under-utilization. Discrete parts manufacturers, especially metal cutting departments, are therefore still organized by function, i.e., as job shops. From both a social and a socio-technical point of view, this is a shortcoming [54][198], which some discrete parts manufacturers try to overcome by creating functional but empowered teams. Indeed, socio-technical cells should be product-oriented in theory, but in practice these cells are more parts-oriented, based on a mix of technical and social design principles, like self-direction, individual competence management, training programs, and team motivation

There are a number of grouping approaches that all advocate the reduction of logistical complexity, such as the Lean/Agile Manufacturing approach, the Group Technology (GT) / Cellular Manufacturing (CM) approach, and the (Dutch) Socio-Technical Systems (STS) approach; we briefly discuss each of them in this section.

1.2.1 Lean and agile manufacturing approach

Agile manufacturing is the organizational capability to re-engineer and adjust to continuous change by empowering employees through (e-commerce enabled and agent-based) information and communication technology in a decentralized organizational setting [127][128]. Agile manufacturing makes extensive use of the grouping methods of lean manufacturing and combines that with recent ICT developments such as e-commerce, intranet, and XML-based integration [86].

The difference between lean manufacturing and agile manufacturing is that the principle of lean manufacturing strongly focuses on the reduction of complexity and variability to hedge against uncertainty with the help of the methods, concepts, and tools comprised by Total Quality Management (e.g., Kaizen, continuous improvement, statistical process control), Total Preventive Maintenance, and Just-In-Time (i.e., kanban) philosophies. However, in an increasingly hostile and dynamic global manufacturing environment in which manufacturers operate in versatile global supply networks [15], the drastical reduction of complexity and variability would also limit the total degrees of freedom (i.e., flexibility as measured by future options). This would, according to the theory of requisite variety [5], temper the ability to cope with today's dynamism. In contrast, agility builds upon lean principles to reduce unnecessary, generally self-imposed, complexity and variability, but it adapts to increased rate of change with a combination of individual and organizational capabilities in which recent technological innovations are prerequisites.

Nevertheless, the methodology to reorganize the company into a lean enterprise proceeds by first analyzing the value stream on redundant waste and then making the remaining value steps flow. Subsequently, the primary process is segmented into flow-oriented manufacturing groups. Lean manufacturing cells should have unidirectional flow and they require a frozen schedule and so-called level scheduling to eliminate variability and to find ways to reduce set-up times and run smaller batch sizes.

A *lean manufacturing group* is based on the use of standard operating procedures, and there is a clear hierarchy in the group. A worker in a lean manufacturing system is expected to deliver a certain amount of work within a specified time span, and the group lacks influence on their manufacturing targets in that specific time span. An important aspect of lean manufacturing is the distribution of leadership and formal authority in the group and especially the position of the hierarchical shop floor group leader, i.e., the supervisor. A lean manufacturing group is not *internally* autonomous but subject to its supervisor. Generally, the group is supported from functional service departments for production planning and control issues as well as the development of the frozen schedule. Hence, it is a management approach in which groups or teams play an important role, but in which hierarchical control remains. Besides inter-group coordination, this type of group is also subject to intra-group coordination, which requires even more production planning and control activities.

1.2.2 Group technology and cellular manufacturing approach

Another grouping approach is *cellular manufacturing*. This approach generally proceeds by a Group Technology perspective in which the aim is to reduce (logistical) complexity from a manufacturing and operations management point of view, and to achieve economies of scale effects in batch manufacturing [43]. Burbidge [43] claims that a product-oriented layout, designed by use of Group Technology principles, always outperforms its process-oriented counterpart. However, the studies of Flynn and Jacobs [73][74] and Morris and Tersine [174] show that process layout is not necessarily inferior to dedicated product-oriented cellular layout. Quite the contrary, dedication of cells may lead to workload balancing problems resulting in longer waiting times, larger work-in-process inventory and longer total flow times, while similar machines in other cells are underutilized. Therefore, Flynn and Jacobs [73] opt to build flexibility into shops by using interchangeable machines and to allow inter-cell movement. This would, however, increase logistical complexity and inter-cell coordination, which indicates even more production planning and control requirements.

1.2.3 (Dutch) Socio-technical systems approach

The socio-technique as an integrated organizational design methodology states that an organization must match its environment. The flow of orders from the environment determines the required cycle of activities, as it introduces the degree of diversity, dynamics, and complexity that is permitted to enter the organization.

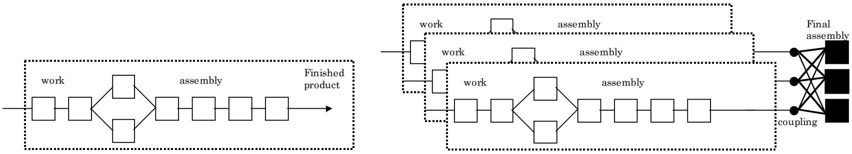
The socio-technical systems design approach is based on the law of requisite variety [5] that states that the control capability must be proportional to what is to be controlled, to match external input variability and internal variability. If there is insufficient control capability one can satisfy the law of requisite variety by 1) reducing the control requirements and/or 2) increasing the control capability (i.e., increasing the channel capacity for transmitting variety). The socio-technical systems design approach aims to reduce the control requirements by the reduction of the input complexity through the creation of parallel flows and segments in the primary process, the design of a production structure from a top-down approach, and the design of a control structure from a bottom-up approach. Order flows are grouped in order families with common operations characteristics to create parallel flows. Subsequently, these parallel flows are segmented to create sensible cells. Finally, local control capacity of the cells is increased and the responsibility of the tasks to complete parts of the order flows is given to these cells. Hence, a flow oriented organization structure with more or less semi-autonomous cells arises systematically; see Figure 1-2.

Figure 1-2: The creation of parallel flows and segments (Kuipers and Van Amelsvoort [143]).

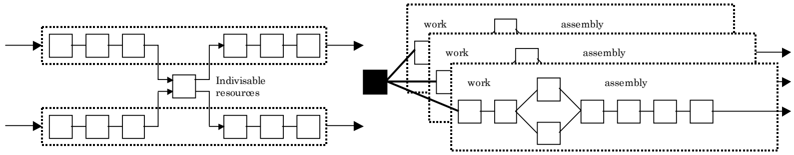
Design rules for socio-technical cells include elements as minimal labor division, internal coordination, personal mutual adjustments, team-based organization instead of individual-based organization, multi-skilled personnel, and the acceptance of responsibilities [198]. Another important rule is that socio-technical cells have a certain degree of autonomy in the choice of work methods. Basically, the socio-technical systems design approach distinguishes four types of cells; see Figure 1-3:

1. Fully autonomous cells, for instance product cells;

2. Output-dependent cells, for instance module cells;
3. Output- and input-dependent cells, for instance phase cells;
4. Input-dependent cells, for instance market cells.



a) An example of product groups b) An example of module groups



c) An example of phase groups d) An example of market groups

Figure 1-3: Socio-technical cells (adapted from De Waard [234]).

A pure *socio-technical shop floor team* has in principle the freedom to organize its own work: the team is autonomous in the acceptance, production planning and control of the orders. It should have its own office or space, its own equipment, and its own information. A worker in a socio-technical shop floor team should be capable of performing a wide range of tasks, both operational tasks and production planning and control tasks. In addition, the team's internal leader or representative does not have formal authority over the other members.

While there are many advantages of the socio-technical systems design approach, there are also some important considerations. The socio-technical systems design approach focuses on maximal integration of control cycles, hence minimal labor division, including production planning and control activities. Therefore, it strives for cell concepts with unfragmented control cycles within the task groups, i.e., fully autonomous groups.

Although numerous authors claim that implementing autonomous groups increases flexibility, in practice, the autonomy, decision authority, and hence the level of flexibility of groups are very dissimilar, and in general limited [54][142][167]. Cox-Woutstra [54] states that there are plenty of independent and reliable observations in socio-technical practice that found differences in the degree of autonomy of groups, even within the same organization. For instance, De Leede and Stoker [153] observe that only few groups in The Netherlands are completely autonomous. However, they also found that many are moving in that direction and only few organizations claimed to have completed the design and implementation of groups. Surprisingly, it also appeared that there was no relation between the design of the groups and the nature of the order flow.

An important reason for this phenomenon is that segmentation generally leads to input- and/or output dependent cells, generally phase cells. Hence, a need of inter-cell coordination persists, even within the socio-technical systems design approach, in which the local control cycles have to be grouped based on separation rules and coupled again on inter-cell level. The objective of the socio-technical systems design theory is to develop cell-based control cycles in which intrinsic control is performed on personal mutual coordination, and that the external coupling structure between control actors is simple. However, based on a literature review and the conduction of some case studies, Riezenbos [189] found various types of interdependence between cells that particularly determine the control requirements of these cellular manufacturing systems. As a result, Riezenbos [189] states that the commonly accepted point of view that coordination issues in cellular manufacturing are quite easily tractable is far too simple.

In addition, production planning and control requirements, and the corresponding structure of the production planning and control hierarchy, are generally underexposed in socio-technical literature; whenever it is a subject of discussion, it covers planning issues within a single group. Hence, there is insufficient attention for inter-cell coordination (i.e., external coordination). Furthermore, based on a systems-theoretic analysis of the socio-technical control model, Cox-Woudstra [54] concludes that control within a pure socio-technical organization involves emergent control. This means that control on a lower aggregation level influences control on higher aggregation level. Hence, the classical hierarchical production planning and control architecture no longer satisfies.

1.2.4 Social issues and competence management

Human resource management is a system of practices and policies designed to influence employees' attitudes, behaviors, and performance. Individual performance depends on having the necessary skills and abilities for the job, and being motivated to apply those skills and abilities; accordingly, these skills and abilities have to be coached or even managed. In work teams, and especially in socio-technical teams, these skills and abilities are collectively monitored and developed; individuals in work teams coach each other. The use of work teams increases involvement by decentralization of decision making and by giving the employees greater control over planning and coordination of their work [171]. However, dependent on the organizational environment, employees must have specific competencies. These competencies provide the basis for appropriate required behavior to obtain distinctive competitive advantage from manufacturing; see for instance Boudreau et al. [37] or Hopp and Spearman [110]. Indeed, individual competence management has become an important part of today's high performance human resource management practices. Accordingly, Boudreau et al. [37] state that while operations management (OM) and human resource management (HRM) have historically been very separate fields, operations are the context that often explains or moderates the effects of human resource activities. Reversely, human resource practices highly affect OM modeling practices, for instance, the resource loading problem [19][95][104] or the modeling of operators in queuing networks [136][244]. *Integrated Factory Effectiveness*, in which various High-Performance Work Practices and organizational disciplines cohere to achieve competitive advantage, will become a key dimension of operations strategy. Indeed, predominantly more high performance plants have adopted such an integrative approach recently, in which they make use of both OM and a more sophisticated understanding of motivation (i.e., the management of worker behavior). In this thesis, we address a specific dimension of High-Performance Work Practice, since we study the impact of line management's support of individual competencies on financial performance.

1.3 Production planning issues

Production planning comprises the coordination of tasks among manufacturing actors, i.e., manufacturing stages, departments, cells, or individual machines [31]. Aggregate planning tries to answer the question of how, or with what (individual) resources and what capacity types to manufacture, while detailed planning (i.e., scheduling) determines when exactly to perform the tasks; see for instance Figure 1-4.

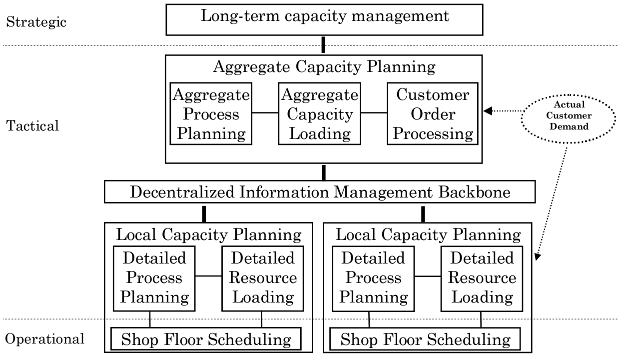


Figure 1-4 : Part of the modified-hierarchical MPCS architecture (Van Assen et al. [6]).

The applicability and specific usage of aggregated planning as well as detailed planning models and applications, however, depends on the production planning requirements of the specific manufacturing environment, characterized by a specific degree of PMT-uncertainty (i.e., complexity and rate of change).

We briefly discuss some production planning aspects. The outline of this section is as follows. In Section 1.3.1, we discuss a planning framework and related planning tasks. In Section 1.3.2, we discuss Manufacturing Resources Planning (MRP-II), a push system that is commonly used in practice. In Section 1.3.3, we briefly discuss Advanced Planning and Scheduling.

1.3.1 A planning framework and related planning tasks

In the discussion of the different manufacturing strategies corresponding to the possible CODP positions (see Section 1.1, page 22), we inherently discussed different levels of aggregation, for example the level of aggregation of products and the aggregation of the facilities. Dependent on the characteristics of the Product/Market/Technology combinations of the specific manufacturing environment, several important aggregation decisions have to be made for the planning model before actual planning (and control) can take place [224].

According to the length of the planning horizon and the importance of the decision to be made, planning tasks are usually classified into three different planning levels [4]:

- *Long-term planning*: Decisions of this level are called *strategic decisions* and should create the prerequisites for the development of the enterprise/manufacturing system of the future. They typically concern the design and structure of a manufacturing system and have long-term effects, noticeably over several years.
- *Mid-term planning*: Within the scope of the strategic decisions, mid-term planning determines an outline of the regular operations, in particular rough quantities, milestones, and authorization time fences for the order flows in the given manufacturing system.
- *Short-term planning*: The lowest planning level has to specify all tasks as detailed instructions for immediate execution and control. Therefore, short-term planning models require the highest degree of detail and accuracy. The planning horizon is usually between a few days and three months. Short-term planning is restricted by the decisions on structure and quantitative scope from the upper levels. Nevertheless, it is an important factor for the actual performance of the manufacturing system, e.g., concerning lead-times, delays, customer service, and other strategic issues.

To describe the various planning tasks that may exist, we use a description derived from Hans [95]. According to Hans [95] *strategic planning* involves long-range decisions, such as make-or-buy decisions, where to locate facilities, to determine the market competitiveness strategy, and decisions concerning the available machining capacity, or the hiring or release of staff. The basic function of strategic planning is hence to establish a production environment capable to meet the overall goals of a manufacturing system. Generally, a *forecasting* system is used to forecast demand and other market information. This demand forecast, as well as other process requirements, is used by *capacity/facility planning systems* to determine the need of more machines or systems. The same analysis is performed by a *workforce planning* system to support personnel hiring, firing, or training decisions. Finally, an *aggregate planning* system determines rough predictions of future production mix and volume. In addition, it supports other structural decisions regarding for example which external suppliers to use, and which products/parts to make in house (i.e., make-or-buy decisions).

Tactical planning on a mid-term horizon is concerned with allocating sufficient resources to deal with demand projected in the (strategic) aggregate planning system, as effectively and profitably as possible. The basic problem to be solved is the allocation of resources, such as machines, workforce availability, storage and distribution resources [35]. While some basic physical production capacities are fixed by the long-term strategic capacity plans, on mid-term tactical planning level actual, resource capacity can temporarily be increased or decreased between certain limits set by strategic planning.

Generally, an *order processing* system processes the immediate customer demand by quoting due dates and prices and accepting or rejecting new orders. On the arrival of each new order, a *macro process planning* step is executed to determine the rough production tasks and the way they are roughly performed [93][111]. Hence, a new production order is divided into work-packages, with precedence relations, estimated aggregate processing times, and, when applicable, extra production related constraints. Using the analysis of the work-package characteristics, and the current state of the production system, orders are accepted or rejected based on strategic and tactical considerations.

Finite capacity planning comprises both aggregated finite capacity loading and detailed resource loading. *Aggregated finite capacity loading* (A-FCL) aims at parameter setting for detailed finite capacity loading at an aggregated planning level, and is concerned with the overall loading of a given set of work-packages over the manufacturing stages; see Figure 1-4. Furthermore, it simultaneously determines reliable internal due dates and other important milestones for each work-package as well as the workload limits and corresponding required regular and non-regular resource capacity profiles within each cell. Accordingly, it determines appropriate *workload norms* per manufacturing stage (i.e., cells) as well as capacity budgets in each period; it typically decides to hire temporal staff or subcontract parts to adjust available capacity versus requirements. Furthermore, A-FCL aims to determine an appropriate internal authorization time fence for each work-package.

Detailed resource loading (D-FCL), on the other hand, aims to determine the use of various resource capacities, i.e., regular and non-regular capacity, within each cell to complete the work-package, where the different types of resource capacity profiles (i.e., available capacity budgets) is determined by the aggregated loading system. Typical decisions for detailed resource loading hence include utilization of regular and overtime labor capacity.

Aggregated finite capacity loading as well as detailed resource loading are important production planning and control systems to adapt to the fluctuations in resource capacity requirements of order-driven manufacturing environments. Subsequently, these systems are important for order processing, since, to some extent, they both can establish the feasibility and suitability of the entrance of new customer orders given a set of already accepted orders. Note that this concurs with the finding of Wester et al. [239] that a monolithic approach of order acceptance (i.e., the acceptance decision is based on detailed information on a current detailed production schedule for all formerly accepted orders) does not definitely outperform hierarchic and myopic approaches based on global capacity load profiles only. However, on a tactical planning level, (aggregated) finite capacity loading and detailed resource loading reinforce each other determining reliable customer delivery dates.

Finally, *short-term planning* is concerned with scheduling of jobs and corresponding operations passed on by the resource loading system. Before scheduling, a *micro process planning* is performed to complete the process planning of the products in detail to provide among other things the detailed data of the scheduling system. The resource loading system at the tactical level determines the (regular plus non-regular) operator and machine capacity levels available to scheduling.

Frequency of replanning Regardless the type of planning level, there is some degree of uncertainty over the planning horizon, dependent on the complexity and the rate of change of the Product/Market/Technology characteristics of the environment under study. One way to deal with uncertainty is *event-oriented planning*: updating a plan every time an important event occurs. Hence, a new plan is not drawn up in regular intervals but in case of an important event, e.g., unexpected sales, major changes in customer orders or machine breakdowns. Fleischmann et al. [72] states that this procedure requires that all data necessary for planning be updated continuously so that they are available at any event time. Generally, this assumption forms the basis of an Advanced Planning and Scheduling (APS) system, often added onto an Enterprise Resource Planning (ERP) system to receive the necessary data.

1.3.2 Manufacturing resources planning

As mentioned before, the most commonly used planning system in manufacturing environments is MRP, generally as part of an Enterprise Resource Planning system. The MRP planning paradigm is based on a traditional hierarchical planning and control framework with several decision levels; see Figure 1-5.

Within this hierarchy, decisions and plans are also made top-down, based on aggregated data, and as a result each decision level imposes constraints on the lower levels. This was the result of the former need to evaluate the consequences of future demand and events a long time in advance, to have early information whether future customer demand can be satisfied. It was necessary to determine 'appropriate' production quantities and due dates based on aggregated data, because of the small computing power and memory at that time; the number of decision variables had to be low, and as a result, one was bound to use aggregate data.

In the MRP paradigm, specific demand of individual end-products is defined as independent requirements. Independent requirements are planned and coordinated in the Master Production Scheduling module. In other words, the MPS represents the forecasted rough independent requirements of end-products. These independent requirements are spread among the MPS planning periods. Next, this plan is checked and verified by the Rough-Cut-Capacity-Planning (RCCP) module on aggregate machine utilization, and on possible aggregate capacity overloads of each aggregate resource in each planning period. Unfortunately, the RCCP module offers no functionality to propose alternatives for detected aggregate capacity problems automatically.

The relation between end-products and the underlying components are described in the 'Bill of Material'. Requirements for end-products generate requirements for underlying components. This demand is defined as dependent requirements. Dependent requirements that have to be manufactured more or less independently in each manufacturing stage are planned and coordinated in a single Materials Requirements Planning module, and checked by a single Capacity Requirements Planning (CRP) module afterwards. The MRP plan represents latest start dates to manufacture or purchase dependent requirements. A start date of a dependent component is determined by subtracting a fixed offset lead-time from the internal maximum due date of the specific component. This maximum due date corresponds with the calculated latest start date of the item in the upper BOM-level. Again, the plan of dependent requirements is checked and verified for possible detailed capacity overloads of each resource in each planning period. Unfortunately, the CRP module too, offers no functionality to propose alternatives for detected capacity problems automatically.

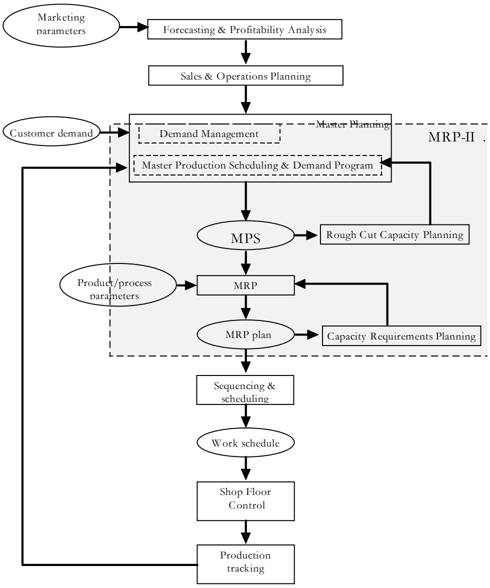


Figure 1-5: The traditional push framework [110].

General deficiencies of MRP There are important general deficiencies with this traditional planning paradigm that makes use of fixed offset lead-times and standard planning parameters. Although MRP was originally proposed as a materials planning system, it has not only severe material coordination deficiencies [69][177], but also makes use of utterly simplistic planning assumptions and corresponding capacity planning procedures [9][110][210]. As the basic principle of MRP is to determine start times of orders, independent of other orders and independent of the actual status of the shop floor, it does not take into account the actual workload. Therefore, it appears as if each order faces infinite resource capacity. Only after the planning cycle is completed, a capacity check is performed to evaluate possible overloads. In addition, in present MRP systems there is no functionality to propose alternatives for detected capacity problems automatically. In other words, if an overload is detected, the planner has to find a solution manually. Unfortunately, shifting orders into less busy planning periods is often complicated by the availability constraints of required materials and auxiliary systems, or by due date constraints. What is more, from standard MRP overload messages, the planner still lacks insight, which order causes the problem, and if there are no overloads detected, there is no guarantee that order-processing times will be exposed in the specific planning period, i.e., specific time-bucket, as determined, because of the fixed offset lead-times. Actual queuing times vary from period to period due to varying product mix, and thus varying workload. This is especially true for discrete parts manufacturing environments. In addition, actual queuing times are generally longer that those used as input in the MRP system, as a result of the push characteristic of the MRP paradigm, in which orders are released independent on the actual status of the shop floor. Orders are released simply on predetermined start times that in turn are based on fixed offset lead-times. Consequently, work-in-process increases, and more orders compete for available resource capacity. In other words, more orders are possibly released than can actually be handled, and consequently actual lead-times increase. This phenomenon is the *lead-time syndrome* or *planning loop* [110][251] already mentioned in the introduction. It is generally compounded by using excessive buffer time (slack) to compensate the fixed offset lead-times for uncertainty, or for efficiency reasons [216]. Although we found evidence of the lead-time syndrome in practice, the vicious cycle is laboriously stopped by taking *ad hoc* actions, which are generally costly. Indeed, if lead-times increase too much, management often decide to increase capacity by scheduling overtime and extra shifts, by hiring temporary workers, or by subcontracting, to handle the increased levels of work-in-process. As an alternative, management may decide to stop unjustified releases of orders temporarily. These temporary capacity expansions prevent lead-times to grow further.

Deficiencies of MRP for decentralized environments The MRP paradigm has also some specific deficiencies for decentralized environments since it is strongly connected with a top-down hierarchical planning and decision structure. Accordingly, it does not account for emergent control. Indeed, it is questioned whether the use of MRP/ERP is diametrically opposed to the decentralization of the locus of control, i.e., the hierarchy of decision-making. After all, the established decisions on the MPS level are the basis for an MRP explosion to determine dependent demand and accordingly the start times for underlying components. The use of workload independent overall standard lead-times can be false, even if the lead-times in a group are reasonably reliable and accurate, because inter-cell waiting times are generally not incorporated in these lead-times.

1.3.3 Advanced planning and scheduling systems

Recently, advanced planning and scheduling (APS) systems that offer intelligent batching and scheduling functionality as well as intelligent manufacturing planning have received a lot of attention to overcome part of the deficiencies of the rigid traditional MRP paradigm [210]. The current state of the art shows the integration of hierarchical planning architectures with Linear Programming tools for aggregate production and capacity planning, and, sometimes, advanced shop floor scheduling systems at a low level in make-to-order production environments [254].

Unfortunately, commercial APS software packages are especially aimed at the semi-process industry, but not so much at decentralized discrete parts manufacturing environments. Thus, although there are plenty of detailed multi-resource job shop scheduling systems available to intelligently support operational planning and scheduling problems, intelligent finite capacity production planning and control systems for mid-term planning purposes in decentralized discrete parts manufacturing environments are fairly uncommon. What's more, for intelligent finite capacity production planning and control methods like aggregated finite capacity loading and detailed resource loading, there is also a gap in academic literature (i.e., theory).

Furthermore, although much research on APS systems focuses on algorithms behind the screen of these systems [138][210][254], less research is conducted on APS adoption issues. Nevertheless, any technology adoption is best understood by analyzing and understanding the various contextual factors both from within and from the external environment that resulted in adoption of the technology [50][144][188]. In this thesis, we use the factors approach to identify some static factors that influence the adoption of APS systems.

1.4 Research methodology

We give the research questions, domain, objectives, and design.

1.4.1 Research questions

From the theoretical rationale discussed in the previous sections, we derive the central research question of this thesis:

> ***What is the impact of PMT-uncertainty on important discrete parts manufacturing management issues, such as the strategic focus on competitive priorities, the dominant type of manufacturing layout, the decentrality of the locus of production planning and control, the use of production planning and control tools, and the line management's support of individual competencies?***

From this main research question, we derive the following subquestions:

1) To what extent do firms with a cellular manufacturing structure differ in various dimensions of PMT-uncertainty, such as the factors related to information deficiency, rate of change, and complexity from firms with a functional layout?
2) What factors affect the choice of a specific manufacturing layout most?
3) How is PMT-uncertainty related to the locus of production planning and control (and the frequency of production planning and control meetings)

given a particular situation specified by the main (set of) PMT combination(s)?

4) What is the impact of PMT-uncertainty on the use of different production planning and control tools, such as kanban control, conventional plan board, spreadheet, ERP, and APS?
5) What is the state-of-the-art (i.e., the adoption rate and related adoption issues) of advanced planning and scheduling in the discrete parts manufacturing industry?
6) What is the impact of innovation and organizational factors on APS adoption?
7) What is the difference in APS adoption rate between discrete parts manufacturers with a functional layout and discrete parts manufacturers that are organized in cells?
8) What is the impact of line management's support of individual competencies on financial performance?
9) What is the relation between line management's support of individual competencies and the firm's strategic focus on competitive priorities related to agile manufacturing?

1.4.2 Research domain and objectives

Since the research domain 'discrete parts manufacturing management' is huge, the scope of this thesis is restricted to empirical research on some recent manufacturing management issues in the (Dutch) discrete industry, such as the impact of PMT-uncertainty on the locus of production planning and control, the use of various production planning and control tools, and APS adoption issues in particular. Furthermore, we focus on the differences between cellular layouts and functional layouts for PMT-uncertainty, competitive priorities, and social issues such as individual competence management. Accordingly, the research presented in this thesis contributes to the body of knowledge on the impact of PMT-uncertainty on various operations and manufacturing management aspects.

The academic research objective is

- ***to contribute to the body of knowledge of the impact of PMT-uncertainty on discrete parts manufacturing management issues, such as locus of production planning and control and -tools, and the dominant type of manufacturing layout;***
- ***to contribute to the body of knowledge of the adoption of advanced planning and scheduling systems in discrete parts manufacturing environments in general, and for cellular manufacturing systems in particular;***
- ***to contribute to the body of knowledge of the impact of line management's support of individual competencies, and the strategic focus on agile competitive priorities on financial performance.***

1.4.3 Research design

The nature of the research question determines the right research strategy and research design [248]. Meredith [165] contrasts case/field research with rationalist research, such as optimization models, simulation modeling, and survey methodology. Rationalism, the dominant research paradigm in operations management, generally employs quantitative methodologies to describe or *explain* what happens and how, to predict manufacturing system performance for a set of decisions. Case/field study is an example of an alternative research paradigm (known as interpretivism) that uses both quantitative and qualitative methodologies to help *understand* phenomena. It helps the researcher comprehend why certain characteristics or effects occur, or do not occur.

Case study research designs are appropriate when there is a low state of knowledge about a phenomenon of interest. Single-case research designs are appropriate particularly if the situation investigated is a revelatory case [248], in which the investigator has the opportunity to observe a phenomenon that was not previously accessible. A case study typically uses multiple methods and systems for data collection from a number of entities by a direct observer in a single, natural setting in its context, without experimental controls or manipulations. Example entities include financial data, interviews, memoranda, business plans, organization charts, systems and other physical artifacts, questionnaires, and observations of managerial or employee actions and interactions. The objective is to *understand* as fully as possible the phenomenon being studied through 'perceptual triangulation', i.e., the accumulation of multiple entities as supporting sources of evidence to ensure that the facts being collected are indeed correct. Table 1-2 illustrates some major advantages and disadvantages of rationalist and case research methods.

	Advantages	Disadvantages
Rationalist	Precision Reliability Standard procedures Testability	Sampling difficulties Trivial data Low explained variance Thin results
Case	Relevance Understanding Exploratory depth	Access and time Triangulation requirements Lack of controls Unfamiliarity of procedures

Table 1-2: Advantages and disadvantages of rationalist and case research methods (adapted from Meredith [165]).

Advantages and disadvantages of rationalist research The strengths of rationalist research are the precision it can achieve in its variables (e.g., costs, capacities, lead-times) and thus, the testability and reliability this offers. That is, the measurable quantitative variables can be very carefully specified and then precisely tested, or checked by another researcher. Another major advantage of the rationalist approach is the knowledge and wide acceptance of its standard research procedures of model formulation, testing, and validation, particularly in operations management. However, while there are many advantages of the rationalist research method (to operations management), there are also some important considerations concerning (the phase of) model and solution testing in practice [126]. That is, validation –and in particular conceptual validation (i.e., assessing the relevance of the assumptions and theories which underpin the view of the situation under study held by decision makers and modelers)– appear to be given little consideration in the rationalist research practice yet [126]. In this context, we also mention the habit of presenting and comparing computer run times of algorithms in scientific Operations Research papers without the reader knowing full details of (i) how these algorithms are coded and (ii) CPU usage due to data synchronization issues. Hence, rationalist research methods also have their drawbacks, among which the abstract and remote character of key variables, the lack of comparability across studies, the failure to achieve much predictive validity, and the difficulty of understanding, interpreting, and especially implementing the results of these studies in practice [165].

Advantages and disadvantages of case study research The advantages of case study are: 1) the phenomenon can be studied in its natural setting—hence, meaningful theory can be generated from the understanding gained through observing the actual practice; 2) the case method allows the much more meaningful question of *why*, rather than just *what* and *how*, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon; and 3) the case method lends itself to early, exploratory investigations when the variables are still unknown and the phenomenon is not fully understood. However, case study research also has some drawbacks. Some difficulties of doing case study research are the requirements of direct observation in the actual contemporary situation: cost, time, information access hurdles, need of multiple research methods for example to account for triangulation, lack of controls, and several complications as a result of the contextual dynamics. We conclude that the rationalist research methods are best in telling us *what* the phenomenon entails and *how* it works, while the case study research tells us *why* it works that way. Hence, rationalist research methods are most appropriate for *testing* or *verifying existing* theory, while case studies are best for *generating* or *extending* theory.

Table 1-3 shows the different stages of the theory development process against the research objectives of *what* (i.e., identification), *how* (i.e., explanation), and *why* (i.e., understanding). Across the top is the progress in theory development, starting with theory building, followed by testing and then modification of the theory to account for the test results. In the body of the table, the case and rationalist research methods are positioned where they find greatest applicability.

	Theory building	**Theory testing**	**Theory modification**
What (i.e., identification)	Case	Rationalist (Case)	Rationalist Case
How (i.e., explanation)	Case	Rationalist (Case)	Rationalist Case
Why (i.e., understanding)	Case	(not relevant)	Case

Table 1-3: Theory development under rationalist and case research methods (adapted from Meredith [165]).

As noted earlier, the rationalist research methods are primarily directed to the *what* and *how* rows but only the case research method is positioned along the *why* row. For the columns, the rationalist research methods are most appropriate for testing theories that have been previously developed by other methods, such as case/field studies or other interpretive methods. Hence, case research to build theory precedes survey research to test the theory. Since our research questions are primary 'what' and 'how' questions, we particularly follow the rationalist survey research method.

1.5 Outline of the thesis

This thesis is structured along nine chapters; see Figure 1-6. In Chapter 2, we present an exploratory longitudinal case study at "Urenco Aerospace" to gain insight in the problem domain and the various constructs that form the basis for answering the research questions. In particular, this chapter addresses questions 1) and 2). Chapter 2 is partly based on Van Assen and Van de Velde [10].

In Chapter 3, we study the impact of PMT-uncertainty (with the dimensions complexity, rate of change, and information deficiency) on the locus of production planning and control in the Dutch discrete parts industry, for which we developed a full-blown questionnaire. Chapter 3 addresses research question 3). Chapter 3 is based on Van Assen and Van de Velde [11][12].

In Chapter 4, we explore the impact of PMT-uncertainty on the use of various production planning and control tools (i.e., kanban control, conventional plan board, spreadheet, ERP, and APS). Chapter 4 addresses research question 4) and is based on Van Assen and Van de Velde [13].

In Chapter 5, we study the impact of organizational and innovational factors on the adoption of APS systems within the Dutch discrete parts industry with the help of a second questionnaire. Chapter 5 addresses research questions 5) and 6). Chapter 5 is based on Van Hezewijk [105] and Van Hezewijk, Van Assen, and Van de Velde [106].

In Chapter 6, we address research question 7). Furthermore, this chapter addresses the issues of operations management sophistication, and communication channels in relation to APS adoption for firms with a cellular layout versus traditionally organized firms. Chapter 6 is based on Van Assen et al. [14].

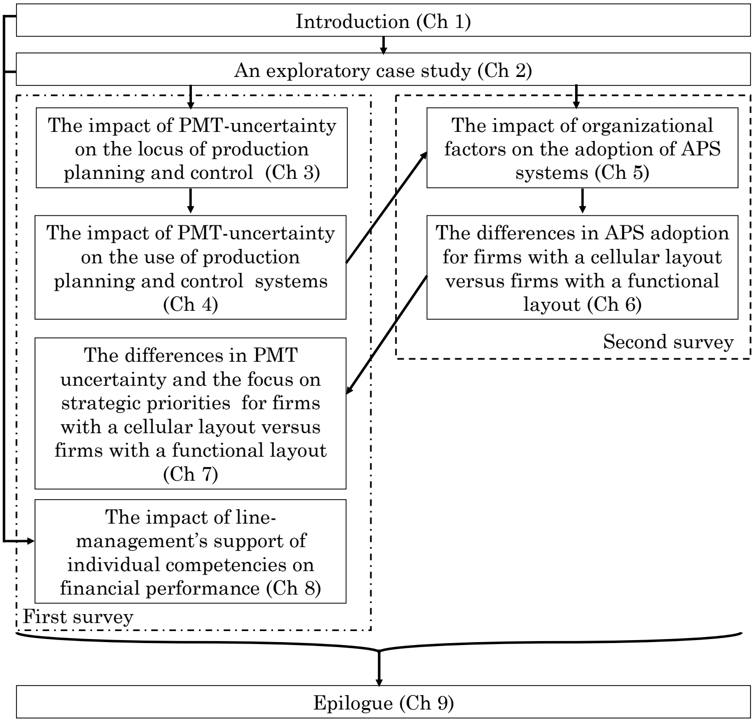


Figure 1-6: Overview of, and relationships between the chapters.

In Chapter 7, we explore the differences in PMT-uncertainty, the extent of customer's influence on the productmix, customer's vendor-switching possibilities, and the focus on strategic priorities between firms with a cellular layout and firms with a functional layout. Chapter 7, which is based on Van Assen and Van de Velde [16], also addresses research question 1).

Chapter 8 addresses research questions 8) and 9): 'what is the impact of line management's support of individual competencies on financial performance', and 'what is the relation between line management's support of individual competencies and the firm's strategic focus on particular competitive priorities related to agile manufacturing?' Chapter 8 is based on Van Assen [7] and Van Assen and Van de Velde [17].

Finally, Chapter 9 ends this thesis with conclusions and avenues for further research; in particular the design, the implementation, and the validation of an applicable dynamically modified-hierarchal multi-agent MPCS system; see Van Assen et al. [6], Van Assen [8], Van Assen et al. [19], Van Assen and Meinders [20], Bekkenutte [25], Hentschke [104], Van 't Klooster [136], and Wormgoor [244].

2 An exploratory longitudinal case study

To gain more insight in the manufacturing and operations management issues pointed out in Chapter 1, we have conducted exploratory longitudinal case studies at Urenco Nederland BV. The manufacturing division of Urenco Nederland BV is divided into three manufacturing business units: the Dynamic Parts unit, the Static Parts unit, and the Aerospace unit. The first two are strongly related, both aimed at the manufacturing of the ultra-centrifuge. However, in this chapter we only discuss the Aerospace unit. The classified nature of the centrifuge production prohibits a detailed discussion of these products or their operations.

During this research project we more-or-less actively experienced the transition from a rigid hierarchical organization into a functional organization structure with production teams controlled by functional departments, and subsequently into a highly decentralized organization split in three market-based manufacturing units. In addition, we actively participated in the SAP R/3 implementation project and a number of production and logistical improvement projects. Furthermore, we were indirectly involved in the team development process at this company and we joined team members with some visits to other manufacturers that had implemented more or less self-governing groups.

As mentioned in Chapter 1, numerous grouping approaches aim to reduce complexity of manufacturing and operations management and to achieve economies of scale effects in batch manufacturing [43]. Burbidge [43] claims that a dedicated product-oriented layout, designed by use of Group Technology principles, always outperforms its process-oriented counterpart. However, this is refuted by some studies, e.g., [73][74][174]. In this chapter, we primarily address the question whether a dedicated product-oriented cellular layout outperforms a functional cellular layout. However, next to this basic research question, we also explore 1) how the characteristics of the major Product/Market/Technology combinations in a specific discrete parts manufacturing organization relate to the locus of production planning and control, 2) to what extent this structure is changed by the implementation of a specific type of team; and 3) what the impact of decentralization is on the used Manufacturing Planning and Control System (MPCS).

To answer these questions, we were given the opportunity to conduct intervention research, resulting in an in-depth case study of Urenco Aerospace, a second-tier supplier in the aerospace industry. For this specific manufacturing unit of Urenco Nederland BV, we extensively explored the quantitative operational (i.e., expected) performance measures of both alternative manufacturing layouts with the help of MPX, a performance evaluation system based on Rapid Modeling Technology [218]. In concurrence with the conclusion of Huber and Brown [115] that human resource issues, such as planning, job analysis and selection, training, and reward structures are extremely important for successful implementation of cellular manufacturing, we also explore the impact of social issues that may hinder the adoption of a specific manufacturing layout. Based on follow-up interviews with a number of employees on different organizational levels, we evaluated the relevance and contribution of both technical information and various social issues on management's choice of a new manufacturing layout. Indeed, we also examined the impact of cross-training, labor flexibility, employee resistance, and skepticism on the choice of a new manufacturing layout.

The structure of this chapter is as follows. In Section 2.1, we discuss our fact-finding longitudinal research method in which we combine a performance evaluation study of both alternative layouts with follow-up interviews in one single company. In Section 2.2, we give an overview of the Urenco Group as a whole (until 2002) and the manufacturing division of Urenco Nederland BV in particular. In Section 2.3, we extensively report on our case study of the aerospace manufacturing unit as a discrete parts manufacturer that operates as a second-tier supplier in the global aerospace supply chain. The management of Urenco Aerospace is forced to choose a new manufacturing layout to improve performance drastically. Section 2.4 completes this chapter with conclusions and a discussion of the lessons learned.

2.1 Research method

2.1.1 Intervention research: 2001

Organization studies are frequently accused of having limited relevance to practice. The roots of the theory-practice gap have often been related to the overwhelming influence of positivism on the social sciences. Although the advent of methodological pluralism has enriched the perspectives on our subject matters, non-orthodox approaches, such as intervention research, still has little scientific credibility and, thus, public voice [39]. However, Breu and Peppard [39] state that action and intervention research, including co-operative, participatory, and transformative forms of inquiry, are particularly responsive to the expectation by our organizational audiences (i.e., POM scientists and practitioners) of relevant and timely research. In action and intervention research approaches, concepts and models are developed and immediately implemented in actual practice, i.e., they are immediately made available in the practical context where they have been elicited—thus achieving a balance between theory and practice. As this type of research is also perfectly appropriate for the issues of this thesis, we conducted intervention research at Urenco Aerospace. Based on an analysis of two alternative manufacturing layouts for the manufacturing unit under study, as well as on interviews and active participation in various in-house meetings and discussions, we also suggested a number of logistical improvements. Two years later, we revisited the manufacturing unit to explore the 'new' situation and we tried to discover the reasons behind the related management choices.

2.1.2 Analysis based on rapid modeling software

We analyzed both alternative manufacturing layouts with the help of MPX, which is an easy-to-use software tool to assist firms in achieving and sustaining quick response in their manufacturing operations. In addition, MPX can assist engineers and managers to analyze their operations to find opportunities for improvements related to capacity, work-in-process, labor allocation, new product introduction, and many other manufacturing issues [218]. Embedded within MPX is the methodology Rapid Modeling Technology (RMT), which is based on *queuing theory*, a branch of mathematics to describe factory floor dynamics.

Interviews, discussions, and improvement decisions Before conducting the case study and the MPX analysis, however, we designed a case study protocol to account for triangulation. The protocol comprises a method to account for *validity* and *reliability* by using multiple sources of evidence among which 1) the SAP R/3 database, 2) several proposals for the long-term investment plan of Urenco Aerospace, 3) consecutive business plans 2001/2005, and finally 4) management minutes and records, to which we had full access. In addition, we used various case study instruments, among which various interviews with the sales department representatives, the order entry representative, the production team leaders, the operations manager, the CEO, the operators, the MPS planner, and the process planners. Based on this information and our MPX analysis, we wrote a report on the pros and cons of both layouts with suggestions for logistical improvements. Finally, we had a key informant reviewing the drafts of this case study report.

2.1.3 Follow-up visit and interviews: 2003

In 2003, we revisited Urenco Aerospace to find out management's choice of layout and to analyze employees' experiences and opinions about the new situation. After all, the design of manufacturing cells is not complete without consideration of the social or human aspects involved [247].

2.2 The manufacturing division of Urenco Nederland BV

In the early 1970s, the German, Dutch, and British governments signed the Treaty of Almelo, an agreement under which the three partners would jointly develop the ultra-centrifuge process of uranium enrichment. This agreement was effectively the cornerstone of the close cooperation between the enrichment enterprises in Germany, The Netherlands, and the United Kingdom—in 1993 Urenco Limited became the holding company for the Urenco Group. This merger of the formerly independent companies has led to greater efficiency and higher standards of management and safety. Today, Urenco is a truly global supplier of enrichment services.

Although Urenco's core business remains the enrichment of uranium, it has successfully utilized its ultra-centrifuge technology to diversify their expertise to other fields, for example the aerospace and medical industries. Urenco's success is based on its ability to provide customers with an outstanding service that can cater precisely to their needs, combined with a highly advanced technology ensuring a secure and reliable supply.

Figure 2-1 displays the structure of the Urenco Group. Next to the enrichment sites located at Capenhurst in the United Kingdom (Urenco Capenhurst Ltd), Gronau in Germany (Urenco Deutschland) and Almelo in The Netherlands (Urenco Nederland BV), each country has another division. Research, development, and design of the ultra-centrifuges are carried out in Jülich, as part of Urenco Deutschland. Urenco Capenhurst has an engineering division for the design and layout of the enrichment plants; and Urenco Nederland BV has a manufacturing division (M-div) for the manufacturing of the ultra-centrifuges. The manufacturing division of Urenco Nederland BV (M-div), and in particular the aerospace manufacturing unit, is the focus of our exploratory case study.

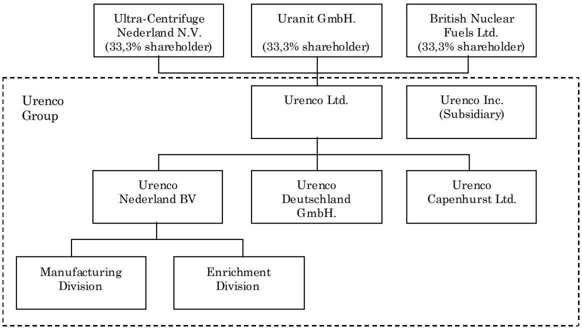


Figure 2-1: Organizational structure of the Urenco Group.

Until 1996, M-div was functionally organized for a manufacturing volume of about 4000 ultra-centrifuges, but facing an annual demand of 2000 ultra-centrifuges. The relatively low demand of ultra-centrifuges was, among others, due to international aversion to nuclear power after the Chernobyl incident, but also due to a tight replacement market—the high-quality ultra-centrifuges have a much longer lifespan than expected.

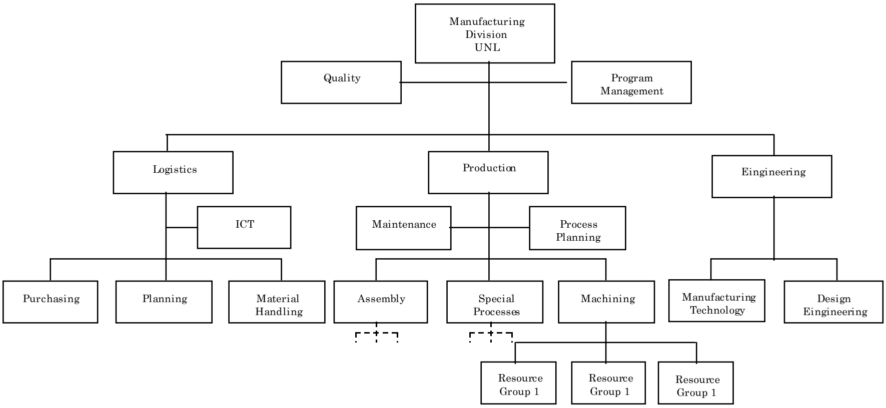


Figure 2-2: Organizational structure of M-div until summer 1999.

To more strongly engage shop floor workers in product quality and manufacturing performance, for instance with the help of management on commitment, M-div decided to implement manufacturing groups in the Manufacturing departments, whereas the structure and work methods in the supporting departments, *Logistics*, *Quality*, and *Engineering* remained unchanged; see Figure 2-2. These productions groups, or rather resource groups, were also functionally organized around a group leader.

When manufacturing demand increased tremendously, several organizational complexity problems arose. Summer 1999, management decided to reorganize for a more flow-like manufacturing and to flatten the organizational structure further. More or less complete, or at least coherent, manufacturing activities were joined together in a specific focused manufacturing unit. Shared manufacturing resource groups, such as the (surface) cleaning room, as well as the supportive functional departments were dissolved. Three more or less autonomous focused manufacturing units, each with its own operations manager, have emerged—the Static Parts unit, the Dynamic Parts unit, and the Aerospace unit; see Figure 2-3.

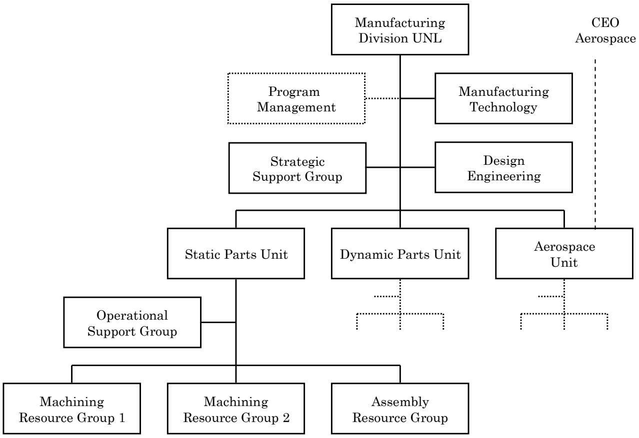


Figure 2-3: Current organizational structure of M-div.

Each manufacturing unit has several self-governing manufacturing groups who, next to manufacturing, are responsible of various operational tasks in the area of detailed planning and order dispatching, quality, maintenance, safety, and environment. The objective of these tasks is to make the employees even more aware of the impact of their behavior on manufacturing performance. The Dynamic Parts unit has eight shop floor teams. The Static Parts unit has eleven shop floor teams across three resource groups.

The manufacturing groups of each focused manufacturing unit are supported by an *operational support group* for tasks, such as work preparation, purchasing, and workload control; this support group is also responsible of the initiation of improvement projects. M-div still has a *manufacturing engineering* department for the improvement of the technical manufacturing process, and a *design-engineering* department for product-design improvements. The *strategic support group* is responsible of strategic purchasing, demand management, and logistical reengineering projects.

2.3 Aerospace unit

The Aerospace unit of M-div is relatively independent of the ultra-centrifuge manufacturing units. It has different Product/Market/Technology characteristics but exhibits great resemblance with respect to the culture and team development processes. It also shares the same, slightly differently customized ERP system. Within this unit, we were given the opportunity to conduct intervention research. Urenco Aerospace's management needed to redesign its manufacturing layout to improve performance drastically to cope with increasing uncertainty in the global aerospace market. Management's objective is both a significant lead-time reduction and an efficiency increase against minimal investments. Because of the preferences of Urenco Aerospace's customers (i.e., the main suppliers in the aerospace industry) and industry's current manufacturing practice (i.e., one-piece flows), Urenco Aerospace's management had a slight preference of a lean dedicated product-oriented cellular manufacturing layout to a functional cellular layout. Nevertheless, before taking a final decision about a new layout, the CEO of Urenco Aerospace invited us (i.e., late 2000) to conduct a study to answer the question: *Does a dedicated product-oriented cellular layout outperform a functional cellular layout?* This gave us the opportunity to study 1) the current situation (i.e., a job shop with teams) and the need to change to a new manufacturing layout, 2) the future situation, i.e., a lean dedicated product-oriented cellular layout or a functional cellular layout, and 3) the underlying reasons for the final choice. Furthermore, in this case study, we extensively explore the technical aspects, i.e., expected performance measures, of the two alternative manufacturing layouts with the help of MPX [218].

2.3.1 Organization structure and culture

Recall that Urenco Aerospace is a second-tier Original Equipment Manufacturing (OEM) supplier in the aerospace industry that produces fast rotating sub-assemblies, such as load compressors and air turbine starters. Urenco Aerospace aims to provide high quality and cost-effective systems and spare parts to the main suppliers in the global aerospace industry.

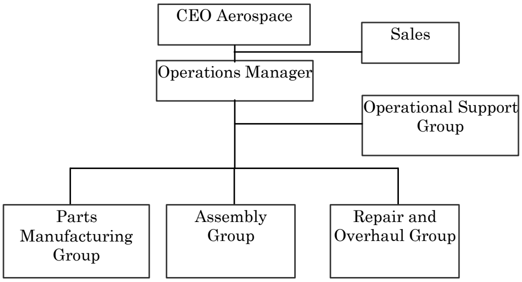


Figure 2-4: Organizational structure of Urenco Aerospace.

In 1999, Urenco Aerospace was transformed from a traditional hierarchical organization to one with three self-governing manufacturing groups: Parts Manufacturing, Assembly, and Repair and Overhaul. These self-governing manufacturing groups are, next to manufacturing, also partly responsible of several operational tasks concerning planning, quality, maintenance, safety, and environment. These tasks empower employees and make them more aware of the impact of their behavior on performance. This transformation was expected to lead to a more efficient and effective manufacturing. A separate operational group (i.e., Operational Support Group) supports these manufacturing groups for tasks, such as work preparation and purchasing, and it initiates improvement projects; see Figure 2-4. However, the culture of Urenco Aerospace still echoes a traditional bureaucracy, where shop floor employees still heavily rely on support group members for production planning and control issues and on mechanical engineers for improving technical manufacturing processes.

2.3.2 The PMT characteristics of Urenco Aerospace in 2001

We primarily focus on the Parts Manufacturing Group; accordingly, we omit the discussion of the Repair and Overhaul Group, as its activities have only a minor impact on the performance of the internal supply chain of spare parts and OEM products; see Figure 2-5.

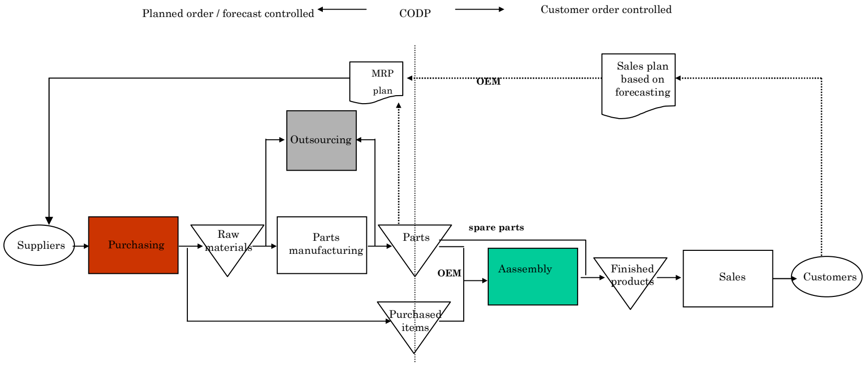


Figure 2-5: The OEM and spare parts supply chain of Urenco Aerospace.

Market characteristics Urenco Aerospace serves as a second-tier supplier of OEM subassemblies in the aerospace industry. This is a highly competitive market in which a few licensed players have exclusive rights to manufacture specific parts, components, and subassemblies. This does, however, not imply that performance, such as low price, high quality, short delivery times, and high delivery dependability, are not of importance. Quite to the contrary, in this 'global, highly competitive market' Urenco Aerospace is forced to quote extremely low prices for OEM products on which it makes no profit at all, which in turn must be set off against the profit of selling future spare parts. In the spare-market, there is an increasing pressure on shorter delivery times while demand uncertainty is very big. Generally, manufacturers in this industry cope with demand uncertainty by keeping safety stocks of spare parts, which is economically justified by the high profit margins. However, the bankruptcy of Fokker (a Dutch aircraft manufacturer) made a lot of inventory obsolete, which made Urenco Aerospace's management reluctant to keep a large variety of spare-part products in stock.

Manufacturing Strategy Urenco Aerospace's strategy is to focus on the core competences of designing, parts manufacturing, assembling, and testing of highly dynamic loaded aerospace systems to order. In Urenco Aerospace's business plan this is stated as:

> *"At present, final assembly and repair and overhaul activities are executed based on fixed purchase orders from our customers. The manufacture and purchasing of components and materials is largely based on forecast* (Business plan 2001)."

In practice, however, not a true 'to-order' strategy has been implemented; in fact, the manufacturing system still operates under a push strategy. While numerous parts are kept in stock to anticipate late internal delivery from the Parts Manufacturing Group, this practice is not fully satisfactory, as the market dynamics of Urenco Aerospace recommends the company to migrate to a make-to-order (MTO) strategy:

> *"To reduce risk exposure, free capital tied up in stock and work in process, to respond faster to changes in demand and reap benefits of improvement sooner, we need to speed up our processes, so more of the parts manufacture and purchase activities can be based on fixed purchase orders instead of forecast. This implies that batch sizes are reduced and products flow through production based on customer demand. As a result the throughput times will be reduced drastically, as are stock, WIP, and total cost* (Management note)."

Product characteristics Urenco Aerospace manufactures five types of subassemblies, each of which consists of a variety of purchased components and in-house manufactured parts. Next to these 'new' OEM products, Urenco Aerospace offers a variety of spare parts of the present and former types of subassemblies. The underlying parts are classified according to the shape and the required metal cutting operations. *Type A* parts are impellers, fans, and wheels; these are highly dynamic loaded parts that have to be manufactured in house. Type *A* parts have production routings with on average 15 operations, including turning, milling, and grinding. Next to these operations, the parts have to be measured, balanced, and tested. Processing times of these operations vary between one minute and several hours for each part. *Type B* parts are large castings, for example diffusers, housing inlets, and nozzles. Type *B* parts have production routings with on average eight operations, such as turning, milling, and grinding. Finally, *Type C* parts are small castings and other smaller parts, for example valves. These parts can be outsourced but also made in house.

All types of parts require turning, milling, and grinding. Because of the high quality requirements, each part may only follow one out of a set of predetermined, qualified routings. Process batches are equal to transfer batches and vary between 5-25 pieces.

Technology characteristics There are about 21 machines, of which 18 are metal cutting machines: mills, turns, and grinding machines. The other machines are for cleaning, measuring, and testing the parts. The machines of the Parts Manufacturing Group are rather randomly functionally placed on the shop floor. This grouping is a legacy of the former functional organization in which there was one single large machining department for both centrifuge and aerospace production. Indeed, in 2001 the Static Parts Unit and Urenco Aerospace made still use of the same production hall, in which tools and fixtures are centrally stored.

Parts of types *A*, *B*, and *C* require on average 15, 8, and 7 in-house metal cutting and some outsourced operations, respectively. The metal cutting machines require a significant amount of set-up time. In addition, the type and precision of these internal operations require an operator's full-time attendance. Nevertheless, occasionally, dependent on the actual mix of products at a time on the shop floor, several machines may be operated by a single operator at the same time.

Machinery to perform the turning and milling operations on type *A* parts (i.e., the wheels) are the Hermle, the Dixi, the 5-axis Wahli, and the Emag6. Machinery for type *B* parts (i.e., the big castings) are the Emag8/Index, the 4- and 5-axes Wahlis, and the Weiler. Machinery for type *C* parts are the Emag6s, the 4- and 5-axes Wahlis, the Spinner, the Boley, and some other conventional machines. Hence, all type *A* and type *B* parts require milling on the Hermle/Wahlis and turning on the Emag6s. In addition, some type *A* parts are machined on the Wahli 5-axis. Furthermore, for all milling and turning operations, there is not only significant set-up time required from one part type to another, but also between different parts of the same type.

The Parts Manufacturing Group employs 18 highly skilled and reasonably flexible operators that can operate different machines. Dependent on their skills, some operators work in a two-shift schedule while others only work in daytime.

A rough estimate of the required capacity in net man-years (1530 hours) to satisfy expected demand in 2002 is given in Table 2-1. This includes processing time and setup time given fixed predetermined batch sizes. Note that the Hermle, the Emag8/Index, and the Kellenberger need more than a 2-shift schedule to match demand. However, management expects that the processing times of these machines are overestimated to hedge for technical problems, i.e., they expect the process planners to include quite some slack in the processing times of operations on these machines and that a reduction of more than 20% is possible. Nevertheless, from Table 2-1 we observe that, given the present predetermined qualified routings, at least a new Hermle (5-axis mill) is required to meet future demand.

Work center	Wheels	Large castings	Small Castings/Rest	Total required	# of available machines	Present # shifts
Hermle	4.3			4.3	1	2
Dixi	1.8			1.8	1	2
Wahli 5-axis		0.7	0.5	1.2	1	2
Wahli 4-axis		2.2	1.1	3.3	2	2
Kellenberg	1.5		0.8	2.3	1	2
Mori Seiki	0.1		0.1	0.2	1	1
Deckel	0.01	0.15	0.02	0.18	1	1
Emag6 (+ Boley)	1.5		0.6	2.1	2 (1)	1
Emag8/Index	0.3	1.6	0.6	2.5	1	1
Weiler		0.8		0.8	1	1
Spinner			0.2	0.2	1	1
Fehlmann		0.1	0.2	0.3	2	1
Total	**9,51**	**5,55**	**4,2**	**19,18**	**15**	**21**

Table 2-1: Required rough machine capacity including average setup-time in man-years to meet expected demand in 2002.

Production planning and control The current method for production planning and control is MRP (SAP R/3), see for instance Vollman et al. [233]. The operational support group is responsible of demand management, sales and operations planning (SOP), resources planning, and the coordination among the manufacturing groups. Converting the customer orders from the SOP into planned orders in the Master Production Schedule (MPS) is the responsibility of the MRP planner of this operational support group. Finally, converting the planned orders into production orders, after checking whether all necessary raw materials (or parts) are available, and subsequently releasing the order, is the responsibility of the self-governing groups.

Performance In 2001, the internal delivery performance was abominable, with the ratio of average lead-time versus processing time of about 100 for all types of parts. However, on time delivery of spare parts was relatively high (87%) compared to the internal on-time delivery of OEM parts (< 60%) by the Parts Manufacturing Group to the Assembly Group. However, external delivery reliability charts indicated a reliability of 91%; see Table 2-2. Close examination learned that this number was an intervention dependent performance measure, since for on-time orders, it turned out that there was excessive slack in planned assembly lead-times as well as ‘hidden’ inventory of end-products built up by the Assembly Group; recall that due to the high profit margin on spare parts, lost sales is not an option. This leads to an ambiguous approach;

on the one hand, management is reluctant for high inventory levels, while on the other hand, management claims to have structurally too little inventory. As a management note said: "*The financial inventory numbers are associated with distressing deficiencies resulting in a deteriorating delivery performance*". This contradicts the objectives in the business plan.

Furthermore, type *A* parts generally had better internal delivery reliability than the other product types. Closer investigation indicates that these products are given priority by planners and shop floor workers, as the result of the one-sided management attention for type *A* parts.

	On time		**Late**	
Date 03-2001	**Frequency**	**%**	**Frequency**	**%**
Total spares	697	87%	101	13%
LC350 OEM	9	100%	0	0%
LC350 spares	450	100%	0	0%
LC400 OEM	0		0	
Starter TAY (Gulf)	3	38%	5	63%
BR-700	48	72%	19	28%
Total	**1207**	**91%**	**125**	**9%**

Table 2-2: External on time delivery performance (intervention dependent).

2.3.3 MPX analysis of alternative manufacturing layouts

Urenco Aerospace's performance in terms of internal delivery reliability and other internal operational objectives was poor. In addition, customer service as perceived and indicated by leading customers was too low. Both management and customers suggested Urenco Aerospace be reorganized into dedicated lean product-oriented cells, as it was expected to reduce logistical complexity, and ultimately, to achive one-piece flows. Besides, it would fit present culture best.

However, it was acknowledged that in the short term, it is not an easy task to improve the situation without drastic actions like subcontracting and hiring extra employees to create a buffer between the Parts Manufacturing Group and the Assembly Group. Due to excess capacity in the Assembly Group as well as slack in the processing times of the assembly tasks (i.e., management expects that process planners incline to overestimate processing times to hedge for uncertainty), Urenco Aerospace's management claims that each of its product configurations can be assembled by the agreed customer delivery dates, if there are sufficient parts in stock. Put differently, in the long run, an assemble-to-order strategy may resolve the problem if the Parts Manufacturing Group replenishes in time. Given this assemble-to-order strategy, the question is '*how to improve the performance of the Parts Manufacturing Group?*'

With the help of the MPX software package, we compared a process-oriented cellular layout with a dedicated product-oriented cellular layout for the expected demands in 2001, 2002, and 2003 as stated in the business plan. We are primarily interested in the findings of the analysis rather than the discussion of how to precisely model both alternative configurations and their logistical parameters. Furthermore, systematically layout planning (SLP) issues also fall beyond the scope of this chapter, as transportation time and work-in-process buffer space is not an issue at Urenco Aerospace. Hence, the discussion of the modeling issues is omitted from this chapter.

From the available data (obtained from the ERP system and from the business plan; see Appendix 11), such as routings, processing times, and set-up times, both alternative production configurations have been specified. Table 2-3 presents the dedicated product-oriented layout with three subcells (as proposed by Urenco Aerospace's management): i) the wheels cel, ii) the large casting cell, and iii) the small casting cell. Table 2-4 presents the functional layout with four subcells: i) the 5-axis milling cell (including the 3-axis Mori-Seiki to cut the spline), ii) the 4-axis milling cell, iii) the grinding cell, and iv) the turing cell. In addition to the costs of relocating the machines, the dedicated product-oriented layout requires an extra capacity investment of Euro 400K and the functional layout requires an extra capacity investment of Euro 225K to meet expected demands. Furthermore, a preliminary MPX analysis showed that both configurations require at least 21 operators, with a slight understaffing of the Emag8/Index, the current Hermle, and the new Hermle. Recall, however, that management expects that the processing times for turning operations for the Emag8 are overestimated, i.e., they exhibit slack to buffer for technical problems, and that this is to be resolved with the replacement of the Emag8 with the new Index. Note that we accounted for possible overestimation of the processing times in the MPX analyses.

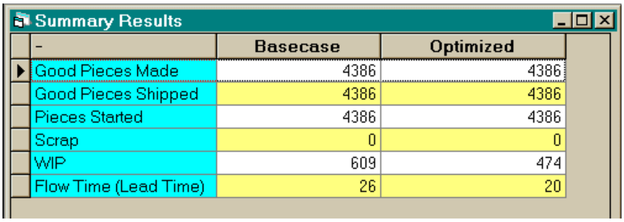
The final MPX analysis showed that the average lead-time in the optimal dedicated product-oriented layout is 20 days and the average lead-time in the optimal functional layout is 17 days; see Figure 2-6 and Figure 2-7 (p. 59). Hence, the average lead-time in the optimal functional layout is 18% less than in the optimized dedicated product-oriented layout. Furthermore, from these figures we observe that the average work-in-process is 21% lower in the functional layout than in the dedicated product-oriented layout. In other words, the product-oriented layout requires on average higher work-in-process levels to achieve the required output, at the cost of longer lead-times.

Cell name	Wheels cell (type *A* parts)	Large casting cell (type *B* parts)	Small casting cell (type *C* parts)
Number of operators	10 operators in 2/3 shifts	6 operators in 2-shifts	5 operators in 2-shifts
Machines	5-axis mill (Hermle) 5-axis mill (Dixi) 3-axis mill (Mori Seiki) Conventional lath (Deckel) Lath's (Spinner, Emag6 and Boley) Grinding mahine (Kellenberger) **New 5-axis mill (Hermle)** **New lath (chuck diameter 315)** Balancing and Overspeed testing	Lath (Emag8/Index) 5-axis mill (Wahli3) 4-axis mill (Wahli1) Conventional lath (Weiler) Technica	Lath (Emag6) 4-axis mill (Wahli2) Fehlman Jung **New Grinding machine (Kellenberger) required**
Capital investment of new machinery in Euro	225K		175K
Main products	Wheels Impellers Fans	Diffusers Housing inlets Nozzles	Valves

Table 2-3: Machinery allocation in the product-oriented cells.

Cell name	5-axis milling cell	4-axis milling cell	Grinding cell	Turning cell
Number of operators	6 operators in 2-shifts	4 operators in 2-shifts	3 operators in 2-shifts	6 operators in 2-shifts
Machines	Hermle, Dixi Wahli 5-as **New Hermle** Mori Seiki (3-axis; only used for the spline) Balancing and Overspeed testing	Wahli2 Wahli1	Jung Technica Kellenberger	Emag8/Index, Emag6 (2x) Spinner (Boley, Deckel, Fehlman)
Capital investment of new machinery in Euro	225K			
Main operations	Milling	Milling	Grinding	Turning

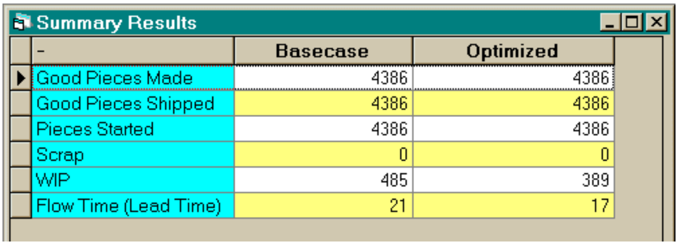
Table 2-4: Machinery allocation in the functional cells.



Summary Results

-	Basecase	Optimized
Good Pieces Made	4386	4386
Good Pieces Shipped	4386	4386
Pieces Started	4386	4386
Scrap	0	0
WIP	609	474
Flow Time (Lead Time)	26	20

Figure 2-6: Summary of the results for the dedicated product-oriented layout given the expected demand in 2001 (average flow time of internal production orders in days



Summary Results

-	Basecase	Optimized
Good Pieces Made	4386	4386
Good Pieces Shipped	4386	4386
Pieces Started	4386	4386
Scrap	0	0
WIP	485	389
Flow Time (Lead Time)	21	17

Figure 2-7: Summary of the results for the functional layout given the expected demand in 2001 (average flow time of internal production orders in days).

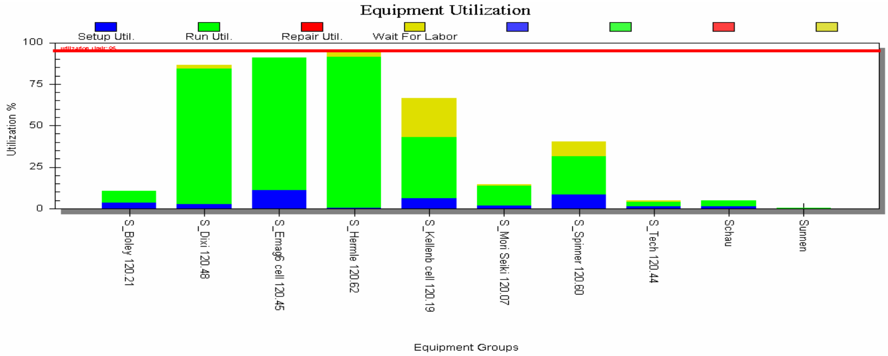


Figure 2-8: Machine utilization in the wheels cell (of the product-oriented layout).

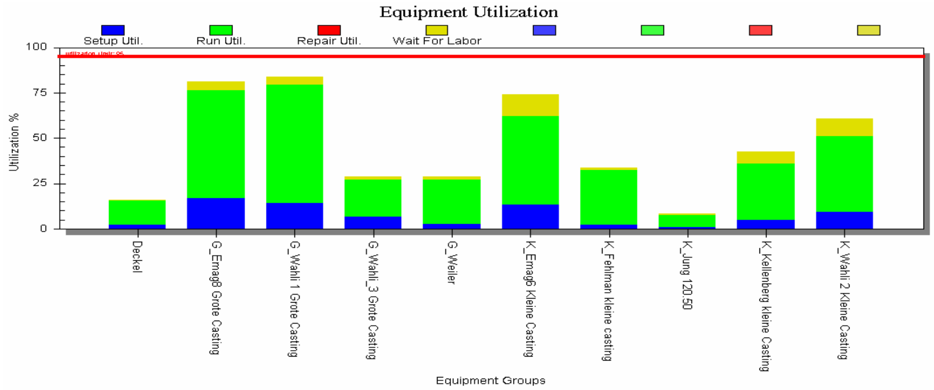


Figure 2-9: Machine utilization in the large casting cell and the small casting cell (of the product-oriented layout).

There is a simple explanation for these remarkable findings. The utilizations of the Hermles, the Dixi, and the Emag6 in the wheels cell (the most important cell in the dedicated product-oriented layout) lead to large queuing times, which lead to long lead-times and a high level of work-in-process inventory; see Figure 2-8. Note, however, that the high utilization of the Hermles is due to processing times, not set-up times.

In contrast, the 5-axis Wahli in the large castings cell is operating in a 2-shifts schedule and has a capacity utilization of less then 35%; see Figure 2-9. We conclude that the 'dedicated' product-oriented configuration is not well balanced. In particular, the dedicated wheels cell exhibits longer lead-times for the important part *A* types; see Table 2-5. Furthermore, from Figure 2-10 we conclude that machine utilization is lower in this functional layout than in the dedicated product-oriented cell as it can be better balanced.

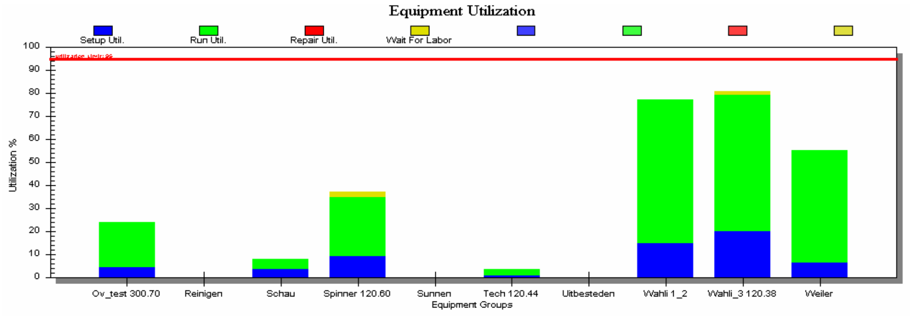


Figure 2-11: Machine utilization in a functional cellular layout.

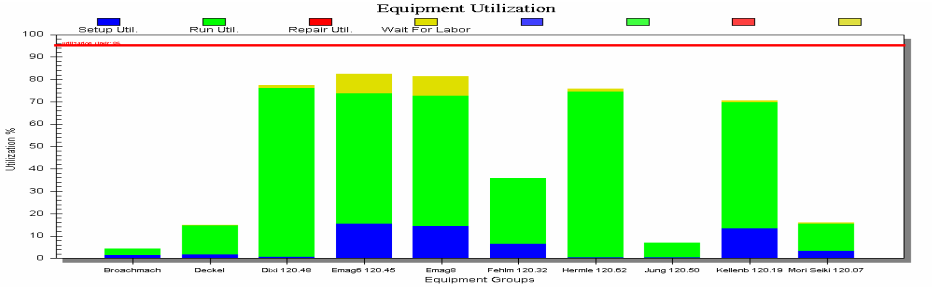


Figure 2-10: Machine utilization in a functional cellular layout (continued).

In addition, we conclude that for Urenco Aerospace, type *A* parts have longer expected lead-times in a product-oriented layout, even after significant set-up time reduction. This is primarily due to the high utilization rates of the Hermle and the Dixi; these are primarily determined by the metal cutting processing times, which is reflected in Table 2-5 and Table 2-6, in which we draw a comparison between the expected lead-times of type *A* parts and type *C* parts in the functional layout and the product-oriented layout, respectively. Furthermore, allowing inter-cell movement of the parts would greatly enhance the performance of the product-oriented layout, since machine utilization, work-in-process, and expected lead-times of type *B* parts in the large casting cell are considerable lower due to the low utilization of the 5-axis Wahli in the large casting cell.

	Functional		**Product-oriented**	
	Av. CT (days)	**Av. WIP (pieces)**	**Av. CT (days)**	**Av. WIP (pieces)**
Impeller1	10,7	3,5	25,5	8,3
Impeller2	9,6	1,8	24,2	4,5
Impeller3	11,4	15	26,5	43,5
Wheel 1	5,4	7,2	22	29,7
Wheel 2	3,8	2,7	6,7	4,7
Wheel 3	12,9	2,9	27,3	5,7
Fan	18,3	19,1	30	47,9
Impeller4 LC350	44,4	26,7	101,6	61
Impeller LC400	22,5	3,4	57,6	8,6
Wheel ATS	18,9	8	38,4	16,1
Wheelturbine BR700	36,2	51,8	59,1	84,6

Table 2-5: Expected lead-time and work-in-process of type *A* parts in the functional and the dedicated product-oriented layout for the expected demand in 2001.

	Functional		Product-oriented	
	Av. CT (days)	**Av. WIP (pieces)**	**Av. CT (days)**	**Av. WIP (pieces)**
Housing Exhaust ATS	22,8	8,7	25,7	9,8
Housing Exhaust BR700	36,9	10,6	11,4	16,3
Nozzle	24,4	3,9	22	3,5
Carrier assy	18,2	7	25	9,6
Shaft ATS	14,8	5,7	24,3	9,3

Table 2-6: Expected lead-time and work-in-process of type *C* parts (i.e., small castings) in the functional and the dedicated product-oriented layout for the expected demand in 2001.

These conclusions also hold for the expected demands in 2002 and 2003. The functional layout is not only more flexible than a dedicated product-oriented layout, resulting in lower expected lead-times due to balancing opportunities, it also requires less capital investments for new machines and the relocation of machines. Apart from the high utilization of the Hermle due to the balancing problems in the dedicated product-oriented layout, these results are mainly, but not entirely, dictated by the high set-up times, which cannot be easily reduced. In addition, the operator flexibility and cross-trained skills are too low to implement a product-oriented layout efficiently. This concurs with the conclusions of Eckstein and Rohleder [65] and Suresh and Gaalman [215] that dedicated cells only outperform the functional layout if set-up times are small and operators have been cross-trained.

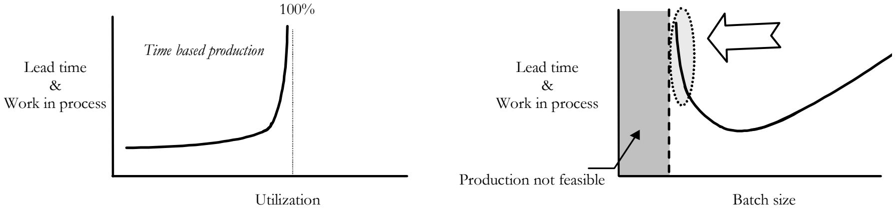


Figure 2-11: Relation between batch size, lead-time, and work in process (Suri [216]).

The results of the MPX analysis contrasts the expectations of Urenco Aerospace's management that the dedicated product-oriented layout is suitable to, ultimately, achieve one-piece flows. Indeed, additional analysis showed that in the wheels cell, an average set-up time reduction of more than 80% is required, while the Emag6 and both Hermles require a set-up time reduction of more than 90% to enable one-piece flow. Even then, lead-times may still be relatively long because of the high utilization rates of the Emag6, the Dixi, and both Hermles. In contrast, larger batch sizes may lead to an average lead-time reduction of 20%, since for both configurations a considerable part of the total machine utilization is the result of the large set-up times on the machines. For both configurations it holds that, if these set-up times cannot be drastically reduced, an increase of the batch sizes lead to more effective net metal cutting capacity. In other words, given the present large set-up times, batch sizes are too small; see Figure 2-11.

As Urenco Aerospace had attempted to initiate a suitable set-up time reduction program for quite some time, it was unlikely that set-up times could be drastically reduced in the near future. This is partly due to the high precision with which parts have to be set-up on machines. Set-up time reduction is possible, though, but at relatively high cost. As a result, it is unlikely to achieve one-piece flows in the dedicated product-oriented layout.

Another keynote is management's expectation that processing times are overestimated. However, if processing times turn out to be quite accurate, for instance due to (re)learning effects on the new machine, things are even worse. In that case, the functional layout offers more flexibility than the dedicated product-oriented layout. In a process-oriented layout with functional cells, part of the turning work can be transferred from the Emag8/Index to the Weiler or to both Emag6s. In the dedicated product-oriented layout there is only a fall-back arrangement to the Weiler, as both Emag6s are in another dedicated cell. Recall that inter-cell movement is forbidden in the dedicated product-oriented cellular layout.

A similar observation applies to the 5-axis milling operations. In a functional layout, all 5-axis mills can be used, where in the dedicated product-oriented layout a 3rd unmanned shift is required for both Hermles, since using the other 5-axis mills leads to inter-cell movements. In other words, for given expected demand and current logistical parameters, the functional layout offers more flexibility and balancing opportunities than the dedicated product-oriented layout.

2.3.4 Analysis of social and cultural issues

The migration from functional to cellular manufacturing is strongly influenced by the organizational culture, including such factors as underorganization, avoidance, lack of mutual respect, crisis urgency, and complacency [247]. Huber and Brown [120] state that human resource issues are equally important for the successful implementation of cellular manufacturing as technical issues. Other social and human factors are, for instance, the workers' personalities, the ability of groups to exercise control, and the assumed responsibility [193]. Indeed, a survey among cell users revealed that implementation problems were primarily related to people, not to technical issues [237]. In this case study, we also examine social and cultural issues: the impact of group size, cross-training and labor flexibility, employee resistance and skepticism, avoidance, rigid group boundaries, internal and external champions, and change agents.

Group size Although general group theory, and the socio-technical systems design theory in particular, prescribes that a group should comprise 5-15 employees [199], the Parts Manufacturing Group currently employs 18 operators, including the group leader that should both manage the group and give hand to some operations. However, his span of control is too large, as he needs all his time to manage the group. Hence, the group is too large from a socio-technical point of view, and a group split seems to be justified.

Cross-training and labor flexibility Operators at Urenco Aerospace are highly skilled technicians that perform the high-tech functional metal cutting activities in isolation. As a result, an open product-oriented layout is not directly compatible with the present skills (technical capabilities as well as interpersonal relations). Employees are functionally trained and supported by mechanical engineers to optimize processes on a micro-level. As mentioned before, the culture of Urenco Aerospace is still characterized as one that matches the traditional hierarchical organization, where shop floor employees still rely on support group members for production planning and control issues, and simultaneously are critical of each other as well as on support group members, mechanical engineers, and management. This signals a culture of *avoidance* where organizational members shun responsibility and avoid the possibility of being blamed; they do not want to make decisions, take action, or accept risks [247]. Hence, the migration into a dedicated product-structure can be hampered by employee resistance as well as by the risk that workers exaggerate on inspecting and criticizing their peers. In addition, one employee noticed that management had a hidden agenda—the actual objective was to uncover worker inefficiency. This states the lack of mutual respect and trust between employees and management, which also hampers the migration into dedicated product-oriented cells [247].

Employee resistance and skepticism Another cultural factor identified by Yauch and Steudel [247] is *conversion*, i.e., the employees and management do not appreciate each other's contributions and/or believe that the others are dishonest; employees respond to this perceived lack of respect by doing the least amount of work necessary to retain their jobs. These issues were confirmed by empirical work of Wemmerlöv and Hyer [236] in which employee resistance and skepticism were cited as a major problem implementating dedicated cells.

We asked several operators about their opinion on, and preference for a specific type of manufacturing layout. In general, operators are not very confident in the final decision of Urenco Aerospace's management—they all indicate to attach great importance to a clear decision along with arguments and a solid implementation plan. In addition, some employees are happy with and accept current methods, practices, and conditions, which indicate a *complacency*-related cultural factor that may hamper the conversion to new structures unless there is a crisis urgency [247]. The few generalists and the rookies at Urenco Aerospace prefer the product layout, while the specialists prefer the layout with process-oriented cells.

Champions and change agents Potential adopters of an innovation are aided in evaluating an innovation if they are able to observe it in use under conditions similar to their own. Rogers [191] states that such an observation often occurs naturally, when one individual views another one's experience in using the innovation. However, such an observation may also be put forward by an internal change agent or an external project champion. Change agents may try to increase the observability of an innovation with the help of internal demonstrations and external meetings to speed up the rate of adoption. The innovation may also be imposed by external stakeholders, for instance the customers or competitors. This also holds for a new manufacturing layout.

Within Urenco Aerospace there are several proponents of the product-oriented layout. These proponents act as internal change agents, and they are reinforced by the preferences of the main customer (although some interviewees state that the latter is made-up by the change agents). The operations manager also advocates the product-oriented layout, since it was expected that performance of type A parts would be increased significantly. More thorough investigations indicated that it was common practice of planners and shop floor workers to give type A parts priority over the other part types because of the one-sided management attention for type A parts.

The handicap of the presence of internal change agents is that some activities or requests, for example the temporal movement of a machine or the technical preparation of an alternative route, are not carried through, as it would not match the specific layout of their preference. It is this political pressure of change agents and the like that influences the operations manager, especially when the operations manager is already inhibited to search for alternatives because of his preferences.

2.3.5 Follow-up visits (2003)

Until summer 2003, we visited Urenco Nederland BV (and consequently Urenco Aerospace) regularly. It turned out that management had decided to strive for a product-oriented layout in the medium term; not at once, since the plan was approved to build a new production hall for Urenco Aerospace. The reason for choosing the product-oriented layout with three dedicated cells was the perceived match between this layout and the stability of the order book and future demand. It also matched the culture better, it would be more transparent for workers involved and, accordingly, easier to manage and to control. In contrast, next to the use of SAP R/3 and several spreadsheets models (particularly by employees in the Operational Support Group but also in the teams), management had also chosen to adopt and implement a low-end APS, i.e., an advanced multi-resource scheduling system, to gain even more insight in the logistical processes involved. This system was implemented in close cooperation with the planner from the Operational Support Group as the key-user; it was also the objective, or at least management left open that possibility, the use in each cell in the future. However, it remained unclear how this had to be achieved.

Soon after, however, the catastrophe of 11 September 2001 became reality, affecting the entire aerospace industry; it certainly harmed the business operations of Urenco Aerospace. Demand declined significantly and accordingly, management of Urenco Aerospace decided to produce centrifuge parts. It still produces a number of centrifuge parts nowadays. Consequently, a migration into really dedicated product cells has not been taken place.

In addition, numerous staff changes have occurred on various levels. One team leader was replaced; another team leader decided to leave; the operations manager retired. The new operations manager has completely different ideas about production management, the working of teams, and the use of an APS system in particular. Just a few months after the APS system properly functioned with respect to (i) the quality of the data extracted from SAP R/3, (ii) the implementation of customer specific planning rules and extra customer specific system requirements, and (iii) exhaustive training on the job, it was decided to shelve the system, and instead change over to a more simple production control system called ‘visual manufacturing’, which strongly resembles the idea of kanban (i.e., visual card) control [219].

2.4 Discussion and lessons learned

2.4.1 Discussion of the planning and control issues

The production planner, a proponent of the APS system, assured us that the system functioned very well, even in a cellular environment. It forced both management and team workers to clearly communicate on the actual and future status of the manufacturing system, i.e., order progress and work-in-process levels. In contrast, the new visual manufacturing control system gives the teams more freedom and autonomy, but also more problems, since teams are given the responsibility to complete a specific planned amount of products each period, without clearing all constraints and bottlenecks. Since there is much less transparency in real internal delivery dates, team leaders and team workers responsible of planning more frequently meet for production planning meetings to be assured that specific orders will be delivered on-time.

In contrast, the APS system graphically displayed expected completion times; if disturbances occurred, the impact on specific orders became immediately clear. However, since it required tracking and tracing of orders to keep schedules up-to-date, it forced teams to work properly according to agreements. However, the general opinion at Urenco Aerospace is that an APS system is too prescriptive, and accordingly too restrictive in drawing upon the knowledge, experiences, and flexibility of shop floor workers. On the other hand, it is acknowledged that with the present coordination concept, there is no prevention for covering up sloppy work coordination, leaving the teams with impracticable orders.

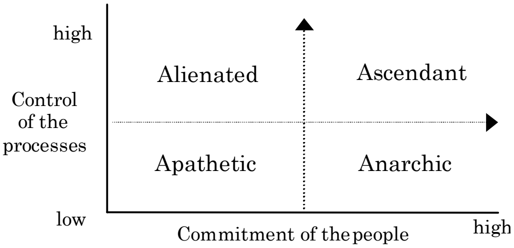


Figure 2-12: Typology of Wickens [241].

During our active participation of the SAP R/3 implementation project, we experienced that production teams have an urgent need of information on future internal deliveries and the reliability thereof, since teams are held responsible of their delivery performance even when other internal or external suppliers deliver the products too late. Team leaders and workers responsible of planning assumed that full insight in long planning horizons was necessary to promise commitment on the completion of future workload in their teams. In other words, despite of the low rate of change, internally as well as externally, there are quite some planning and control requirements in the non-dedicated product-oriented cellular layout because of various interdependencies, also between the Operational Support Group. The ERP system insufficiently provides (i) insight in the actual status of the shop floor, and (ii) accurate information on future internal deliveries, while important planning and control decisions are taken by the MRP planner in the Operational Support Group. In fact, the introduction of SAP R/3 implied that shop floor workers had to do more, mostly trivial, administrative tasks, while important planning decisions had to be taken by support group employees. An important implication of this situation is that orders are planned and released again based on MRP schedules made by the planner in in the Operational Support Group. There is no system to support commitment-based management of the shop floor teams, to create an ascendant organization, see Figure 2-12, in which simultaneously the processes are properly controlled and the commitment of the people involved is high.

2.4.2 Lessons learned

This case demonstrates the difficulty to obtain consistency, which is the main prerequisite for effectiveness [100]. *Internal consistency* indicates the consistency within the manufacturing structure and the organization of secondary processes. At Urenco Aerospace it appeared difficult to organize the relationship between the characteristics of the environment (and more specifically the level of uncertainty of the Product/Market/Technology characteristics) and the so-called organizational arrangements to coordinate the processes and activities consistently. These formal arrangements should constitute a consistent manufacturing structure and organizational structure including job specialization, behavior formalization for instance by individual competence management, unit grouping, and lateral linkages [169]. It appeared difficult to choose the appropriate manufacturing structure (i.e., layout) and corresponding locus of production planning and control and corresponding systems. Simultaneous with the decision for the product-oriented layout with reduced production planning and control complexity, management had, at first, chosen to adopt and implement an APS system; and subsequently a more simple production control system. It turned out that informal arrangements are even more important than structure, systems, and tools; informal arrangements refer to aspects of the organizational culture that constitute the key values, beliefs, understandings and norms shared by members of the organization. It is demonstrated that the change of the manufacturing structure requires complementary efforts in organizational and individual development including such factors as avoidance, mutual respect, and complacency [247].

External consistency indicates the consistency between the manufacturing arrangements (i.e., manufacturing layout, production planning and control structure en tools) and the environment of the firm in order to augment competitiveness. At Urenco Aerospace there was no consensus about the impact of the environmental conditions on the manufacturing layout and corresponding arrangements –this is a well-known deficiency of the socio-technical design theory– it was unclear how to obtain external consistency in the relationship between Product/Market/Technology-uncertainty and the locus of production planning and control; and ultimately what type of production planning and control system is appropriate. Hence, exploratory research into the relationship between Product/Market/Technology characteristics and the use of specific production planning and control tools (see Chapter 4) is, therefore, justified.

It turned out that exactly the non-technical dimensions of an innovation influence its rate of adoption. This became evident after the impassively slow acceptance of our MPX results: a dedicated product-oriented layout does not necessarily outperform its process-oriented counterpart. Indeed, it is the level of consistency between the manufacturing arrangements and the environmental characterics that counts. In this thesis, we therefore study the impact of PMT-uncertainty on the locus of production planning and control (Chapter 3), the impact of PMT-uncertainty on the use of various production planning and control tools (Chapter 4), and the impact of organizational and innovational factors on the adoption of APS systems (Chapter 5). In addition, we investigate issues of operations management sophistication, and communication channels in relation to APS adoption for firms with a cellular layout versus traditionally organized firms (Chapter 6). Furthermore, we explore the differences in PMT-uncertainty, the extent of customer influence on the productmix, customer's vendor-switching possibilities, and the focus on strategic priorities between firms with a cellular layout and firms with a functional layout (Chapter 7). Finally, in Chapter 8 we study the impact of line management's support of individual competencies on financial performance, and the relation between line management's support of individual competencies and the firm's strategic focus on particular competitive priorities related to agile manufacturing.

3 PMT-uncertainty and the locus of production planning and control

In today's uncertain manufacturing environments firms must be flexible and agile. In theory, an effective strategy to gain flexibility and agility is to decentralize by implementing resource groups in a product-oriented manufacturing setting [212]. This way, problems can immediately be solved locally, in and by the specific resource group, when the problem arises [141][164], as it facilitates personal mutual adjustments and face-to-face interactions (i.e., production planning and control meetings).

The more uncertain the environment, the more likely the firm's operational decision structure may have a decentralized hierarchy [44][125], and the higher the frequency of these production planning and control meetings [81]. However, it remains unclear which PMT-uncertainty dimensions (i.e., complexity, rate of change, and information deficiency) impact the locus of production planning and control most. As a result, it is of interest to explore the extent to which these PMT-uncertainty dimensions determine the level of decentrality of the locus of production planning and control and the frequency of production planning and control meetings in discrete parts manufacturing firms. We aim to provide empirical content to and detail the present theory on the relationship between PMT-uncertainty and the locus of production planning and control (i.e., the locus of control) by exploring internal and external environmental differences for phenomena like *complexity* and *rate of change* of discrete parts manufacturers with decentralized locus of production planning and control versus those who have more central locus of production planning and control.

The plan of this chapter is as follows. In Section 3.1, we discuss the relationships between the constructs *complexity* (i.e., variety), *rate of change*, *information deficiency*, *locus of production planning and control*, and *frequency of production planning and control meetings*, and formulate our propositions. (Note that in this thesis, we write constructs in italic). We distinguish between the complexity and rate of change of the external environmental characteristics that cause uncertainty, i.e., the market perspective of uncertainty, and the complexity and rate of change of the internal environmental characteristics that cause uncertainty, i.e., the product and operations technology perspective of uncertainty. In Section 3.2, we discuss the research method of this study, including the development of a questionnaire and the statistical procedures to validate the propositions. We discuss the sample, the respondents, and the analysis of late/non-response bias. In Section 3.3, we discuss the operational definitions (and corresponding reliability analysis based on Cronbach's alpha and confirmatory factor analysis) of all constructs. In Section 3.3.5, we present the results from a statistical analysis of the hypothesized relationships between the unobserved constructs. In Section 3.4.1, we present a structural equations model (i.e., an extended path analytic model). In Section 3.4.2, we present an alternative structural equations model with factors obtained from an exploratory factor analysis for all items. Subsequently, we briefly discuss differences in means of firms with a high score versus a low score on these factors (i.e., complex − non-complex situations, dynamic − stable situations, and the level of information deficiency). Finally, in Section 3.5, we end this chapter with a brief discussion of the results, managerial implications, and conclusions.

3.1 Propositions

3.1.1 Uncertainty and PMT characteristics

Hatch [97] states that organizations traditionally consider uncertainty as a property of the environment resulting from two powerful forces: (environmental) complexity and rate of change. Complexity refers to the number and variety of the elements in an environment characterized by the major Product/Market/Technology (PMT) combinations. In other words, if we decompose complexity, we may identify various elements of the PMT combinations that make the situation appear complex. Note that in this chapter, we study PMT-uncertainty from a rationalist perspective. Consequently, the complexity of a specific situation is determined by [75]:

- The size of the situation as measured by the number of elements that are recognized (e.g., the number of products, customers, orders, suppliers, resources, and so on).
- The number of interactions between the elements (e.g., the entanglement between departments and cells, or the entanglement between the manufacturer and suppliers).
- The degree in which relationships between elements are linear or nonlinear.

We do not consider complexity caused by time-dependent patterns between and within the PMT combinations as this can be studied only by exhaustive longitudinal research projects. Furthermore, we do not consider complexity caused by non-linear relationships between constructs as these types of issues are extremely difficult to model.

In this chapter, we let the manufacturing environment consist of the *external* manufacturing environment, i.e., the market, and the *internal* manufacturing environment, i.e., the manufacturing system, which may be characterized by the products that have to be manufactured, and the (operations) technology to manufacture these products. In fact, the product is boundary spanning between the market characteristics and the operations technology characteristics. In general, complexity of the operations technology originates mainly from the division of labor. The manufacturing system then becomes a complex mutually dependent network of workers and machines among which various interactions occur. As the complexity of a system increases, the control of the system becomes harder. Each resource has to be aligned to perform the manufacturing tasks. This can be done well only if the resources and the relationships between these resources are coordinated in a timely, complete, and reliable fashion. In addition, the challenging task of production planning and control to cope with this internal complexity is complicated by external complexity.

Numerous authors claim that the construct *rate of change* in the PMT characteristics determines PMT-uncertainty more than the construct *complexity* [44][125][169] and that higher rates of change advocates organic decentralized organization structures and corresponding locus of production planning and control. As a result, the rate of change of the environmental elements (i.e., how rapidly these elements change) is even more important for controllability issues, as it is an indicator of the validity of the information on the status of the elements. The higher the *rate of change*, the more momentary available information is. This is acknowledged in the information perspective of uncertainty, where the lack of information about tasks before actually performing these tasks is the key issue [62][81].

In this chapter, we also adopt the information perspective of uncertainty, but only consider its rationalist aspects. That is, we do not consider perceived uncertainty due to important cultural, human nature, personality characteristics, individual competencies, and the incorrectness of the point of reference of the decision-making unit. Hence, we operationalize the higher-order construct *PMT-uncertainty* by *complexity*, *rate of change*, and *information deficiency*. In other words, the higher the level of *complexity* of the characteristics of the dominant PMT combination, the higher the level of *PMT-uncertainty*; the higher the *rate of change* of the characteristics of the dominant PMT combination, the higher the level of *PMT-uncertainty*; and the higher the levels of *information deficiency*, the higher the level of *PMT-uncertainty*.

3.1.2 PMT-uncertainty and the locus of production planning and control

To analyze the relationship between the *locus of production planning and control* and *PMT-uncertainty* as a property of a specific manufacturing environment, we adopt the definition of production planning and control of Bertrand et al. [31] as the coordination of supply and production tasks in manufacturing systems to achieve specific delivery flexibility and delivery reliability at minimum costs. This definition provides directions for appropriate operational definitions of the construct *locus of production planning and control*, as it is closely related to the locus of decision-making [176][182]. Nahm et al. [176] define the locus of decision-making as the degree to which decisions are made higher or lower in the organizational hierarchy. Note that this perspective concurs with the propositions of Katz and Kahn [125] and Mintzberg [169] who stipulate that the more uncertain the manufacturing situation is, the more decentralized the locus of production planning and control will be. Firms operating in an uncertain environment should delegate decisions to the level where workers may quickly adjust to the changing situations [60]. As a result, we claim that *PMT-uncertainty* is positively related to the decentrality of the *locus of production planning and control*. That is, the higher the level of *complexity* is, the more decentralized the *locus of production planning and control* is; the higher the level of *rate of change* is, the more decentralized the *locus of production planning and control* is, and the more *information deficiency* there is, the more decentralized the *locus of production planning and control* is. As a result, we have the following propositions.

PROPOSITION 3-1: *The higher the level of complexity is, the more decentralized the locus of production planning and control is.*

PROPOSITION 3-2: *The higher the level of rate of change is, the more decentralized the locus of production planning and control is.*

PROPOSITION 3-3: *The more information deficiency there is, the more decentralized the locus of production planning and control is.*

3.1.3 PMT-uncertainty and the frequency of planning meetings

A well-known type of lateral adjustment to cope with uncertainty is the organization of prearranged planning meetings [81], where the frequency of these meetings generally depends on the levels of PMT-uncertainty. In addition, Nahm et al. [176] show that organizations with a high level of time-based manufacturing practices have communication levels that are fast, easy, and abundant, where the level of communication is operationally defined by items, such as ‘lots of communications are carried out among managers’. This leads to the following propositions.

PROPOSITION 3-4: *The higher the level of complexity is, the higher the frequency of the production planning and control meetings is.*

Proposition 3-5: *The higher the level of rate of change is, the higher the frequency of the production planning and control meetings is.*

Proposition 3-6: *The more information deficiency there is, the higher the frequency of the production planning and control meetings is.*

3.2 Research method

The propositions of this study are validated by means of survey research in the Dutch discrete parts industry. The analytic procedures in this study include the calculation of descriptive statistics, reliability analysis, factor analysis (exploratory and confirmatory), and multi-item path analysis (i.e., structural equations modeling) for which we use the statistical software packages SPSS 11 and AMOS 4.0, respectively. For detailed background information on survey research and used statistical methods, we refer to the appendix (A10).

Although most of the items in this study are Likert-type ordinal-scaled variables, for which we assume that they fully represent their underlying continuous variables–i.e., we treat them as interval variables, we apply parametric univariate and multivariate procedures. This is quite common in the survey literature [134], if the kurtosis and the skewness of each variable are smaller than 7 and 2, respectively [238]. The variables used in this study satisfy this rule. A classical parametric procedure to study the properties of measurement scales and the items that make them up is Cronbach's alpha. Hence, reliability is operationalized as internal consistency, which is the degree of intercorrelation among the items that make up a scale [181]. After this step, three possibilities exist—note that this procedure is consistent with other survey research in operations management [192]. First, a scale is accepted straightaway if it has a reasonably strong alpha value (at least .60). Second, scales with alpha values varying between .45 and .60 are further analyzed to determine whether alpha can be improved by the removal of one or more items. However, we proceed our analysis with care if alpha values are around .55, and we investigate the measurement of the scale in a full measurement model of all primary constructs with confirmatory factor analysis as we would like to have instruments that are both reliable and valid—there is, however, no reason to expect that results from validity and reliability assessments will always coincide.

Furthermore, we aim to develop and to validate second-order measurement models (i.e., confirmatory factor analysis) of *complexity* and *rate of change*, which is evaluated like any other SEM model, using the goodness of fit measures χ^2/df ratio, CFI, NFI, TLI, and RMSEA; for details on these fit indices, we refer to the appendix (p. 255). By convention, NFI values below .90 indicate a need to respecify the model. Hence, we require NFI > .90. In addition, we require TLI > .95 and indicate models with RMSEA < .065 to have good fit, and .1 > RMSEA ≥ .065 for adequate fit [46][113][114][135].

There is no point in proceeding to the structural equations model until *the researcher* is convinced that the measurement model is valid. Kline [135], therefore, urges SEM researchers always to test the pure measurement model underlying a full structural equation model first, and if the fit of the measurement model is found acceptable, then to proceed to the second step of testing the structural equations model by comparing its fit with that of different structural equations models (i.e., with models generated by trimming or building, or with mathematically equivalent models). In this thesis, we follow Kline's recommendation.

3.2.1 Questionnaire development

In this study, we use constructs that cannot be measured directly (i.e., latent variables); hence, they have to be operationally defined, by one or more observed items. Content validation was assessed through (i) the theoretical basis for the items in literature, (ii) the discussion of the preliminary drafts of the questionnaire with academic scholars, and (iii) pre-testing of the preliminary draft of the questionnaire in five manufacturing firms. Furthermore, we followed the guidelines for writing questions presented by Fink and Kosecoff [71]. For all questions in the questionnaire, we used 5-point scales as much as possible to facilitate the use of statistical analysis without recoding. Pre-testing the questionnaire indicated the appropriateness of the 5-point scales for the respondents. However, since we aimed to prevent from situations that a respondent decides to not fill out an answer or guess an answer because he does not know the answer, we decided to include the option 'Not known' occasionally. Note, however, that this option also provides an easy escape for more difficult questions. The same holds for the option 'Not applicable', which we also occasionally used. Furthermore, we occasionally allowed the respondents to give multiple answers. In all, we developed a comprehensive questionnaire with 111 items to represent all constructs and to check response bias and authenticity.

3.2.2 Population and sample selection

The data for this study were collected through a comprehensive mail survey among Dutch discrete parts manufacturing firms listed in a commercial database for manufacturing firms with more than 20 employees. The manufacturing firms selected belonged to International Standard Industrial Classification of all Economic Activities (ISIC) codes 20 and 27…36. These categories include firms that manufacture basic metals and fabricated metal products, (electronical) machinery, equipment and apparatus and products of wood. If the ISIC classification for a firm could not be determined, because the respondent had failed to identify his firm, or filled out another non-process industry ISIC code, the firm was classified as 'other'. Respondents from firms in the process industry were removed immediately. In 2002 there were in total 20,625 Dutch firms listed under the ISIC codes under study. However, according to the central bureau of statistics (CBS) there were only 5020 firms with more than 20 employees; i.e., 75% of the Dutch firms (with above mentioned ISIC codes) have less than 20 employees. Hence, the population under study is 5020 firms. We randomly phoned 697 of these firms to inquire their willingness to participate in this study, where we initially asked for a Production and/or Operations Manager. Almost 57% firms agreed to participate, so a package containing a cover letter, a questionnaire, and a pre-paid reply envelope, was sent to 394 firms. All respondents were assured of confidentiality. 74 respondents returned the questionnaire within 5 weeks, so there were 320 initial non-respondents. We then decided to phone the firms of which we suspected not to have returned the questionnaire to inquire whether they had sent back the questionnaire yet. If not, we asked again to still fill it out and return it. 51 questionnaires returned without (re)contacting (i.e., five weeks after initial sending). 77 non-respondents could not be re-contacted, or were not willing to be contacted by phone again. 48 firms said that, at second thought, they would not fill out the questionnaire, while 37 firms said they already had sent it back (which could be true because respondents were offered the option to fill out the questionnaire anonymously) and 54 firms indicated that they still would send it back. From this group of 202 firms, we had to resend the questionnaire to 23 firms because they had misplaced the questionnaire. In this second round, 83 firms eventually returned the questionnaire.

In all, 208 questionnaires were returned. However, two firms were excluded from the final sample because they proved to be no discrete manufacturers after all. Hence, we have 206 useful responses and a final response rate of 29.6% of the 697 initially phoned firms, which is quite acceptable compared to other mail surveys reported in literature [140][161].

	Sample		**Population**	
number of employees	**frequency**	**%**	**frequency**	**%**
< 20	0	.0%	0	.0%
20 - 49	39	19.0%	2805	55.9%
50 - 99	73	35.6%	1115	22.2%
> 99	93	45.4%	1100	21.9%
Total valid	**205**	**100.0%**	**5020**	**100.0%**

Table 3-1: Comparison of the number of employees (>20 employees) of the sample and the population.

3.2.3 Respondents and non-response analysis

Respondents A comparison of the composition of the 206 responding firms with the composition and characteristics of the entire population (according to CBS [i]) gave no reason to expect bias towards any particular branch, according to the ISIC codes, of discrete parts manufacturing industry. However, comparison of the 206 responding firms with the firm characteristics for the number of employees of the entire population indicates that small firms are somewhat underexposed; see Table 3-1. This is, however, of no burden, as small firms are generally managed centrally by one factory manager, often the founding entrepreneur, independent of the level of PMT-uncertainty. Hence, we claim that for small firms the type of decision structure is not an appropriate item of the production planning and control requirements of that specific situation. From this perspective, we actually appreciate the overrepresentation of medium-sized and larger firms. Our sample reflects the firms with more than 50 employees in the entire population fairly well; see Figure 3-1.

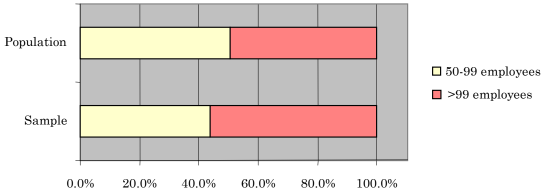


Figure 3-1: Comparison of the number of employees (>50 employees) of the sample and the population.

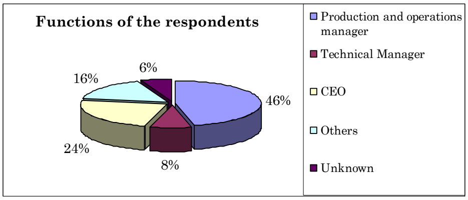


Figure 3-2: Functions of the respondents.

At least 46% of the respondents were Production or Operations Managers. Remember that the letter that accompanied the questionnaire emphatically asked the survey be completed by a Production and/or Operations Manager that was responsible of both manufacturing management and had knowledge of production planning and control issues. However, some firms decided that the responsibility for production and/or operations management lied with the general manager, the technical manager, the quality manager, or even the financial director (the latter types are grouped under others; see Figure 3-2).

Non-response bias We assumed the group of late-respondents (81) to be representative of the group of non-respondents for purpose of non-response bias tests. We compared these late respondents with the 74 early-respondents on 1) branch of industry, 2) number of employees, and 3) organizational turnover. This did not reveal any statistically significant differences.

3.3 Operational definitions

3.3.1 Locus of production planning and control

Numerous researchers have developed measurement items for decentralization of decision-making [78] [168][176]. Vickery et al. [232] measured decentralization by having the respondents select the level in the organization that had the authority to make certain decisions. The locus of production planning and control of discrete parts manufacturers is generally a hierarchical one, in which the decision function is delegated to various levels in the locus of production planning and control. This concurs with the planning hierarchy proposed by Anthony [4] and Thomas and McClain [224]. As a result, we operationally define the decentrality of the *locus of production planning and control* with the items 1) 'decision level of due date quoting', 2) 'decision level of order acceptance', 3) 'decision level of capacity planning of departments', 4) 'decision level of resource loading', 5) 'decision level of sequencing', 6) 'decision level of dispatching', and 7) 'decision level of material availability check'. The corresponding answering options are: i) central by management, ii) central by a staff department, iii) decentral by a production leader or teamleader, and iv) decentral on the shop floor by an operator. We recoded the values of these items into values of a 5-points scale. The Cronbach's alpha is .7228, which indicates that the measurement of this construct is quite accurate; see Table 3-3. However, we also note from Table 3-3 that the correlation coefficient between the items 'decision level of order acceptance' and 'decision level of due date quoting' is much higher ($r_{i\,=}$ .4856) than the correlation coefficient between the items 'decision level of order acceptance' and any other item. We, therefore, suspect that these two items measure a different dimension of the construct *locus of production planning and control* than the other items in the scale. This is confirmed by a factor analysis (KMO = .683, p_{BTS} = .000), from which we obtained two factors with eigenvalues greater than 1 and small construct correlation coefficients (r_f = .024); see Table 3-2. In other words, the seven items measure two separate decentrality-related constructs, which we indicate as *planning decisions decentrality* and *customer-order processing (COP) decisions* *decentrality*. Note that with the values of Cronbach's alpha of .7302 and .6448, respectively, these operational definitions are sufficiently reliable.

Variables (items)	***planning decisions decentrality***	***COP decisions decentrality***
decision level of order acceptance		.463
decision level of due date quoting		.989
decision level of capacity planning of departments	.511	.352
decision level of sequencing	.663	
decision level of resource loading	.881	
decision level of dispatching	.409	
decision level of material availability check	.368	
Cronbach's alpha	.7302	.6448
planning decisions decentrality	.831	
COP decisions decentrality	.024	.995

Table 3-2: Rotated factor matrix (varimax; cutoff = 0.3) (*locus of production planning and control*) and factor score covariance matrix.

3.3.2 Frequency of the production planning and control meetings

To operationally define *frequency of the production planning and control meetings,* we use the items 1) 'frequency of planning meetings between managers on production management level', 2) 'frequency of planning meetings between production management and team leader/sector manager', 3) 'frequency of planning meetings between planner(s) and representatives of groups or functional departments', and 4) 'frequency of planning meetings between production manager and planner(s)'. The corresponding answering options are: 1 = once a month, 2 = once per two weeks, 3 = once a week, 4 = twice a week, 5 = every day. With a value of .6391 for Cronbach's alpha (and one factor obtained from a factor analysis on these items), this operational definition is sufficiently reliable; see Table 3-3.

3.3.3 Complexity of the PMT characteristics

We discuss our operational definitions of the PMT characteristics that affect complexity. Mintzberg [169] states that an organization's environment can range from *simple* to *complex* (i.e., the complexity dimension) and from *integrated* to *diversified* (i.e., the diversity dimension). The complexity (i.e., number of elements) of the market affects production planning and control through the comprehensibility of the work to be done. This external environment of organizations consists of several stakeholders: customers, material, hardware- and software suppliers, competitors, financiers, the government, labor markets, and unions.

The customers and suppliers of the primary products are directly included (competitors are indirectly included) in the set of relevant market elements. On the input side of the manufacturing system, we distinguish *supplier complexity*; on the output side (i.e., demand side), we distinguish *customer order complexity*. In other words, a complex external environment (i.e., the market) forces the organization to have a great deal of sophisticated knowledge about customers and suppliers.

Customer order complexity To operationally define *customer order complexity*, we use the items 1) 'size of customer orders', 2) 'type of orders', 3) 'predictability of demand of specific orders', and 4) 'number of orders per month'. Table 3-4 shows that the value of Cronbach's alpha is .7105, which indicates that this operational definition is fairly reliable. However, we already like to mention that the item 'predictability of demand of specific products also correlates with *information deficiency*. As the removal of this item only leads to a slight decrease of the value of Cronbach's alpha, we removed this item from the scale to obtain orthogonal factors as much as possible.

Supplier complexity Other important aspects of the external environment are the characteristics of suppliers of materials and resources. Accurate supply as for time, volume, place, and specification is essential for a firm to be able to conduct its transformation process and to produce output in the same terms. The number of elements and the comprehensibility of these elements on the input side of the system indicate supplier complexity. Hence, we operationally define the construct *supplier complexity* by the items 1) 'number of suppliers', 2) 'number of supplied parts and components', and 3) 'number of production steps subcontracted', for which we obtain a value of .5434 for Cronbach's alpha (which is rather low); see Table 3-4.

In addition, we observe that the value of Cronbach's alpha can be increased by removing the item 'number of production steps subcontracted'. However, this leaves us with only two items for this construct, which increases the possibility of an empirically underidentified CFA measurement model. Hence, we postpone the decision whether to remove 'item 3' from this operational definition until the analysis of the full measurement model of the *complexity* constructs.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$

Construct	Cronbach's alpha	Variables (items)	Pearson correlation (two-tailed)							Mean	SD	Alpha if item deleted
frequency of production planning and control meetings ($N = 185$)	.6391	on production management level	1.000							3.1946	1.2225	.6155
		between management and team leader	.432**	1.000						3.7514	1.0998	.4633
		between planner and repr. of group / funct. dpt.	.160	.446***	1.000					4.0432	1.2633	.5902
		between production manager and planner	.230	.318**	.286*	1.000				3.6757	1.1528	.6036
production planning and control structure ($N = 183$)	.7228	decision level of order acceptance	1.000							1.6721	.7151	.7162
		decision level of due date quoting	.487***	1.000						1.9235	.6482	.6952
		decision level of capacity planning of departments	.144	.382	1.0000					2.1858	.7324	.6687
		decision level of sequencing	.122*	.168	.343***	1.000				2.5191	.6564	.6898
		decision level of resource loading	.142	.126*	.440***	.578***	1.000			2.5683	.6910	.6649
		decision level of dispatching	.263*	.193	.291***	.207**	.329***	1.000		2.2568	.6650	.6930
		decision level of material availability check	.106	.233	.294**	.196*	.311**	.307*	1.000	2.4098	.6941	.7029
COP decisions decentrality ($N = 197$)	.6448	decision level of order acceptance	1.000							1.6751	.5768	-
		decision level of due date quoting	.476***	1.000						1.9289	.5847	-
planning decisions decentrality ($N = 187$)	.7302	decision level of capacity planning of departments	1.000							2.1979	.7394	.6736
		decision level of sequencing	.372***	1.000						2.5294	.6333	.6835
		decision level of resource loading	.469***	.592***	1.000					2.5722	.6791	.6271
		decision level of dispatching	.328***	.241**	.364***	1.000				2.2620	.6727	.7064
		decision level of material availability check	.302**	.206*	.319**	.320*	1.000			2.4118	.6692	.7212

Table 3-3: Operational definition of *locus of production planning and control* and *frequency of planning and control meetings*.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$

Construct	**Cron-bach's alpha**	**Variables (items)**	**Pearson correlation (two-tailed)**								**Mean**	**SD**	**Alpha if item deleted**
customer order complexity ($N = 194$)	.7105	size of customer orders	1.000								3.2113	1.3852	.5895
		type of orders	.539***	1.000							3.1701	.9854	.6205
		predictability of demand of specific orders	*.318***	*.346*	*1.000*						*3.5258*	*.8768*	*.7051*
		number of order per month (inv)	.456***	.381**	.299***	1.000					2.8557	1.3770	.6556
product mix complexity ($N = 170$)	.6526	number of product families	1.000								2.8294	1.1411	.7273
		number of variants per product family	.174**	1.000							3.1059	1.6749	.5457
		number of different end-products	.391***	.574***	1.000						3.6059	1.5203	.2782
supplier complexity ($N = 200$)	.5434	number of suppliers	1.0000								2.9700	1.0700	.3692
		number of supplied parts and components	.431**	1.000							3.0450	1.4641	.3088
		number of production steps subcontracted	.183**	.239***	1.000						2.9800	1.0512	.5819
operations technology complexity ($N = 124$)	.6410	entanglement of production steps	1.000								4.2258	.6848	.6262
		entanglement of departments	.161**	1.000							4.5645	1.1910	.5882
		entanglement of machines	.335***	.314***	1.000						3.9516	1.1815	.5562
		number of visiting groups or dept. in the route (inv)	.022	.395**	.081**	1.000					3.5081	.9413	.6493
		number of production steps in the route	.108**	.242*	.345*	.092**	1.000				1.9274	.9892	.5747
		average utilization levels	.062	.147*	.251**	−.064*	.266*	1.000			3.2339	1.0524	.6361
		number of different types of machines in a department	.248***	.162**	.421	−.013*	.388**	.117**	1.000		3.0726	1.0529	.5906
		number of levels in the BOM	.076	.099	.099	.100	.228**	.103*	.185**	1.000	2.3145	.9658	.6364

Table 3-4: Operational definition of the complexity related constructs.

Product-mix complexity Important internal organizational characteristics that may lead to PMT-uncertainty are the characteristics of the products that have to be made, the activities needed to transform the input into the required output, and the technology needed for the transformation. In fact, the characteristics of the 'product' are generally boundary-spanning between the external and the internal environment. In other words, the characteristics of the external environment influence the internal environment via the product characteristics.

If the various product designs have many similarities respecting commonality of production processes required and commonality of parts (both are strongly linked to modular product design), then a firm can offer a high variety, while at the same time, there is similarity in production [180]. Hence, we operationally define *product-mix complexity* by the items 1) 'number of product families', 2) 'number of variants per product family', and 3) 'number of different end-products'. This operationalization gave a Cronbach's alpha of .6526, which is sufficiently high; see Table 3-4.

Operations technology complexity The difficulty to coordinate activities depends on the interrelation between these activities. Thompson [225] distinguishes three ways in which work can be coupled: 1) pooled task interdependence, 2) sequential task interdependence, and 3) reciprocal task interdependence. *Pooled task interdependence* occurs in cases in which little direct contact is needed between groups, where the output of the organization is primarily the sum of efforts of each group. Members share common resources but are otherwise independent. Groups that differ due to day and night shifts on the same assembly line are an example of groups that operate with pooled task interdependence. Thompson [225] states that groups operating with pooled task interdependence demand very little coordination. The coordination required can generally be achieved through the use of rules and standard procedures for routine operations. *Sequential task interdependence* occurs in cases in which members work in series, and the work tasks are performed in a fixed sequence. In general, sequential task interdependence requires more planning and scheduling than pooled interdependence. *Reciprocal task interdependence* occurs in cases in which there is need of exchange of information between workers during the performance of their tasks if the scope of the 'task' is too large for one individual to perform the transformation alone. The members feed their work back and forth among themselves; in effect, each receives inputs from and provides outputs to the others. In addition, there are different types of interdependencies among organizational groups.

Reciprocal interdependent activities require mutual adjustment, planning, scheduling, and rules and procedures as coordination mechanisms. In contrast, pooled interdependent activities only require rules and procedures. In other words, the type of interdependency becomes more complex if the entanglement between activities and between resources increases. As a result, we operationally define *operations technology complexity* by the following items: 1) 'entanglement of production steps', 2) 'entanglement of departments', 3) 'entanglement of machines', 4) number of visiting groups or departments in the route, 5) 'number of production steps in the route', 6) 'average utilization levels', 7) 'number of different types of machines in a department', and 8) 'number of levels in the Bill-Of-Material', which indicates the extent of technology complexity in case of a project layout; see Table 3-4. With a value of .6410 for Cronbach's alpha this scale is sufficiently reliable.

3.3.4 Confirmatory factor analysis – complexity

We discuss the first-order and second-order measurement models of *complexity*. The final first-order measurement model originated after model trimming of the initial first-order measurement model with the complexity related constructs *customer order complexity*, *supplier complexity*, *product-mix complexity*, and *operations technology complexity*. Unfortunately, many factor loadings and covariances proved to be insignificant: all factor loadings on the items of the construct *product-mix complexity*, the factor loadings on the items 'entanglement of production steps' and 'number of visiting groups or departments in the route' of the construct *operations technology complexity,* and the covariances between the construct *product-mix complexity* and the other constructs. After the removal of the construct *product-mix complexity* as well as the two items for *operations technology complexity*, we obtained a final first-order measurement model with the constructs *supplier complexity*, *customer order complexity*, *operations technology complexity*. This final 1st-order measurement model fits the data according to the relative fit indices (i.e., $df = 51$, $\chi^2 = 88.101$, $p_{model} = .001$, CFI = .993, NFI = .984, TLI = .989, and $\text{RMSEA}_{[.038,.080]} = .060$). However, support for convergent validity is somewhat problematic, since the error-terms of some items are rather high, and the explained variance of some items is low, which might make estimates of factor loadings and path coefficients in a path model less reliable. Since there are no common cut-off/threshold values for measurement errors, we proceed with the development and analysis of a second-order measurement model.

In Figure 3-3, we present a CFA model of the 2nd-order construct *complexity* with unstandardized and standardized estimates. The unstandardized factor loadings are interpreted as regression coefficients that indicate expected change in the item given a 1-point increase in the factor. For example, scores on the 'entanglement of machines' are predicted to increase by .59 points for every 1-point increase in the *operations technology complexity* factor. Standardized loadings are interpreted as correlations and their squared values as proportions of explained variance. The standardized factor loading of the 'entanglement of machines', for instance, is .38, which means that .38², or 14.5% of its variance is shared with the *operations technology complexity* factor. Furthermore, note that the factor loading, as well as the level of explained variance of the construct *operations technology complexity* is fairly low.

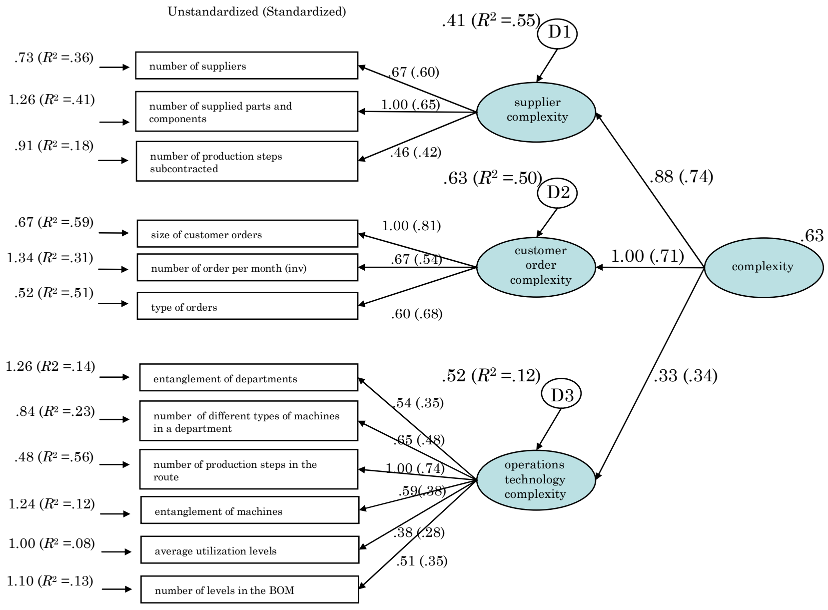


Figure 3-3: CFA model of the 2nd-order construct *complexity*.

			Factor loading	Critical Ratio	Sign.
supplier complexity	↔	*complexity*	.88	2.023	.043
customer order complexity	↔	*complexity*	1		
operations technology complexity	↔	*complexity*	.33	2.004	.045
number of suppliers	↔	*supplier complexity*	.67	4.908	0
number of supplied parts and components	↔	*supplier complexity*	1		
number of production steps subcontracted	↔	*supplier complexity*	.46	3.541	0
Order size	↔	*customer order complexity*	1		
number of order per month	↔	*customer order complexity*	.67	6.091	0
Type of orders	↔	*customer order complexity*	.60	6.583	0
Entanglement of departments	↔	*operations technology complexity*	.54	3.325	.001
number of different types of machines	↔	*operations technology complexity*	.65	4.441	0
number of production steps	↔	*operations technology complexity*	1		
Entanglement of machines	↔	*operations technology complexity*	.59	3.459	.001
Average utilization levels	↔	*operations technology complexity*	.38	2.931	.003
number of levels in BOM	↔	*operations technology complexity*	.51	3.671	0

Table 3-5: Factor loadings of the 2nd-order measurement model of *complexity*.

Nevertheless, all factor loadings are significant; see Table 3-5, and (of course) the relative fit indices of the overall model are also acceptable (i.e., $df = 51$, $\chi^2 = 88.101$, $p_{model} = .001$, CFI = .993, NFI = .984, TLI = .989, and $\text{RMSEA}_{[.038,\ .080]} = .060$). However, for the disturbance terms of the 1st-order constructs, Figure 3-3 also displays the levels of explained variance of these constructs. Note that almost 55% of the variance of *supplier complexity* is explained by this model. In addition 50% and 12%, respectively, of the variance of *customer order complexity* and *operations technology complexity* is explained by this model. In addition, Figure 3-3 also displays the squared multiple correlations (R^2) for each item, indicating the level of explained variance. Most R^2-values are fairly low. For example, only 8% of the variance of the item 'average utilization levels' is explained by this model. Nevertheless, as there are no commonly accepted cut-off measures for the measurement errors, we continue this exploratory chapter with this second-order measurement model of complexity.

complexity	**D1**	**D2**	**D3**	***rate of change***	**D4**	**D5**	**D6**
D1	.0			D4	.0		
D2	.2	.0		D5	− 1.6	.0	
D4	.3	.0	.0	D6	.1	1.8	.0

Table 3-6: Critical ratios of differences among disturbance terms of *complexity* and *rate of change*.

Finally, we examine the critical ratios of differences among residual variables, which can be considered as a table of the standard normal distribution to test whether two parameters are equal in the population [46], which would decrease the number of parameters to be estimated. Given that the values of the critical ratios of differences of the disturbance terms for D1, D2, and D3 are less than 1.96 (i.e., $p < .05$), the hypothesis that these three residual variances are equal in the population could *not* be rejected; see Table 3-6. Given these findings, it seems reasonable to constrain variances related to these three residuals to be equal. As such, the 2nd-order measurement model will be further overidentified with two more degrees of freedom. As a result, we maintain this 2nd-order operational definition of *complexity* in the analysis of causal effects between the constructs in a structural path analytic model.

* significant at p < .1, ** significant at p < .05, *** significant at p < .01

Construct	Cronbach's alpha	Variables (items)	Pearson correlation (two-tailed)			Mean	SD	Alpha if item deleted
rate of change of products	.7164	rate of change of the number of end-products	1.000			3.3988	1.0390	.5830
(N = 168)		rate of change of the number of variants per product family	.174**	1.000		3.3869	1.0994	.4961
.7413, N = 193		rate of change of the number of different modules	.391***	.574***	1.000	2.6429	.8977	.7518
rate of change of operations technology	.5836	rate of change of the number of different routes	1.000			2.3743	.8289	-
(N = 187)		rate of change of the number of production steps	.412**	1.000		2.4332	.8293	-
rate of change of suppliers	.5259	rate of change of the number of procured and subcontracted parts	1.000			2.9529	.9475	-
(N = 191)		rate of change of the number of supplied parts on stock	.359*	1.000		2.7173	.8421	-
rate of change of customer orders	.5333	rate of change of the size of customer orders	1.000			3.8095	1.0446	.2069
(N = 189)		rate of change of the number of orders per month	.409***	1.000		3.7090	.8660	.4794
		rate of change of the number of customer specific parts in end-products	.316***	.120**	1.000	3.2540	1.1294	.5732

Table 3-7: Operational definitions of rate of change related constructs.

* significant at p < .1, ** significant at p < .05, *** significant at p < .01

Construct	Cronbach's alpha	Variables (items)	Pearson correlation (two-tailed)					Mean	SD	Alpha if item deleted
information deficiency	.7971	information about the products	1.000					1.5792	.7236	.7896
(N = 202)		information about the processing times	.459***	1.000				1.8713	.9219	.7739
		information about material availability	.230	.415**	1.000			2.2021	.8245	.7544
		information about available operator capacity	.305	.462**	.464***	1.000		2.0297	.8691	.7116
		information about available machine capacity	.282	.418	.454**	.763	1.000	1.9158	.8741	.7229

Table 3-8: Operational definition of *information deficiency*.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$

Construct	**Cron-bach's alpha**	**Variables (items)**	**Pearson correlation**				**Mean**	**SD**	**Alpha if item deleted**
size	.7507	turnover	1.000				3.1150	1.0134	.6699
(N = 200)		number of employees	.733**	1.000			3.3800	.9219	.6139
		number of production related managers	.315	.438**	1.000		1.6200	.9434	.7305
		number of employees with at least a bachelor degree in logistics	.325	.368**	.405	1.000	2.0600	.9544	.7453
financial performance	.5589	market share	1.000				2.3497	1.0088	.5505
(N = 143)		return on investment	.229*	1.000			2.3566	1.1346	.4196
		return on sales	.231	.478	1.000		2.4895	.7399	.4197
		growth of turnover	.136**	.221	.276***	1.000	2.9371	1.1881	.5544

Table 3-9: Operational definitions of *size* and *financial performance*.

3.3.5 Rate of change of PMT characteristics

An organization's environment can range from *stable* to *dynamic* [169]. Real problems are caused by environmental changes that occur unexpectedly, for which no patterns could have been identified in advance. This stability dimension affects production planning and control through the predictability of the work to be done. In other words, a dynamic environment makes the organization's work more uncertain or unpredictable. There is not only lack of information on the appearances of the specific activities to perform, but also on the timing of execution. In other words, it is unknown what to do when! In this study, we consider the rate of change of the PMT characteristics and initially distinguish between the rate of change of customer demand, suppliers, products, and operations technology.

Rate of change of customer orders Customer order attributes have to be met by the capabilities of the manufacturer. Generally, the supply will not fully meet the actual demand—on the one hand, the supplier may be put in default if he delivers the product too late; on the other hand, actual customer orders may be changed. Uncertainty of the customer order (and corresponding aggregated customer demand) is the result of the complexity and the rate of change of demand and order attributes.

Numerous items to measure the extent of *rate of change* can be developed. However, to keep the questionnaire concise, we only asked for a limited number of items (which, looking backwards, is regrettable), as we operationalized *rate of change of customer orders* by the items 1) 'rate of change of size of customer orders', 2) 'rate of change of number of orders per month', and 3) 'rate of change of number of customer specific parts in end-products', for which we obtain a value of Cronbach's alpha of only .5333. From Table 3-7, we observe that the removal of the third item would increase the value of Cronbach's alpha, but it also increases the chance of empirically underidentification [133] in the measurement model (which is to be discussed in the next section), given the fairly low correlation coefficients obtained in this study. Hence, we postpone the final judgment on maintaining the scale until after the analysis of the first-order measurement model of *rate of change*.

Rate of change of suppliers We operationalized *rate of change of suppliers* by the items 1) 'rate of change of the number of procured and subcontracted parts', and 2) 'rate of change of supplied parts on stock', for which we obtain a value of Cronbach's alpha of .5259, which is too low to indicate this scale as reliable.

Rate of change of products We operationalized *rate of change of products* by the items 1) ‘rate of change of number of end-products’, 2) ‘rate of change of number of variants per product family’, and 3) ‘rate of change of number of different modules’, for which we obtain a sufficiently large value of Cronbach’s alpha of .7164.

Rate of change of operations technology We operationalized *rate of change of operations technology* by the items 1) ‘rate of change of the number of different routes’, and 2) ‘rate of change of number of production steps’, for which we obtain a value of Cronbach’s alpha of .5836, which is also rather low.
As a result, the constructs *rate of change of suppliers* and *rate of change of operations technology* have scales with low values of Cronbach’s alpha and both scales have only two items, which increases the possibility of empirical underidentification of the first-order measurement model of the *rate of change*. We therefore applied a factor analysis on the items of these constructs and obtained a third factor with a value of Cronbach’s alpha of .5968. As this value is near .60, we continue our (reliability) analysis with the measurement model of *rate of change* that comprises the constructs *product change*, *customer order* change, and *rate of change remaining*. Note that the last construct includes items of both *rate of change of suppliers* and *rate of change of operations technology*.

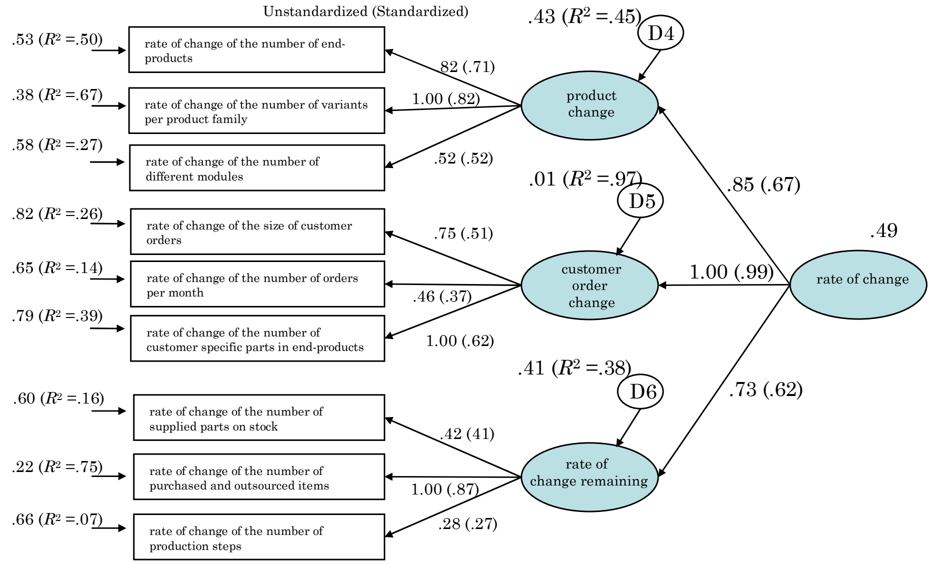


Figure 3-4: CFA model of the 2nd-order construct *rate of change*.

3.3.6 Confirmatory factor analysis – rate of change

We present the second-order measurement model of *rate of change*. As was expected from the fairly low value of Cronbach's alpha, the factor loading on the item 'rate of change of number of different routes' of the construct *rate of change remaining* appeared to be non-significant. If we omit this item, we obtain a first-order measurement model that fits the data according to the relative fit indices except for RMSEA which is large, but still lies within its bounds (i.e., $df = 24$, $\chi^2 = 87.723$, $p_{model} = .000$, CFI = .986, NFI = .981, TLI = .974, and $\text{RMSEA}_{[.089,\,.140]} = .114$).

In Figure 3-4 , we present a 2nd-order CFA model of *rate of change*. Note that this figure also displays the levels of explained variance of the 1st-order constructs. For example, 97% of the variance of *customer order change* is explained by this model as well as 45% and 38% of the variance of *product change* and *rate of change remaining*, respectively. Furthermore, the factor loadings for the 2nd-order constructs *rate of change* are all significant and sufficiently large. Furthermore, note that this measurement model explains 67% of the variance of the item 'rate of change of the number of variants per product family'. In contrast, it only explains 7% of the variance of the item 'rate of change of the number of production steps'.

In all, we would accept this 2nd-order measurement model based on the relative fit indices. Nevertheless, as the values of the critical ratios of differences of the disturbance terms for D4, D5, and D6 are less than 1.96, the hypothesis that these three residual variances are equal in the population could *not* be rejected; see Table 3-6. Given these findings, we constrain the variances related to these three residuals to be equal. As such, the 2nd-order measurement model will be overidentified with two more degrees of freedom.

3.3.7 Information deficiency

Several authors claim that the construct *information deficiency* is a major determinant of uncertainty [81][169], where the lack of information of tasks before actually performing these tasks is the key issue. Since the main objective of this chapter is to explore the relationship between *PMT-uncertainty* and the *locus of production planning and control* and *frequency of production planning and control meetings*, respectively, we operationally define *information deficiency* by the items 1) 'extent to which product information is available at the time of planning', 2) 'extent to which processing time information is available at the time of planning', 3) 'extent to which material availability information is available at the time of planning', 4) 'extent to which information is available on the availability of operator capacity at the time of planning', and 5) 'extent to which information is available on the availability of machine capacity at the time of planning', ranging from full availability of information until complete information deficiency. From Table 3-8 (p. 88), we observe that reliability analysis of this scale give a Cronbach's alpha value of .7971, which indicates that it is sufficiently reliable. In addition, a factor analysis (KMO = .744) leads to only one factor with 'eigenvalue' of 1.

3.3.8 Confirmatory factor analysis – production planning and control

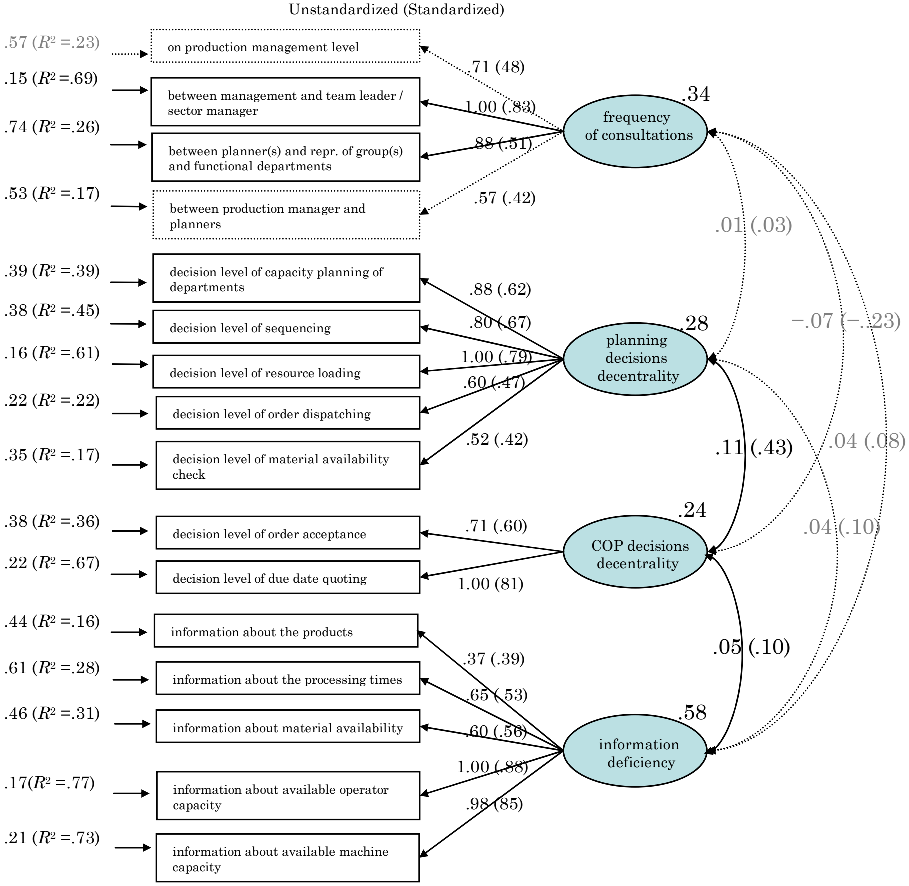


Figure 3-5: Measurement model of planning and control related constructs plus *information deficiency* (covariances in dotted lines are non-significant).

We discuss the measurement model of the production planning and control related constructs plus *information deficiency*. Although the fit indices of the initial first-order measurement model are $df = 98$, $\chi^2 = 212.334$, $p_{model} = .000$, CFI = .984, TLI = .978, NFI = .971, and $\text{RMSEA}_{[.062,.089]} = .075$, the factor loadings on the items 'frequency of planning meetings between managers on production management level', and 'frequency of planning meeting between production manager and planner(s)' of the construct *frequency of production planning and control meetings* appeared to be non-significant; see Figure 3-5. In addition, covariances between 1) *frequency of production planning and control meetings* and *planning decisions decentrality*, 2) *information deficiency* and *frequency of production planning and control meetings*, 3) *information deficiency* and *planning decisions decentrality* are also non-significant.

From an analysis of a comprehensive measurement model of all constructs, we also observe that the covariances between *frequency of production planning and control meetings* and the 2nd-order constructs *complexity* and *rate of change* are also non-significant. This does, however, not hold for *information deficiency*. Hence, the construct *frequency of production planning and control meetings* is removed from this measurement model, as well as from the path analytic model to be discussed in Section 3.4.1.

3.3.9 Secondary constructs and remaining items

As we also aim to investigate 1) spurious relationships between possibly causal effects of the 'primary' constructs and *size*, and 2) the effect of the type of locus of production planning and control given a specific degree of PMT-uncertainty on *financial performance*, we briefly discuss our operational definitions of these 'secondary' constructs.

Size We operationally define the construct *size* by the items 'turnover', 'number of employees', 'number of production related managers', and 'number of employees with at least a bachelor degree in logistics', for which we have a value of .7507 for Cronbach's alpha; see Table 3-9. Furthermore, a factor analysis of these items gives only one factor.

Financial performance In concurrence with the operational definitions proposed by Maani et al. [160] and Fynes and Voss [78], we operationally define the construct *financial performance* by the items 'market share', 'return on investment', 'return on sales', and 'growth of turnover'. However, the value of Cronbach's alpha (.5589) for this operational definition is rather low; see Table 3-9. However, the removal of the items 'market share', and 'growth of turnover' gave a value of .5969 for Cronbach's alpha.

From the measurement models discussed in previous sections, we know that it is impossible to develop a correct 3rd-order construct *PMT-uncertainty* measured by the constructs *information deficiency*, *complexity* ands *rate of change*. Furthermore, from the measurement models we conclude that there are no significant associations with the construct *frequency of production planning and control meetings*. We therefore have left only the meta-hypothesis that states that *complexity*, *rate of change*, and *information deficiency* are positively related to the decentrality of the *locus of production planning and control*.

3.4 Results

We discuss the results of hypothesis testing with the help of a structural equations model (i.e., path analysis). In addition, we use an exploratory factor analysis to explore alternative factors to develop an alternative structural equations model. Furthermore, for each factor, we categorize respondents into a group with a low score on the factor and a group of respondents with a high score on the factor, and subsequently analyse the differences in means of all other factors.

3.4.1 A structural equations model

We discuss the structural equations model (and statistical equivalents) that we aimed to study in the first place; see Figure 3-6. This model fits the data according to the relative fit indices (i.e., $df = 487$, $\chi^2 = 830.697$, $p_{model} = .000$, CFI = .978, NFI = .949, TLI = .975, and $\text{RMSEA}_{[.052,.065]} = .059$). Furthermore, all significant paths are displayed with normal arrows; non-significant paths were removed but are still displayed in Figure 3-6 with dashed arrows ($\Delta\chi^2_{\text{difference}}(4) = 8.965 < 9.4877$ is non-significant). Hence, there are no significant direct causal relationships between *information deficiency* and *rate of change,* and between *information deficiency* and *planning decisions decentrality*, respectively. There are, however, only significant relationships between *complexity* and the constructs *COP decision decentrality* and *planning decisions decentrality*. Note that the direct relationship between *information deficiency* and *COP decision decentrality* is only significant at .1. Consequently, *rate of change* and *information deficiency* have indirect effects on *planning decisions decentrality* but no direct effects on *planning decisions decentrality*.

Also displayed in Figure 3-6 are the disturbances terms and squared multiple correlations (R^2) for each endogenous construct. These indicate the effects of unmeasured variables not included in the model (i.e., the unexplained variance in the latent endogenous variables due to all unmeasured causes) and the level of explained variances by the model. Note that this model explains 40%

and 29% of the variances of both *COP decisions decentrality* and *planning decisions decentrality*, respectively, which is fairly reasonable.

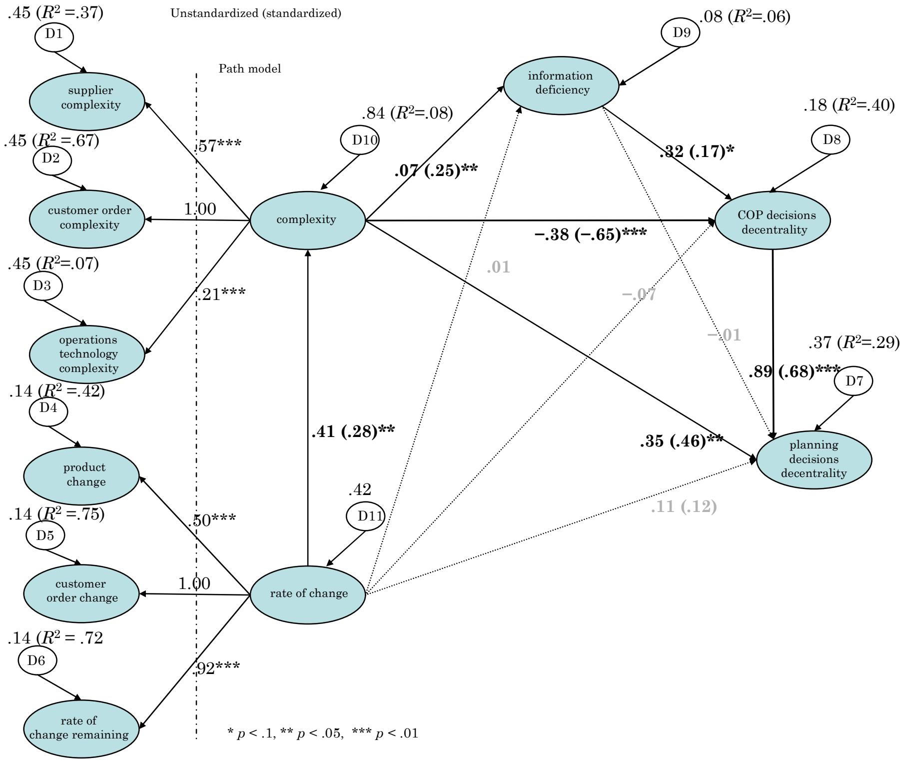


Figure 3-6: A structural equations model of *complexity*, *rate of change*, *information deficiency* and *locus of production planning and control* (*df* = 487, χ^2 = 830.697, p_{model} = .000, CFI = .978, NFI = .949, TLI = .975, and RMSEA$_{[.052,.065]}$ = .059).

The total effects between the constructs in this model are displayed in Table 3-10.

Complexity The total effect of *complexity* on *COP decisions decentrality* is −.61. The total effect of *complexity* on *planning decisions decentrality* equals all (standardized) direct effects plus all (standardized) indirect effects, hence .46 + .68{(−.65) + (.25)(.17)} = .05. In other words, there is only a very small impact of *complexity* on *planning decisions decentrality*.

Rate of change The model indicates only a small indirect effect of *rate of change* on *COP decisions decentrality (*−.17*)* and *planning decisions decentrality* (.03), respectively. We also analyzed statistically equivalent models, among which a model with a significant opposite direction of the relationship between *complexity* and *rate of change*. However, based on theoretical considerations, we prefer the model displayed in Figure 3-6 and conclude that *rate of change* indirectly affects *COP decisions decentrality, planning decisions decentrality*, and *information deficiency* via *complexity*.

Information deficiency The total effect of *rate of change* on *information deficiency* is .07. This means that an increase in *rate of change* leads to a small increase in the level of *information deficiency*. In addition, uncertainty because of the *information deficiency* has only a direct influence on the *COP decisions decentrality*, and an indirect influence on *planning decisions decentrality*.

			Total direct effect	**Total indirect effect**	**Total effect**
complexity	→	*COP Decisions decentrality*	−.65	(.25) (.17) = .04	−.61
information deficiency	→	*COP Decisions decentrality*	.17		.17
rate of change	→	*COP Decisions decentrality*		(.28) {(−.65) + (.25)(.17)} = −.17	−.17
complexity	→	*planning decisions decentrality*	.46	(.68) {(−.65) + (.25)(.17)} = −.41	.05
information deficiency	→	*planning decisions decentrality*		(.68) (.17)	.12
rate of change	→	*planning decisions decentrality*		(.68) (.05)	.03
rate of change	→	*information deficiency*		(.28) (.25)	.07

Table 3-10: Total effects in the initial path model.

Hence, our findings from the final structural equations model are:

1. The higher the complexity, the more *centralized* the decision structure of customer-order processing (i.e., order entry structure) is. Note that this contrasts proposition 3-1 that states that the higher the complexity the more decentralized the locus of production planning and control is;
2. Although the total effects are very small, it holds that the higher the complexity is, the more decentralized the structure of detailed operational planning decisions is;
3. The higher the complexity, the less information is available;
4. The more centralized the decision structure of customer-order processing is, the more centralized the structure of detailed operational planning decisions is.

The results from this structural equations model indicate that PMT-uncertainty due to *rate of change* has almost no impact on the locus of production planning and control (except for the order entry decisions) which may be explained by the inertia of discrete parts manufacturers; apparently, any internal short-term disturbance is handled as business-as-usual).

From an analysis of a structural equations model with only 1st-order constructs, we observe that the construct *customer order complexity* particularly determines the structure of the decision hierarchy; see Figure 3-7. More specifically, based on the measurement model in Figure 3-3, p.86, we conclude that the PMT-uncertainty lies primarily in the variance of the number of customer orders per month and the order size; not in the type of products or the production-related variables, such as rate of change of production routings, the rate of change of the number of production steps, and the rate of change of the number of purchased or outsourced parts. Hence, we conclude that discrete parts manufacturers 'stick' with their product-portfolio, which is in concurrence with the findings of a study by Deloitte and Touche [57] that states that the innovativeness of small and medium-sized Dutch discrete parts manufacturers is (too) low. Simply stated, discrete parts manufacturing firms do not make tractors today and motorcycles tomorrow.

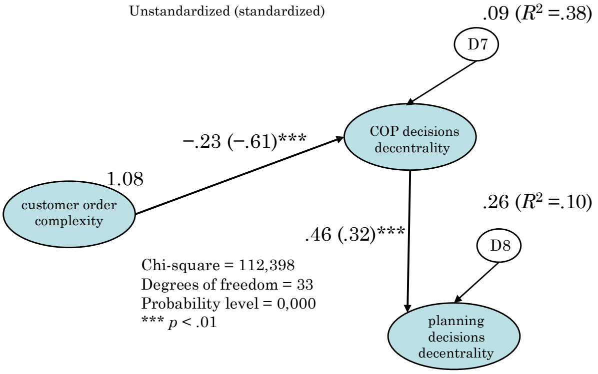


Figure 3-7: *Customer order complexity* as the major cause for decentrality of the *locus of production planning and control*.

3.4.2 An alternative model

Convergent validity of the second-order measurement models underlying the structural equations model displayed in Figure 3-6 is somewhat problematic due to the low factor loading of the second-order construct *complexity* on the first-order construct *operations technology complexity*. To further investigate the differences between respondents on several types of complexity and rate of change variables and their impact on the locus of production planning and control, we also conducted an orthogonal exploratory factor analysis (EFA) on all items. From this factor analysis, we obtained 15 independent factors. For the underlying items of each factor and scale reliability based on Cronbach's alpha, we refer to Table 10-1 (p. 257) in the appendix. The factors are: *customer order complexity* (F1), *information deficiency* (F2), *size* (F3), *planning decisions decentrality* (F4), *end-product change* (F5), *financial performance* (F6), *frequency of production planning and control meetings* (F7), *COP decisions decentrality* (F8), *end-product complexity* (F9), *supplier complexity* (F10), *component and part change* (F11), *delivery time complexity* (F12), *customer order change* (F13), *route change* (F14), and *route complexity* (F15). Note that most of these factors are quite similar to our initial theory-based constructs for which we also found low inter-factor correlation.

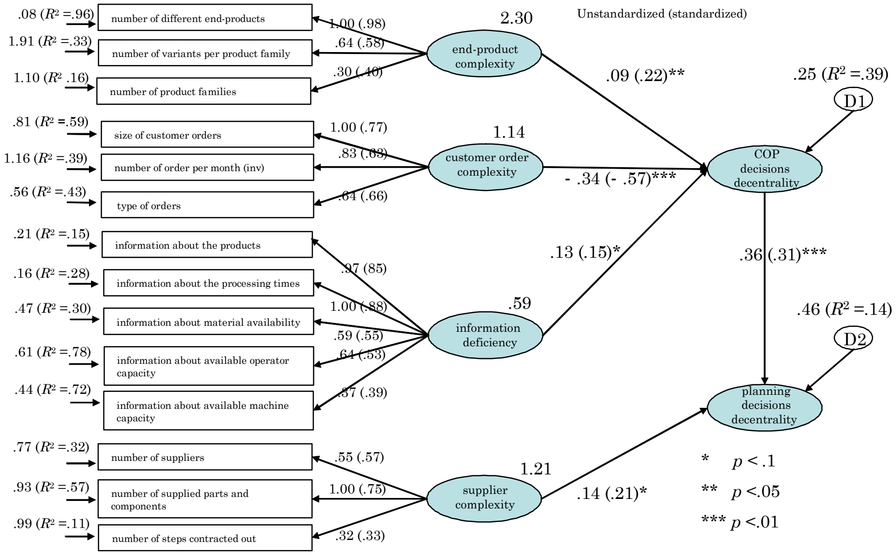


Figure 3-8: An alternative SEM model based on EFA factors (*df* = 204, χ^2 = 451.591, p_{model} = .000, CFI = .975, NFI = .955, TLI = .969, and $\text{RMSEA}_{[.067,.087]}$ = .077).

The extraction of these factors gives us the opportunity to explore an alternative SEM model, namely one with causal effects between all 1st-order PMT uncertainty-related factors and the production planning and control related factors. For sake of brevity, we do not display the full measurement model of these 'orthogonal' factors, but refer to the final hybrid model displayed in Figure 3-8, that fits the data according to the relative fit indices (i.e., *df* = 204, χ^2 = 451.591, p_{model} = .000, CFI = .975, NFI = .955, TLI = .969, and $\text{RMSEA}_{[.067,.087]}$ = .077), which was obtained after the removal of non-significant relationships ($p > .1$) and non-significant factor loadings.

In concurrence with the model displayed in Figure 3-7, we note from this alternative model that *customer order complexity* influences the *COP decisions* *decentrality* most: the higher the *customer order complexity*, the more centralized the COP decision structure. However, *product complexity* and *information deficiency* tend towards a decentralized COP decision structure. In addition, the more centralized the COP decision structure, the more centralized the planning decisions structure. Also, *supplier complexity* positively influences the *planning decisions decentrality* ($p < .1$).

3.4.3 Analysis of differences between subpopulations

Subsequently, we categorize respondents into a low scoring and a high scoring group for each factor (displayed in the columns in Table 10-2, p.267 in the appendix), and we explore differences in means on all other factors displayed in the rows of Table 10-2. Note that the diagonal of this table displays the means of the low and high scoring categories for each factor, which is of course significant at $p < .01$.

Column 3): *customer order complexity* (F1)—From Table 10-2 (p. 267), we observe that firms that face high levels of *customer order complexity*, also have high levels of *information deficiency*. In addition, these firms have more central COP decision structures and a lower *frequency of production planning and control meetings* than firms that face low levels of *customer order complexity*. The latter may be the result of the lower scores on *end-product complexity* and *delivery time complexity*, respectively. Furthermore, firms that have high levels of *customer order complexity* also have high levels of *component and part change*. Finally, we observe that the absence of significant differences in means in the other *rate of change* related factors justifies our choice for the direction of the path between *rate of change* and *complexity* of the initial structural equations model displayed in Figure 3-6. *Rate of change* is related to *COP decision decentrality* and *planning decisions decentrality* via *complexity*.

Column 4): *information deficiency* (F2)—Firms that have high levels of *information deficiency* also have high levels of *customer order complexity* and high levels of *route complexity*, but low levels of *delivery time complexity*. Finally, from this analysis we also conclude that *information deficiency* is not significantly related to the rate of change related factors, except for *component and part change*.

Column 5): *size* (F3)—Smaller firms have high levels of *customer order complexity* but low levels of *supplier complexity* and *route complexity* ($p < .05$). Furthermore, note that there is neither a significant difference in means of the *rate of change* related factors, nor a significant difference in means of *information deficiency*.

Column 6): *planning decisions decentrality* (F4)—Firms that have decentralized planning decisions structures also have high levels of *customer order change*, and they have decentralized COP decision structures. Note, however, that they do not significantly differ on *supplier complexity* compared to firms that have a more centralized planning decisions structure. Hence, the impact of *supplier complexity* on the *planning decisions decentrality* is only modest. Based on this finding, we should remove the construct *supplier complexity* from the alternative structural equations model displayed in Figure 3-8, or search for spurious relationships (which is addressed in the next section).

Column 7): *end-product change* (F5)—Firms that have high levels of *end-product change* also have high levels of *end-product complexity*, *component and part change*, and *customer order change* (for all: $p < .05$). However, they do not significantly differ on *frequency of production planning and control meetings, COP decisions decentrality*, and *planning decisions decentrality*.

Column 8): *financial performance* (F6)—Firms with high *financial performance* have significantly lower levels of *customer order complexity* ($p < .01$) and more decentralized COP decision structures ($p < .1$) than firms with low *financial performance*.

Column 9): *frequency of production planning and control meetings* (F7)—Firms with a high *frequency of production planning and control meetings* have more centralized planning decisions structures and high levels of *end-product complexity*. Furthermore, note that firms with a high *frequency of production planning and control meetings* cannot be discriminated from firms with a low *frequency of production planning and control meetings* based on the rate of change related factors.

Column 10): *COP decisions decentrality* (F8)—Firms with decentralized COP decision structures have low levels of *customer order complexity*, more decentralized planning decisions structures, high levels of *end-product complexity*, *delivery time complexity*, and *financial performance*, but low levels of *component and part change*.

Column 11): *end-product complexity* (F9)—Firms with high levels of *end-product complexity* have low levels of *customer order complexity*, which indicates a more project-oriented production of one or more highly composed end-products. Note that these firms have more decentralized COP decision structures, probably because they also have high levels of *route change*, *customer order change*, and *end-product change*. These findings strengthen our proposition that *rate of change* impacts the decentrality of the *locus of production planning and control* only if there simultaneously is *complexity*; and it justifies the direction between *rate of change* and *complexity* in the structural equations model displayed in Figure 3-6.

Column 12): *supplier complexity* (F10)—Firms that have high levels of *supplier complexity* are larger, have high levels of *customer order complexity*, but they have low levels of *delivery time complexity*. Note, however, that they do not significantly differ on the planning decisions structure. This may be explained by either the relatively small influence of *supplier complexity* or because the relationship displayed in Figure 3-8 is spurious (and there is at least one 'lurking' variable).

Column 13): *component and part change* (F11)—Firms that have high levels of *component and part change* have also high levels of *customer order complexity*, *customer order change*, *end-product change*, *route change*, and *information deficiency*. Furthermore, these firms have more centralized COP decision structures; accordingly, this finding negates the theory that a higher *rate of change* leads to more decentralized organic structures. However, from the results of the structural equations models, we now know that *customer order complexity* more strongly determines the decentrality of the COP decision structure than *component and part change*.

Column 14): *delivery time complexity* (F12)—Firms that have high levels of *delivery time complexity* have more decentralized COP decision structures. This was not expected from the results of the alternative structural equations model displayed in Figure 3-8. Note, however, that firms that have high levels of *delivery time complexity* have low levels of *customer order complexity*, which might explain the more decentralized COP decision structure. In addition, these firms have a high *frequency of production planning and control meetings*, but low levels of *information deficiency* (i.e., more information is available) and low levels of *route change* and *route complexity*.

Column 15): *customer order change* (F13)—Firms that have high level of *customer order change* also have high levels of *end-product change*, *component and part change*, and *end-product complexity*. Nevertheless, these firms do not significantly differ on *frequency of production planning and control meetings*, *COP decisions decentrality*, or *planning decisions decentrality*.

Column 16): *route change* (F14)—Firms that have high levels of *route change* have also high levels of *end-product change* and *component and part change*. Furthermore, we observe that these firms have more centralized COP decision structures, which also negates commonly accepted theory.

Column 17): *route complexity* (F15)—Firms that have high levels of *route complexity* are generally larger and have high levels of *route change*. In addition, note that *route complexity* does not significantly discriminate on *frequency of production planning and control meetings*, *COP decisions decentrality*, or *planning decisions decentrality*.

3.5 Discussion

3.5.1 Insights and implications

This study indicates that each dimension of PMT-uncertainty affects the locus of production planning and control in a different way. When organizational uncertainty is high, strategic decision-making authority may be centralized, but operational decision-making authority should be decentralized [173][232]. The findings of this study support this insight but also detail the impact of the uncertainty dimensions complexity, rate of change, and information deficiency on the level of decentrality of decision-making. These dimensions lead to decentralization of the operational production planning and control decisions structure, but at the same time a centralization of the customer-order processing decisions structure.

Customer order complexity influences the *COP decisions decentrality* most: the higher the *customer order complexity*, the more centralized the COP decision structure. However, *end-product complexity* and *information deficiency* tend towards a decentralized COP decision structure. In addition, the more centralized the COP decision structure is, the more centralized the planning decisions structure is. However, *supplier complexity* positively influences the *planning decisions decentrality* ($p < .1$). This seems to indicate that the higher the level of *supplier complexity* is, the more decentralized the planning decisions structure is. However, this relationship requires closer examination. That is, we explore the relationships in the structural equations model on spurious relationships due to possible 'lurking' variables; see Figure 3-9.

From this analysis, it appears that the use of ERP systems is an important determinant of a more centralized operational planning decisions structure; this concurs with the finding of Davenport [56]. From the extended structural equations model displayed in Figure 3-9, that fits the data according to the relative fit indices $df = 345$, $\chi^2 = 539.895$, $p_{model} = .000$, CFI = .976, TLI = .971, NFI = .953, and $\text{RMSEA}_{[.061,.079]} = .070$), we observe that *supplier complexity* predicts the adoption of an ERP system, that, indirectly, leads to a more centralized planning decisions structure. Furthermore, note that the level of explained variance of the construct *planning decisions decentrality* is increased to 26%. Note that the constructs *end-product complexity* and *supplier complex-*

ity have only a small impact (at the significance level of $p < .05$) on the *planning decisions decentrality*; see Table 3-11.

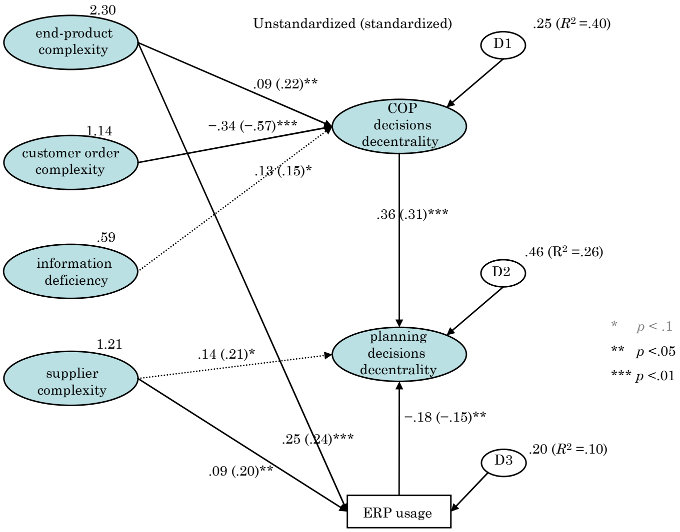


Figure 3-9: The influence of ERP on the *locus of production planning and control* (df = 345, χ^2 = 539.895, p_{model} = .000, CFI = .976, TLI = .971, NFI = .953, and RMSEA$_{[.061,.079]}$ = .070).

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$

			Total direct effect	Total Indirect effect	Total effect
customer order complexity	→	*COP Decisions decentrality*	−.57***		−.57***
product complexity	→	*COP Decisions decentrality*	.22**		.22**
product complexity	→	*planning decisions decentrality*		(.22) (.31) + (.24) (−.15) = .03**	.03**
supplier complexity	→	*planning decisions decentrality*	.21*	(.20) (−.15) = −.03**	.18*

Table 3-11: Total effect of *complexity* on the decentrality of *the locus of production planning and control.*

In particular the constructs *customer order complexity* and *end-product complexity* determine the level of centralization of the decision structure. Note from Figure 3-9, that the beta coefficient between *end-product complexity* and *COP decisions decentrality* is .22; the beta coefficient between *customer order complexity* and *COP decisions decentrality* is –.57. The latter indicates a stronger effect of *customer order complexity* on the *COP decisions decentrality* than *end-product complexity*, which is confirmed by the ANOVA analysis discussed in the previous section.

Another interesting finding with managerial implications is that high performance firms have low levels of *customer order complexity* and decentralized COP decision structures. As a result, organizations that decentralize the structure to cope with uncertainty would be well-advised to reduce customer order complexity first.

3.5.2 Direction for further research

Another strategy to cope with uncertainty is to expand communication channels [81] by the use of intelligent production planning and control systems that simultaneously support material coordination and planning and scheduling of scarce resource capacity [210]. However, ERP systems are centralized systems, often based on the rigid hierarchical MRP paradigm, in which information is stored centrally [56][147]. The structural equations model in Figure 3-9 shows that *end-product complexity* and *supplier complexity* have a positive effect on the adoption and usage of ERP systems; and that the use of ERP leans towards a centralized locus of production planning and control. Nevertheless, we have to investigate possibly spurious relationships, for example because of the factor *size*.

Advanced Planning and Scheduling (APS) systems can also be characterized as centralized control systems [210][254]. In contrast, kanban control systems are generally decentralized systems. The question remains what the impact is of various uncertainty related Product/Market/Technology factors (i.e., *complexity*, *rate of change*, and *information deficiency*) on the adoption and use of various production planning and control methods and systems. These issues are addressed in the next chapter, with the help of the survey-data discussed in this chapter.

4 PMT-uncertainty and the use of various production planning and control tools

Any technology usage is best understood by analyzing and understanding the various contextual factors both from the internal and external environment that resulted in the adoption and the implementation of the technology [52][144][188]. The factors approach attempts to identify static factors that discriminate users of a technological innovation from non-users. Furthermore, Cooper and Zmud [52] state that the interaction of task and technology characteristics is critical for the successful use of production planning and control tools. The production planning and control task characteristics are likely to differ depending on the manufacturing environment, thereby favoring specific production planning and control technologies. Production planning and control in a job shop environment, for instance, requires a more sophisticated planning and scheduling tool than in a repetitive flow line environment. The objective of this chapter is to explore the impact of various dimensions of PMT-uncertainty in discrete parts manufacturing environments (i.e., *complexity*, *rate of change*, and *information deficiency*) on the use of different production planning and control tools (i.e., kanban control, conventional plan board, spreadheet, ERP, and APS).

This research was performed with the intention to explore the relationships between the use of specific production planning and control tools and PMT-uncertainty. Our aim was to examine and to extend existing theory on this relationship by formulating data-driven, though theoretically consistent, propositions to reflect the findings of the survey among the 206 Dutch discrete parts manufacturing firms as discussed in the previous chapter. Hence, this chapter proceeds with the analysis of the data discussed in chapter 3.

The plan of this chapter is as follows. In Section 4.1, we review the scarce literature that addresses the relationships between the use of the different production planning and control tools and PMT-uncertainty. In Section 4.2, we briefly discuss our research method, as well as the operational definitions of the constructs involved. In Section 4.3, we present the empirical results. Finally, in Section 4.4, we end this chapter with a discussion of the findings, resulting in a number of corollaries and conclusions.

4.1 Use of production planning and control tools

Kwon and Zmud [144] identified a number of variables that contribute to the successful introduction of a technological innovation in an organization. These variables are categorized into individual variables, organizational variables, innovation variables, and task-related variables, where the contribution of each variable to the successful implementation of the innovation depends on the specific situation. In addition, in a meta-analysis of the adoption of innovations in organizations, Damanpour [55] examined various organizational properties (i.e., specialization, functional differentiation, sophistication, managerial attitude toward change, technical knowledge resources, administrative intensity, slack resources, external communication and internal communication, centralization, formalization, managerial tenure, and vertical differentiation) that enhance or hamper organizational innovativeness.

Some of these innovation and organizational (behavioral) characteristics are used by researchers for various empirical ICT adoption studies [49][159]. However, Gurbaxani and Mendelson [91] state that a purely behavioral explanation for IT adoption is incomplete and a contingency approach of adoption is required. The condition that a technology should be compatible with the organization and its tasks determined by the products, market, and other technology is prevalent in the innovation and technology diffusion literature [52][132][227]. However, except of the factors *size*, *centralization*, and *functional differentiation* there are, to our best knowledge, no other adoption, implementation, and user studies reported in literature that focus on the impact of Product/Market/Technology (PMT) uncertainty-related factors and the use of different production planning and control tools. Indeed, except for an indirect hint in the paper of Wemmerlöv and Johnson [237], there is no academic literature that addresses the impact (or discriminating power) of PMT-uncertainty on the use of conventional plan boards or APS systems.

4.1.1 Kanban control systems

Hall [94] states that ‘material in a pull system is drawn or sent for by the users of the material as needed’. According to Schonberger [197] pull systems are solely related to the Toyota-style kanban system, i.e., the traditional kanban system. In fact, kanban is the material replenishment method that manages and ensures the success of Just-In-Time manufacturing via production control cards or containers. In the traditional kanban system, work for a machine is only released and actual production at a machine is only started at the arrival of a kanban, after a corresponding product at a successive machine, i.e., downstream machine, is used.

Much research has been conducted on the design and operational issues of kanban control systems, resulting in various types of pull systems within the

Just-In-Time and the lean manufacturing concept [3]. Liker [158] states that the adoption of lean manufacturing techniques will benefit any firm regardless of the type of products it produces. However, Akturk and Erhun [3] state that there is a limit to the extent that kanban control systems can be usefully applied in many industries and that known successes are generally in repetitive manufacturing environments. As repetitive manufacturing environments are characterized by specific PMT combinations, we expect to find differences between various *complexity* and *rate of change* related factors for users of kanban control systems versus non-users, in that users face stable demand (i.e., low *customer order complexity* and low *end-product change*).

4.1.2 Spreadsheets

Although the use of spreadsheet software to support the production planning and control process is frequently mentioned by various authors [48][110][243], we are not aware of any literature on the relationship between the use of spreadsheets for production planning and control purposes and the level of complexity, rate of change, and information deficiency in the manufacturing environment. Kilger [129] state that the use of –department specific or even planner specific– spreadsheets to support the planning process is a cause of suboptimal disconnected planning processes in the external and internal supply chain. However, he does not mention the type of environments in which spreadsheets are particularly used. Brancheau and Wetherbe [38] studied the adoption of spreadsheet software by individual accountants and managers and found that adopters differ from non-adopters on general adoption factors, such as personality and communication characteristics (e.g., age, education, and exposure to media and interpersonal communication). In addition, Chan and Storey [47] investigated the relationships among tasks, spreadsheet proficiency, usage, and user satisfaction. It was found that spreadsheet users often do not use many of the commonly available spreadsheet features, and they do not appear inclined to use other software packages for their tasks, even if these packages might be more suitable. No relationship was suggested between the level of PMT-uncertainty and spreadsheet software.

4.1.3 Enterprise Resources Planning

The majority of industrial firms have adopted Enterprise Resource Planning systems as an enterprise-wide information system to help dealing with their internal supply system, for instance receiving, inventory management, production planning, accounting, and human resource management [56]. Davenport [56] states that a properly selected and implemented ERP system can have significant benefits, but it can also degrade financial performance due to a lack of functionality [200]. In addition, a lack of package adaptation of Enterprise

Resource Planning systems (i.e., the degree to which an innovation can easily be adapted for its future and possibly changing working environment) is frequently cited as a pitfall of successful implementation [56][109][147]. Therefore, package adaptation is considered to influence the rate of adoption of planning software in general [39]. In addition, Umble et al. [229] found some other critical factors for successful ERP system implementation, among which commitment of top management, an excellent project and change management, data accuracy, and extensive education and training.

While ERP systems are considered to be indispensable for all kinds of manufacturing firms given the present competitive manufacturing environment, firm size discriminates the adoption and implementation of an ERP system in that larger firms predominantly more often use ERP than small firms [229]. However, this holds for various types of information technology [58][87], because, among other things, larger firms have larger financial ICT budgets, more functional specialists, larger internal mass media and communication exposure, but also because the environment more-or-less demands it.

Closely related to firm size, is the degree of internal and environmental complexity [176]. However, it remains unclear which specific *complexity*-related factors influence the adoption and the use of an ERP system. As mentioned in the previous chapters, this complexity is the result of the amount and diversity of (relationships between) end-products, components and parts, internal departments and cells, suppliers, and customers, and it generally determines the production planning and control requirements of an organization. If complexity of the manufacturing system and its environment increases, production planning and control becomes more difficult and more production planning and logistical transactions have to be executed and monitored. In other words, complexity increases the ‘information need’ and need of transaction execution capacity. This is exactly what ERP systems are capable of, as ERP systems are particularly considered to be transaction and information processing systems [56][147][254]. Therefore, we postulate that environmental complexity influences the use of an ERP system.

4.1.4 Advanced Planning and Scheduling

One strategy to cope with PMT-uncertainty is to expand communication channels, i.e., variety transmitting capacity [81], by using Advanced Planning and Scheduling (APS) systems [210]. Meyr et al. [166] identify a common thread of most commercial APS systems; they generally encompass top-down intelligent functionality for strategic, tactical, and operational issues, such as Strategic Network Planning, Master Planning, Demand Planning, Demand Fulfillment and Availability To Promise, Master Planning, Distribution Planning, Transport Planning, Production Planning, Scheduling, and Material Requirements Planning. Hence, these APS systems are centralized control systems. Furthermore, APS systems that provide all this functionality for diverse industries are generally classified as high-end APS systems. Global high-end APS vendors are for example I2, Manugistics, and Aspen Technology. In addition, most leading ERP vendors, such as SAP and Peoplesoft, also have an advanced planning and scheduling application. As the objective and scope of the larger ERP vendors primarily is to cross-sell APS solutions to their installed base, i.e., especially multinationals in the semi-process industry, the automotive industry, and the aerospace industry, these ERP vendors generally do not have a specific industry focus.

Regional players, such as KIRAN and ROI Systems in the US and Quintiq, Ortec, and OM Partners in Northern Europe focus more on industry-specific APS solutions. They generally offer less functionality than global high-end APS vendors. For the discrete parts manufacturing industry, for instance, regional vendors generally offer APS systems that emphasize lot-sizing, order acceptance, and production planning and detailed scheduling functionality where the manufacturing system of the user is the centre of attention, i.e., internal tactical and operational planning and scheduling functionalities. These APS systems are generally indicated as mid-end systems. In addition, vendors that only offer one or more stand-alone functionalities, for instance an electronic graphical scheduling system (DSS), are generally indicated as vendors of low-end APS systems. Recall that in this study, we primarily focus on mid-end and low-end APS systems aimed for the discrete parts manufacturing industry, where we define an APS to be a software system with at least a graphical interface and decision support functionality based on Operations Research or Artificial Intelligence models for manufacturing planning and scheduling purposes.

There is a dearth of academic literature on APS adoption in general, but on the relationships between APS adoption and the environmental factors in particular. This chapter aims to fill this void, by analyzing the impact of various PMT-uncertainty-related factors (i.e., *complexity*, *rate of change*, and *information deficiency*) on the use of various production planning and control tools.

4.2 Research method and operational definitions

4.2.1 Research method

The objective of this chapter is to extend the model displayed in Figure 3-9 (p. 104). Indeed, the impact of *complexity*, *rate of change*, and *information deficiency* on the use of various production planning and control tools is investigated with the help of the data obtained from the survey discussed in the previous chapter. Again, the analytic procedures in this study include the calculation of descriptive statistics, reliability analysis, factor analysis, and multi-item path analysis (i.e., structural equations modeling) for which we use the statistical software packages SPSS 11 and AMOS 4.0, respectively.

4.2.2 Production planning and control tools

We asked respondents which advanced manufacturing technology and concepts (i.e., FMS, CAD/CAM, Robotics, JIT/lean, and Six Sigma) and which manufacturing and production planning and control applications (i.e., kanban control system, conventional plan board, spreadsheets, Enterprise Resource Planning, and Advanced Planning and Scheduling) their organization use. For APS systems, we primarily focus on mid-end and low-end APS systems aimed for the discrete parts manufacturing industry. Recall that we defined an APS to be a software system with at least a graphical interface and decision support functionality based on Operations Research or Artificial Intelligence models for manufacturing planning and scheduling purposes. Hence, MS-Project, for instance, is not an APS system. In addition, we asked respondents to fill out the vendor's name of ERP and APS software packages to verify whether they are truly ERP and APS systems.

4.2.3 PMT-uncertainty-related factors

In this study, we use the *PMT-uncertainty*-related factors obtained from the exploratory factor analysis (EFA) discussed in Section 3.4.2. In particular, we distinguish *supplier complexity* at the input side of the manufacturing system; on the output side (i.e., demand side), we distinguish *customer order complexity*. Furthermore, we distinguish *end-product complexity* since it is boundary spanning between the market and the internal manufacturing system. In addition we let the internal complexity be represented by *route complexity*. For the factors related to *rate of change*, we only consider the dynamics of the following PMT characteristics in this study: *end-product change*, *customer order change*, and *component and part change*. Finally, we also consider *information deficiency*.

4.3 Results

4.3.1 Analysis of differences between subpopulations

We analyze differences in means of the PMT-uncertainty-related factors *complexity*, *rate of change*, and *information deficiency* for users versus non-users of production planning and control tools (i.e., APS, ERP, spreadsheet, conventional plan board, and kanban control); see Table 4-1.

Kanban control Firms that use *kanban control* have lower levels of *customer order complexity*, are generally larger, and have higher levels of *supplier complexity* than non-users of kanban control. Based on these findings, we confirm the commonly accepted view that kanban users have a more stable demand.

ERP Firms that use ERP are larger than non-users, have more *end-product complexity* and *supplier complexity*. This supports the claim that ERP systems are primarily used as databases to store information, for instance on products and suppliers, and to maintain logistical and financial transactions [254].

Conventional plan boards Firms that use a *conventional plan board* are smaller than non-users and have lower levels of *supplier complexity*.

Spreadsheets Firms that use *spreadsheets* have less information available than non-users; they have higher levels of *end-product change* ($p < .1$).

APS Firms that use APS have lower *customer order complexity* ($p < .1$), and lower *end-product change* than non-APS users. While the construct *end-product complexity* is not related to the use of APS, firms that use APS also manufacture large numbers of end-products, i.e., a higher score on the single item ‘number of end-products’.

Table 4-1 shows that the factors *customer order change*, *component and part change*, and *route complexity* do not discriminate between users and non-users of the various production planning and control tools. In addition, the factor *information deficiency* only discriminates firms that have adopted spreadsheets. This is confirmed by ANOVA analysis for differences in means on the use of production planning and control tools for firms with a high score versus firms with a low score on *size* and *information deficiency*, respectively; see Table 4-2.

Firms with high levels of *information deficiency* significantly use spreadsheets more often, and APS less often, than firms with low levels of *information deficiency*. Furthermore, from Table 4-2, we also observe that large firms predominantly use kanban control systems and ERP more often, and conventional plan boards less often than small firms.

The factor *size* discriminates between users and non-users of ERP systems, kanban control, and conventional plan boards. Furthermore, Table 4-1 shows that firms that indicated to use ERP systems and/or kanban control have higher levels of *supplier complexity* than non-users of these systems, while firms that indicated to use conventional plan boards are smaller and have lower levels of *supplier complexity* than non-users of conventional plan boards. Therefore, the question remains whether *size* is a ‘lurking’ variable in the spurious relationship between *supplier complexity* and the use of these production planning and control tools.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$; E.S. = Effect Size as measured by Cohen's d

		Kanban			**ERP**			**Plan board**			**Spreadsheet**			**APS**		
Construct	**Use**	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.
customer order complexity	No	3.29	.002	.53	3.24	.233	.18	3.21	.542	.12	3.12	.174	− .20	3.24	.079	.37
	Yes	2.86	***		3.09			3.11			3.29			2.93	*	
information deficiency	No	1.94	.115	.27	1.93	.277	.16	1.88	.481	− 16	1.80	.008	− .39	1.93	.139	.30
	Yes	1.77			1.83			1.97			2.03	***		1.75		
size	No	3.11	.000	− .75	3.10	.000	− .55	3.35	.002	− .61	3.27	.886	.02	3.25	.798	− .06
	Yes	3.76	***		3.58	***		2.82	***		3.25			3.30		
customer order change	No	3.74	.393	− .14	3.76	.535	− .09	3.78	.987	− .00	3.84	.219	.18	3.80	.600	.11
	Yes	3.85			3.84			3.79			3.70			3.70		
end-product change	No	3.13	.812	− .04	3.13	.515	− .11	3.14	.563	− .12	3.06	.074	− .28	3.22	.022	.50
	Yes	3.17			3.22			3.23			3.29	*		2.82	**	
supplier complexity	No	2.89	.003	− .60	2.91	.041	− .35	3.08	.007	.32	3.07	.236	.22	3.04	.215	.26
	Yes	3.33	***		3.18	**		2.68	***		2.92			2.82		
route complexity	No	3.36	.127	− .30	3.46	.198	.14	3.42	.513	.05	3.37	.517	− .11	3.39	.457	− .33
	Yes	3.54			3.33			3.34			3.44			3.48		
end-product complexity	No	3.06	.277	− .16	2.94	.001	− .40	3.09	.728	− .16	3.16	.353	.14	3.11	.819	− .02
	Yes	3.24			3.41	***		3.16			3.02			3.06		
component and part change	No	2.96	.206	− .09	3.03	.500	.17	3.00	.987	.15	3.03	.547	.11	3.01	.619	.11
‘	Yes	3.12			2.95			3.00			2.96			2.94		
financial performance	No	2.39	.406	− .16	2.42	.945	− .01	2.38	.225	− .26	2.37	.439	− .12	2.42	.847	.04
	Yes	2.52			2.43			2.60			2.47			2.39		

Table 4-1: Differences in means on factors for users versus non-users of various production planning and control tools.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$: Effect Size as measured by Cohen's d

		Kanban .24			**ERP .35**			**Plan board .18**			**Spreadsheet .44**			**APS .15**		
Construct	**Use**	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.	Mean	Sig.	E.S.
information deficiency	Low	.26	.563	.09	.37	.524	.10	.15	.261	− .16	.34	.007	− .39	.22	.009	.40
	High	.22			.32			.21			.53	***		.08	***	
size	Small	.12	.000	− .58	.22	.000	− .52	.24	.025	.32	.45	.710	.04	.16	.624	.03
	Large	.36	***		.46	***		.12	**		.43			.14		

Table 4-2: Differences in means on the use of production planning and control tools for firms with low/high score on *information deficiency* and *size*, respectively.

4.3.2 A structural equations model

To explore the impact of the PMT-uncertainty-related factors on the use of various types of production planning and control tools and to investigate possible spurious relationships by the factor *size*, we also developed an exploratory SEM model. To keep the chapter concise, we do not display the full measurement model but we refer to the hybrid model displayed in Figure 4-1 instead.

Construct 1	Construct 1	Covariance	*p*
customer order complexity	*information deficiency*	.20	.004
customer order complexity	*end-product complexity*	− .42	.002
supplier complexity	*customer order complexity*	.45	0
size	*supplier complexity*	.26	0
Kanban	*customer order complexity*	− .06	.008
Kanban	*size*	.09	.001
Kanban	*supplier complexity*	.11	.002
Kanban	ERP	.04	.004
Plan board	*size*	− .05	.039
Plan board	Spreadsheet	.03	.052
ERP	Plan board	− .04	.002
ERP	*end-product complexity*	.17	.001
ERP	Spreadsheet	− .04	.007
APS	Spreadsheet	− .03	.039
ERP	APS	− .04	.003

Table 4-3: Estimated covariances in the measurement model.

Again, support for convergent validity is somewhat problematic, since the error-terms of some items are high and the explained variance of some items is low, which might make estimates of factor loadings and path coefficients in a path model less reliable. For instance, only 12% of the variance of the item ‘number of production steps subcontracted’ is explained by this model. We also tested the model without this item, but this does not lead to great differences. Furthermore, since there have not been established cut-off/threshold values for measurement errors in literature, we continue our analysis based on this final measurement model for which all factor loadings and covariances are significant ($p < .05$). The covariances from the final measurement model are displayed in Table 4-3. From this table, we observe that *supplier complexity* is the only PMT-uncertainty-related factor that correlates with *size*. Therefore, we need only to investigate the relationships between *supplier complexity* and the various production planning and control tools on possible spurious relationships.

The hybrid measurement-path model displayed in Figure 4-1 just fits the data according to relative fit indices ($df = 297$, $\chi^2 = 567.227$, $p_{model} = .000$, CFI = .980, TLI = .976, NFI = .976, and RMSEA$_{[.051,.070]}$ = .067). Although numerous factors influence the adoption and use of a specific production planning and control system, we only include PMT-uncertainty-related factors in this model. As a result, only 5-24% of the variance of each endogenous variable is explained by this model.

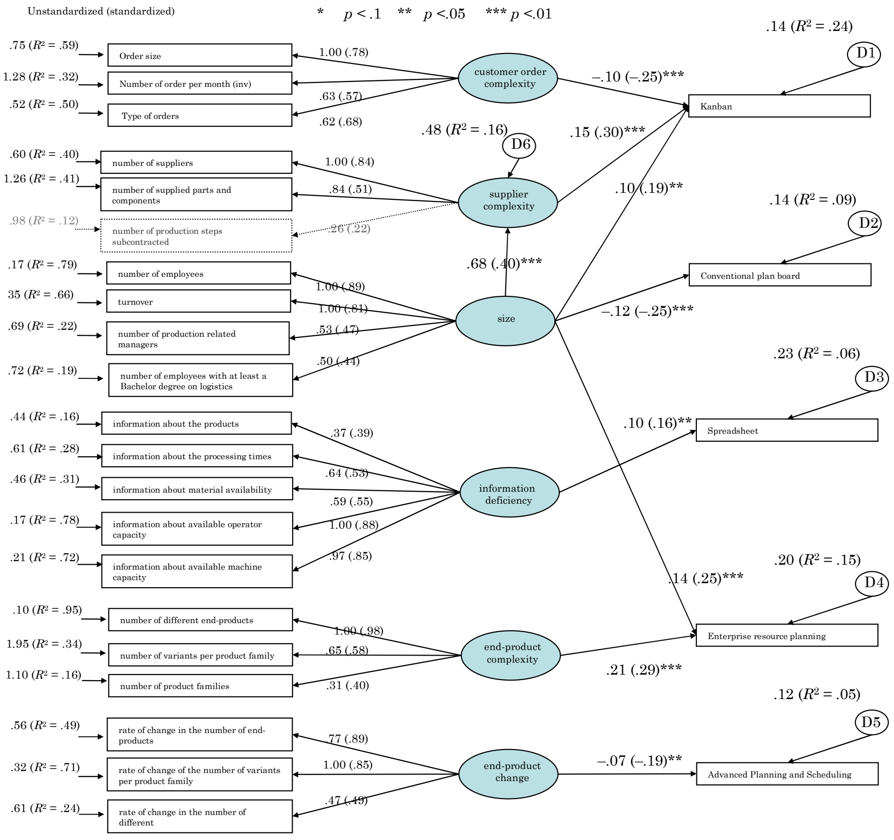


Figure 4-1: Exploratory SEM model of causal effects of PMT-uncertainty-related factors on the use of production planning and control tools (df = 297, χ^2 = 567.227, p_{model} = .000, CFI = .980, TLI = .976, NFI = .976, and RMSEA$_{[.051,.070]}$ = .067).

From Figure 4-1, we also notice that the higher the level of *supplier complexity*, the more a firm is likely to use kanban control. In addition, *size* indirectly and directly influences the use of kanban control; the total impact of *size* on the use of kanban control is .31 (i.e., .40 times .30 plus .19). In addition, there are no significant relationships between *supplier complexity* and the use of ERP and conventional plan boards. The use of these production planning and control tools is (partly) predicted by *size*, not *supplier complexity*. Put differently, users of ERP systems have higher levels of *supplier complexity* because these firms are larger than non-users of ERP systems. Moreover, users of conventional plan boards have lower levels of *supplier complexity* because these firms are smaller. Thus, we ought to adjust the structural equations model displayed in Figure 3-9.

The less information is available, the more a firm relies on spreadsheets only. In addition, *end-product change* is negatively related to the use of an APS system. This supports a proposition of Stadler and Kilger [210] that APS systems to date lack the functionality to cope with dynamic and stochastic environments. However, from the results of this study, we question whether *rate of change* will ever be an important discriminating factor for production planning and control tools and a trigger to use information technology like APS.

Finally, based on this model, we confirm the commonly accepted proposition that ERP systems are predominantly adopted by larger firms and used as a transactional database to centrally store information, such as product and supplier information: the higher the level of *end-product complexity* is, the more a firm is likely to use an ERP system.

4.4 Discussion

4.4.1 Insights and implications

In the previous section, we investigated the impact of different PMT-uncertainty-related factors on the use of various production planning and control tools. The objective of this section is to investigate whether the results can be explained with existing theory. This section aims to discuss and reflect the findings of this study with the findings in literature and to extend theory by formulating six corollaries.

From the structural equations model displayed in Figure 4-1, we observe that the explained variance in the variables related to the various production planning and control tools is fairly low (i.e., 5-24%). Hence, internal and external PMT-uncertainty-related factors are only moderate predictors of the use of a production planning and control tool. This leads to the following corollary.

> **COROLLARY 4-1:** *PMT-uncertainty has only a small impact on the use of a specific production planning and control tool.*

From Table 4-1, we also deduce that the factors *customer order change*, *component and part change*, and *route complexity* do not discriminate between users and non-users of the various production planning and control tools. For the factors related to rate of change, these findings may be biased because of the low reliability of the corresponding operationalizations (i.e., low values for the

Cronbach's alphas). However, an ANOVA analysis on all single items related to *rate of change* also resulted in non-significant differences.

Numerous research (e.g., [95][210][254]) claim that the state-of-the-art production planning and scheduling tools are unsuitable because of internal complexity and technological constraints (i.e., precedence relations) in manufacturing environments. Indeed, a remarkable finding is that the level of *route complexity* does not discriminate users from non-users of different types of production planning and control tools. We, therefore, formulate the following metaphorical corollary.

COROLLARY 4-2: *Route complexity does not discriminate between users and non-users of different types of production planning and control tools.*

This finding is also remarkable in the context of group technology. It is well-known that group technology aims to reduce complexity (and route complexity in particular) by the implementation of product-oriented cells where dissimilar machines are located in close proximity and dedicated to the manufacture of a family of parts. Due to this simplified operations technology, the centralized production planning and control system may be replaced by simpler local scheduling systems [217]. Subsequently, the group operating the cell is given the delivery schedule for that cell's products, and the group then takes responsibility for deciding actual equipment schedules, labor hours, and priorities. The idea is that the aggregated production planning and control system and the simplified structure of the cell allow manual scheduling and dispatching procedures, for instance with the help of a conventional plan board or spreadsheets) in the cell. Recall that the cells at Urenco Aerospace were also planned and scheduled by spreadsheets and that they had been temporally managed based on a low-end APS system. In this case, the production planning and control task boils down to assigning delivery schedules, allocating material, and inter-cell coordination. Wemmerlöv and Johnson [237] indicate that more than 60 percent of the firms that have installed cells have simplified production planning and control procedures, including visual plan boards centrally located on the shop floor [219] and spreadsheets for production planning and order release.

End-user computing, and especially the use of spreadsheets, is an important part of organizational computing to date [47]. The adoption of the spreadsheet software in finance and accounting seems to be led primarily by the end-users [38], not the IT department. Chan and Storey [47] state that this resulted in the use of complicated spreadsheet models, which, linked together, lead to even larger models. There is no reason to expect this to be different in manufacturing. For production planning, spreadsheet models generally do not take various constraints into account, nor do they have sufficient decision support functionality to obtain good planning results [129]. Advanced planning and scheduling systems give better results, provided that accurate data are available. But what if there is lack of data? According to our findings, lack of data forces firms to use spreadsheets. Indeed, spreadsheets are highly flexible, can be used locally, and immediately when information becomes available. In addition, spreadsheets are in principle user-friendly and adaptable to the specific needs of individual users, even on the shop floor.

COROLLARY 4-3: *Lack of data forces firms to use spreadsheets.*

In contrast, ERP systems require many accurate data, including data elements that are generally not maintained in spreadsheets. This is even more true for APS systems [129].

Zijm [254] states that the state-of-the-art APS systems have integrated hierarchical planning architectures with Linear Programming tools for aggregate production and capacity planning, and sometimes advanced shop floor scheduling systems at a low level in make-to-order production environments. However, stochastic models that explicitly address demand or process uncertainties are absent in APS systems [254]. Today's APS systems are not very good in coping with uncertainty—they require a very detailed product structure; data like routings and BOMs are generally not maintained in a quality format requested by an APS system [129]. This is partly confirmed by the findings of Table 4-2, which shows that firms with high levels of information deficiency have predominantly less often adopted an APS system. In addition, from the structural equations model displayed in Figure 4-1, we observe that *end-product change* is negatively related to the use of an APS system.

COROLLARY 4-4: *End-product change is negatively related to the use of an APS system.*

Kilger [129] argues that the use of an APS system requires a precise review of the available data; '*...the data maintenance process in place is an important input to make an assessment about the required effort for an APS implementation project...*'. As a result, APS implementation projects can become extremely expensive. In concordance with ERP systems, we therefore also expected that large firms have higher APS adoption rates than small firms, since firm size discriminates users from non-users of many technologies, including ERP systems [58][87]. This is, as mentioned before, because larger firms have larger financial ICT budgets, more functional specialists, and larger internal mass media and communication exposure. This is, however, not confirmed by our results. Nevertheless, it is worth noting that in this context, the structural equations model does indicate that *size* is negatively related to the use of a conventional plan board.

COROLLARY 4-5: *Size is negatively related to the use of a conventional plan board.*

If firms become larger and have higher levels of *supplier complexity*, the use of a conventional plan board becomes impractical. Moreover, larger firms have higher levels of sophistication and financial contingencies to adopt planning alternatives, for instance kanban control systems.

COROLLARY 4-6: *Size is a stronger predictor for the use of kanban control systems than PMT-uncertainty.*

In principle, kanban control systems reduce production planning and control complexity by creating product-oriented flows and transparent production processes. However, the path model shows that there is a direct relationship between firm size and the probability of using kanban control. Smaller companies are often confronted by limitations of time, capital, and internal expertise in attempting to explore and implement kanban-based control. In addition, there is evidence that JIT implementation is more advanced in large manufacturers with automated and repetitive processes [85][122][240].

Effect Size as measured by Cohen's *d*

			Kanban	
Construct (sample mean)	**user**	**Mean**	**Sig.**	**E.S.**
number of employees (3.39)	No	3.25	.000	− .63
	Yes	3.82	**	
number of employees with at least a bachelor degree in logistics (2.06)	No	1.97	.015	− .38
	Yes	2.35	**	
extent to which complete product information is unavailable at the time of planning (1.57)	No	1.63	.039	− .35
	Yes	1,39	**	

Table 4-4: Differences in means on statements for users of a kanban system versus non-users of a kanban system.

The PMT-uncertainty-related factors and the single items used in this study, show that the use of kanban control and JIT/lean is predominantly predicted by size and sophistication, and not by complexity; see Tables 4-1 and 4-4. Nevertheless, firms that use kanban control have on average more product information available than non-users.

Since we also asked respondents which advanced manufacturing technology and concepts (i.e., FMS, CAD/CAM, Robotics, JIT/lean and Six Sigma) they were using, we also performed an ANOVA analysis on the PMT-uncertainty-related factors for users/non-users of the JIT/lean concept; see Table 4-5. From this table, we observe that JIT/lean users also have lower levels of *customer order complexity*, are on average larger, but also have higher *route complexity* ($p < .01$), *end-product complexity* ($p < .1$), and *supplier complexity* ($p < .1$) than non-users. Hence, we conclude that *size* (measured by the number of employees) and *sophistication* (measured by the the number of employees with at least a bachelor degree in logistics) is a better predictor for the use of kanban control than *complexity*. Nevertheless, users of kanban control have on average lower *customer order complexity* than non-users. Hence, we may detail corollary 4-6 into corollary 4-6b:

> **COROLLARY 4-6B:** *Kanban control is predominantly used in large manufacturing firms that have low levels of customer order complexity.*

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$
Effect Size as measured by Cohen's d

Construct	JIT/lean user	Mean	JIT Sig.	E.S.
customer order complexity	No	3.27	.038	.65
	Yes	2.96	**	
information deficiency	No	1.93	.279	.17
	Yes	1.82		
size	No	3.08	.000	– .79
	Yes	3.78	***	
order dynamics	No	3.11	.394	– .08
	Yes	3.23		
end-product complexity	No	3.07	.072	– .31
	Yes	3.41	*	
supplier complexity	No	2.92	.072	– .30
	Yes	3.25	*	
component and part change	No	3.75	.620	– .09
	Yes	3.81		
route change	No	2.42	.543	.10
	Yes	2.35		
route complexity	No	2.84	.000	– .71
	Yes	3.41	***	
financial performance	No	2.37	.276	– .09
	Yes	2.54		

Table 4-5: Differences in means on factors for users versus non-users of the JIT/lean concept.

4.4.2 Limitations

Single-informant survey-data from an exploratory perspective may cause informant biases. However, since most respondents were manufacturing managers (46%) or technical managers (8%), like the interviewees at the firms where we pre-tested the questionnaire, we believe that our clear Likert-type answering options have precluded inconsistent answers, since the interviewees were very well acquainted with the levels of *complexity*, *rate of change*, and *information deficiency* in their manufacturing environment. Potential limitations of generalizing the results to all industrial firms results from the type and size of most Dutch discrete parts manufacturing firms; they are smaller than their U.S. counterparts, for instance. Furthermore, we only asked whether the respondent was using specific production planning and control tools (i.e., kanban control, conventional plan board, spreadsheet, ERP, and APS); we made no distinction between various implementations stages, such as adoption and infusion [144]. However, the statistical significance of the ANOVA results provides us with a reasonable level of protection against spurious and unreliable findings.

Finally, some critics may insist on analyzing tetrachoric correlation matrices because of the inclusion of dichotomous variables in the structural equations model displayed in Figure 4-1, or the use of alternative models that “fit” the type of scales under consideration such as logistic regression models. There are, however, two major reasons to continue to use structural equations modeling as our standard analytic procedure. First, the analysis of a tetrachoric correlation matrix requires sample sizes of more than 2000 respondents to obtain reliable results [274]; there are, however, only few statistical packages available with the required functionality (e.g., EQS, PRELIS) and these software packages can handle only 20-25 variables at maximum [238]. West el al. [238] states that perhaps the only option would probably be to treat the ordinal data as continuous and estimate the model(s) by Maximum Likelihood. Second, the use of logistic regression implies the need to analyze five separate models without having the advantages of an inherent measurement model. What is more, logistic regression does not allow the analysis of relationships between the independent variables.

5 The impact of innovation and organizational factors on APS adoption

Due to the globalization and technological developments, in particular in information and communication technology, market demands are changing rapidly. The resulting increase in environmental and organizational uncertainty prompts the need for flexible and intelligent production planning and control technologies [52] such as Advanced Planning and Scheduling (APS) systems. These systems simultaneously support material coordination and planning and scheduling of scarce resource capacity [210].

In Chapter 4, we analyzed the impact of the PMT-uncertainty-related factors on various production planning and control tools among which APS. It turned out that, except of the factor *end-product change*, the PMT-uncertainty-related factors do not discriminate APS-adopters from non-adopters. However, respondents of the first questionnaire that indicated to use an APS system also indicated to manufacture a large number of end-products. The question remains, therefore, what organizational and innovation specific factors discriminate APS adopters from non-adopters. However, much research on APS systems focuses on algorithms behind the screen of these systems [138][210][254]. Less research is conducted on APS adoption issues from a factors approach. Nevertheless, any technology adoption is best understood by analyzing and understanding the various contextual factors both from within and from the external environment that resulted in adoption of the technology [52][144][188]. The factors approach attempts to identify static factors that influence the adoption of a technological innovation.

The scarcity of relevant APS adoption publications is partly because APS is a relatively new technology with a moderate adoption rate. The nature of any APS adoption study is therefore exploratory. In this chapter, we investigate the impact of innovation and organizational factors on APS adoption. Hence, this chapter addresses the questions "what is the state-of-the-art of advanced planning and scheduling in the discrete parts manufacturing industry?", and "what is the impact of innovation and organizational factors on APS adoption?" The main contribution of this chapter is a model that embeds these characteristics of APS adoption into the general innovation adoption theory.

The outline of this chapter is as follows. In Section 5.1, we briefly discuss an APS adoption meta-model with both innovation and organizational characteristics. In Section 5.2, we discuss the various propositions in more detail. In Section 5.3, we discuss the research method and the development of *a second* *questionnaire*. In Section 5.4, we provide operational definitions of the constructs. In Section 5.5, we present the results of a non-parametric statistical analysis for associations between the innovation and organizational constructs and APS adoption. Furthermore, we search for spurious relationships. These analyses lead to two conceptual models: a basic conceptual APS adoption model without any spurious relationships and an extended model with possible spurious relationships. In Section 5.6, we apply structural equations modeling to analyze these relationships in more detail. Finally, in Section 5.7, we end this chapter with a brief discussion of the findings and the managerial implications, as well as conclusions and directions for further research.

5.1 Possible factors that influence APS adoption

To our best knowledge, there do not exist any 'factors' studies on APS adoption. As a result, the theory discussed in this section is adapted from strongly related work, such as adoption and implementation research on Enterprise Resource Planning systems [34][56][147], Advanced Manufacturing Technologies [24][207][252], and Computer Aided Manufacturing [84].

Seminal in the area of innovation research is the work of Rogers [191], who describes diffusion of an innovation as the process by which an innovation is communicated through certain channels over time among the members of a social system. It is generally assumed that this theory also holds for organizations as a social system on its own. Furthermore, Rogers [191] states that the rate of adoption, i.e., the relative speed by which an innovation is adopted, depends on the opinion of the organization about the relative advantage, the compatibility, the complexity, the trialability, and the observability as characteristics of the innovation. In addition, a review by Kwon and Zmud [144] of the literature on the relationship of organizational innovation and information systems implementation identifies a number of variables that contribute to the successful introduction of a technological innovation in an organization. These variables are categorized into individual, organizational, innovation, and task-related variables, where the contribution of each variable to the implementation of the innovation depends on the specific situation. Organizational task-related variables have been indirectly addressed in the previous chapter since uncertainty, because of the PMT characteristics, affects the tasks to be done by the firm. In addition, as the adoption of an APS system exceeds individual decision-making and individual task-related activities, we consider only the *innovation characteristics* and the *organization characteristics* in this chapter.

Innovation characteristics In a meta-analysis of the innovation characteristics literature, Tornatzky and Klein [227] identify ten important innovation characteristics: compatibility, relative advantage, complexity, cost, communicability, divisibility, profitability, social approval, trialability, and observability. We also use these innovation characteristics except for profitability (since it coincides with relative advantage), social approval (since we expect it to have no relevance for APS adoption), communicability (since it corresponds to observability), and divisibility (since it is closely related to trialability—i.e., an indivisible innovation has limited trialability). In addition, we include some 'new' innovation-related characteristics: adaptation [209], other users' opinions [67], and vendor support [84][90][163].

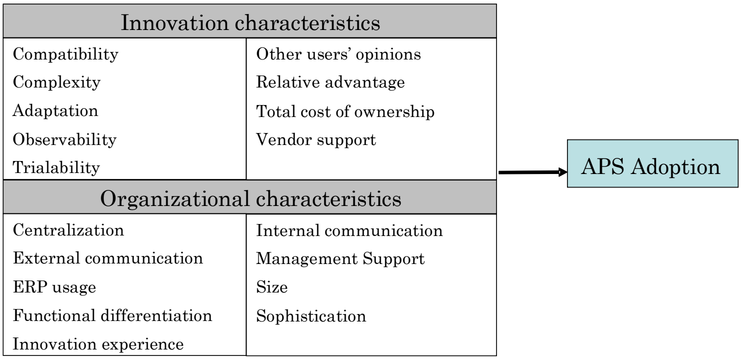


Figure 5-1: Factors with a possible effect on APS adoption.

Organizational characteristics In a meta-analysis of the adoption of innovations in organizations, Damanpour [55] identifies positive relationships between innovation and specialization, functional differentiation, sophistication, managerial attitude toward change, technical knowledge resources, administrative intensity, slack resources, external communication, and internal communication. We do not include all these characteristics of organizational innovation in our research, because they are either more applicable to the adoption of an innovation by an individual (e.g., managerial tenure), or enveloped by other characteristics. We omit technical knowledge resources, since it coincides with sophistication. The latter may also comprise the educational level of employees [33][148]. Furthermore, as they are frequently mentioned in other studies, we also add the organizational characteristics innovation experience [84][89] and size [21][24][132][148][226][253] into our APS adoption model. In addition, since an APS system requires detailed data that is generally stored in, and provided by an ERP system, we also include 'ERP usage' as an organizational characteristic. In summary, we decided to use the following organizational characteristics: ERP usage, external communication, functional differentiation, innovation experience, internal communication, management support, size, and sophistication.

We also investigated possible relationships between APS adoption and environmental characteristics, such as economical condition, market demand characteristics, and the competitive position of respondents, but we found no significant relationships between these variables and *APS adoption*. Note that this concurs with the findings discussed in the previous chapter. As a result, we only discuss the possible relationships between the selected characteristics in the categories innovation and organization, and the decision to adopt an APS system. This meta-proposition is displayed in Figure 5-1.

5.2 Detailing the propositions

We discuss a number of propositions to state the expected directions of the relationships between the innovation and organizational characteristics and APS adoption, displayed in the APS adoption meta-model.

5.2.1 Innovation characteristics

Compatibility Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters [227]. The perceived compatibility of an innovation is positively related to its rate of adoption [191]. Furthermore, Kwon and Zmud [144] state that compatibility is often cited to determine the success of an innovation. Hence, we expect to find a positive relationship between compatibility and APS adoption.

PROPOSITION 5-1: *Compatibility of an APS system is positively related to APS adoption.*

APS complexity Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. In a study on client/server technology adoption, Prakash [185] states that organizations may be unwilling to adopt an innovation if they consider it beyond their ability to comprehend and use. In addition, Venkatesh and Davis [231] conclude that perceived ease of use has a positive influence on increasing the user acceptance of a technological innovation. Hence, complexity of the innovation is negatively related to actual adoption of the innovation [84][144][191][227]. We, therefore, expect to find a negative relationship between APS complexity and APS adoption

PROPOSITION 5-2: *Complexity of an APS system is negatively related to APS adoption.*

Adaptation Adaptation is the degree to which an innovation can easily be adapted for its future, and possibly changing, working environment. Lack of adaptation of Enterprise Resource Planning systems is frequently cited as a pitfall of implementation projects [56][147]. We postulate that if an APS system can easily be adapted into an organization's specific environment, it has a higher rate of adoption. Hence, we expect to find a positive relationship between adaptation and APS adoption.

PROPOSITION 5-3: *Adaptation of an APS system is positively related to APS adoption.*

Observability Observability is the degree to which future benefits of an innovation can be made easily visible to organizational members. Observability of an innovation is positively related to its rate of adoption [191][231]. Hence, we expect to find a positive relationship between observability and APS adoption.

PROPOSITION 5-4: *Observability of an APS system is positively related to APS adoption.*

Other users' opinions Other users' opinions is the degree to which a potential adopting organization attaches importance to the opinions of other APS adopters [67]. The experiences others gained while adopting an APS system can help an organization to overcome barriers in adopting and implementing an APS system [191][188]. Hence, we expect to find a positive relationship between other users' opinions and APS adoption.

PROPOSITION 5-5: *Other users' opinions about an APS system is positively related to APS adoption.*

Relative advantage Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes. A perception of relative advantage of the innovation over existing or alternate products or processes has been found to be positively related to adoption and implementation [144][187][188][227]. In addition, McGowan and Madey [163] state that there is a positive relationship between relative advantage and the extent of EDI implementation, which is consistent with the research of Ettlie and Vellenga [68] on the adoption of transportation related innovations. Prakash [185] provides evidence that relative advantage is a predictor of successful client/server technology adoption. Hence, we expect to find a positive relationship between relative advantage and APS adoption.

PROPOSITION 5-6: *Relative advantage of an APS system is positively related to APS adoption.*

Total cost of ownership The costs of an innovation consist not only of the initial purchase costs but also comprise the costs of implementation and maintenance. Costs are generally assumed to be negatively related to the adoption and implementation of an innovation [227]. The higher the costs of an innovation, the more likely it will not quickly be adopted and implemented, due to increasing chances on low return on investment. This relationship is, of course, strengthened by uncertainty about future revenues because of the innovation. In addition, Bingi et al. [34] state that uncertainty of future implementation costs hinders adoption. Hence, we expect to find a negative relationship between total cost of ownership and APS adoption.

PROPOSITION 5-7: *Total cost of ownership of an APS system is negatively related to APS adoption.*

Trialability Trialability is the degree to which an innovation may be experimented with before definitive purchase. The trialability of an innovation is positively related to its rate of adoption [188]. This is confirmed by Prakash [185] in that trialability is a predictor of successful adoption of client/server technology in organizations. Hence, we expect to find a positive relationship between trialability and APS adoption.

PROPOSITION 5-8: *Trialability of an APS system is positively related to APS adoption.*

Vendor support Vendor support is the degree to which the vendor of an innovation gives support during the decision phase and during the implementation process. Vendor support is positively related to adoption and implementation, because support given by the vendor will help to reduce uncertainty in the innovation process. Ettlie [64] concludes that the vendor-user relationship is an important determinant of successful implementation of manufacturing technologies. McGowan and Madey [163] state hat vendor support can help an organization make greater use of EDI software. Hence, we expect to find a positive relationship between vendor support and APS adoption.

PROPOSITION 5-9: *Vendor support of an APS system is positively related to APS adoption.*

5.2.2 Organizational characteristics

ERP usage ERP systems generally have no intelligent planning and scheduling functionality [210][254], although some ERP vendors offer their customers APS add-ons. What is more, ERP caters for the data required by the APS system. Hence, we expect to find a positive relationship between the use of an ERP system and APS adoption.

PROPOSITION 5-10: *ERP usage is positively related to APS adoption.*

External communication External communication indicates the degree to which the organization is in active contact with its environment. Rogers [191] states that earlier adopters have more social participation, are more highly connected in the interpersonal networks of their system, are more cosmopolite, have more ‘change agent’ contact, have greater exposure to mass media channels, have greater exposure to interpersonal communication channels, and engage in more active information seeking. Organizations are continually identifying problems and considering alternative solutions, attempting to match solutions to problems. Organizations frequently scan the environment looking for solutions or to see how other organizations have dealt with similar problems. Organizations that engage more in this type of activity are more likely to find solutions to their problems [38][55][163][253]. Hence, we expect to find a positive relationship between external communication and APS adoption.

PROPOSITION 5-11: *External communication is positively related to APS adoption.*

Functional differentiation Functional differentiation represents the degree to which an organization is divided into different departments. Baldridge and Burnham [21] conclude that complex organizations are more likely to adopt innovations than simple organizations, since differentiation produces specialists searching for new solutions to the 'task demands' within their specialized realms. This is confirmed by Kimberly and Evanisko [132] and McGowan and Madey [163]. Furthermore, Kwon and Zmud [144] state that there is a positive relationship between functional differentiation and the adoption of technological innovations. We, therefore, hypothesize to find a positive relationship between functional differentiation and APS adoption.

PROPOSITION 5-12: *Functional differentiation is positively related to APS adoption.*

Innovation experience Innovation experience is the degree to which an organization has successfully adopted innovations in the past. Gerwin [84] states that the adoption of an innovation is greatly facilitated by previous successful adoptions of technological innovations. Problem solving experience gained from these previous adoptions and implementations helps to reduce difficulties in adopting and implementing future innovations [90][155]. Hence, we expect to find a positive relationship between innovation experience and APS adoption.

PROPOSITION 5-13: *Innovation experience is positively related to APS adoption.*

Internal communication Internal communication indicates the degree to which the organization internally communicates between different departments. Brancheau and Wetherbe [38] argue that potential adopters of innovations strongly favor the use of internal/interpersonal channels of communication. Internal communication facilitates dispersion of ideas on the innovation in the organization. In addition, Bingi et al. [34] state that implementing an ERP system requires negotiation between departments. We postulate that this also holds for APS systems. Hence, we expect to find a positive relationship between internal communication and APS adoption.

PROPOSITION 5-14: *Internal communication is positively related to APS adoption.*

Management support Management support is the degree to which management supports the entire process of adoption and implementation of innovations; hence, management support is positively related to adoption of an innovation [21][53] [163]. Premkumar et al. [187] state that management that recognizes strategic opportunities from the innovation would be more willing to facilitate adoption and implementation. This is confirmed by the study of Thong and Yap [226] in which they state that organizations that have a management with a positive attitude towards an innovation are more likely to adopt the innovation. Hence, we expect to find a positive relationship between APS adoption and management support.

PROPOSITION 5-15: *Management support is positively related to APS adoption.*

Size The size of an organization is positively related to the adoption and extent of implementation of an innovation [132][148][163]. On the one hand, size enables innovations as it is relatively easy to allocate required resources [186][252]. In addition, Thong and Yap [226] argue that small businesses face more barriers to adopt innovations because of their inability to allocate sufficient resources. On the other hand, size induces the need to innovate, for example to cope with coordination and control problems [21]. Hence, we expect to find a positive relationship between APS adoption and size.

PROPOSITION 5-16: *Size is positively related to APS adoption.*

Sophistication Sophistication is the degree to which an organization is knowledgeable about an innovation and required skills and processes. Sophistication is positively related to the adoption of technical innovations [33][55][163]. Chew et al. [50] conclude that know-how and know-why is needed for successful implementation of new technologies. According to several studies, early adopters are more highly educated or have a greater knowledge of innovations [38][130][188][226]. In addition, Zhao and Co [252] studied the adoption and implementation of advanced manufacturing technologies and found technical knowledge to be a significant determinant of successful usage of advanced manufacturing technology. Hence, we expect to find a positive relationship between APS adoption and sophistication.

PROPOSITION 5-17: *Sophistication is positively related to APS adoption.*

5.3 Research method

5.3.1 Population and sample selection

The data for this study were collected in 2002 through a second comprehensive mail survey among Dutch discrete parts manufacturing firms listed in a commercial database for manufacturing firms with more than 20 employees. The manufacturing firms selected belonged to International Standard Industrial Classification of all Economic Activities (ISIC) codes 20 and 27…36; see Table 5-1 (p. 134). Hence, these selected firms are, again, from discrete parts manufacturing industries as they involve the manufacture of discrete products, primarily of metal and non-metal fabrication, and exclude all process industries.

Recall that in 2002 there were in total 20,625 Dutch firms listed under the ISIC codes under study. Note that Dutch discrete industrial firms are notably small and medium sized enterprises (SME). According to CBS [i] there were only 5020 Dutch firms with more than 20 employees; i.e., 75% of the Dutch firms (with above mentioned ISIC codes) have less than 20 employees. Hence, the population under study is 5020 firms. We randomly phoned 600 of these firms to inquire their willingness to participate in this research, where we primarily asked for an Operations Management employee responsible of renewal and innovation of production planning and control procedures and systems. Almost 47% of the firms agreed to participate, so a package containing a cover letter, a questionnaire, and a pre-paid reply envelope, was sent to 279 firms. In the cover letter, the purpose and necessity of this study were explained, the term APS system was defined, the design of the questionnaire was explained, and the respondents were assured of confidentiality. The definition we used for an APS system was: 'An APS system is a software system with at least a graphical interface and decision support functionality based on Operations Research or Artificial Intelligence models for manufacturing planning and scheduling purposes'. 103 respondents returned the questionnaire within 6 weeks, so there were 176 initial non-respondents. We then decided to phone the firms of which we suspected not to have returned the questionnaire to inquire whether they had sent back the questionnaire yet. If not, we asked again to still fill it out and return it. 27 non-respondents could not be re-contacted, or were not willing to be contacted by phone again. 48 firms said that, at second thought, they would not fill out the questionnaire, while 14 firms said they already had sent it back (this could be true because respondents were offered the option to fill out the questionnaire anonymously) and 87 firms indicated that they still would send it back. From this group of 87 firms, we had to resend the questionnaire to 59 firms because they had misplaced the questionnaire. In this second round, 41 firms eventually returned the questionnaire.

In all, there were 144 questionnaires returned. However, responses from eight firms were excluded from the final sample because these firms did not fulfill the criterion of a discrete parts manufacturer, or the package was sent back as 'undeliverable'. Hence, we have 136 useful responses and a final response rate of 22.6% of the original sample, which is acceptably high compared to other mail surveys reported in literature [140][161].

5.3.2 Respondents and non-response bias

To analyze the representativeness of the sample, we compare the distribution of the organizations in the sample among the various sectors in the discrete parts manufacturing industry and the distribution of the number of employees of the organizations in the sample with these distributions in the whole population. Therefore, we use the following two items: 'total number of employees of the organization' and 'sector the organization operates in'. To check whether the respondents are indeed representatives of our target-respondents, we use the item 'respondent's function in the organization'.

ISIC code	Industry description	No. (%) of responses
20	Wood and products of wood and cork	3 (2.2)
27, 28	Basic metals and fabricated metal products	81 (59.7)
29, 30,	Machinery and equipment	20 (14.7)
31, 32, 33	Electrical machinery and apparatus	7 (5.1)
34, 35	Transport equipment	1 (.7)
36	Furniture & manufacturing n.e.c.	7 (5.1)
	Other	17 (12.5)
Total		**136 (100.0)**

Table 5-1: Distribution of sectors in the sample.

Representativeness of the sample We first list the sectors in which the responding firms are active; see Table 5-1. From this table, we observe that the majority of firms is operating in the sector 'basic metals and fabricated metal products'. If the ISIC classification for a firm could not be determined, because the respondents failed to identify their firms, the firm was classified as 'other'. Respondents from firms in the process industry were omitted immediately.

From the comparison of the distribution of the different sectors of the 136 responding firms and the distribution of the entire population (according to CBS), we observe that the sector 'basic metals and fabricated metal products' is a little overrepresented in our sample. However, since this is the most important group in the entire population, we do not expect this to cause problems with generalizability. In addition, comparing the distribution of the number of employees of the organizations in the sample with the distribution of the number of employees of the organizations in the entire population does not reveal any bias.

Respondents For the type of respondent, we conclude that at least 45% were operations managers. As the letter that accompanied the questionnaire primarily asked the survey be completed by an Operations Management employee responsible of renewal and innovation of planning procedures and systems, some firms decided that this responsibility remained with the general manager, the IT manager, or even an operational IT employee in case of the smaller firms. In addition, a brief investigation by telephone indicated that some operations managers passed the survey on to their responsible specialist or planner. As a result, 13% of the respondents are operational Operations Management specialists or planners; see Table 5-2.

Type of respondents	No. (%) of responses
Manager OM	62 (45.6)
Manager IT	12 (8.8)
Manager General	24 (17.6)
Operational OM (Planners and Specialists)	18 (13.2)
Operational IT	2 (1.5)
Unknown	18 (13.2)
Total	136 (100.0)

Table 5-2: Function of respondents.

Non-response bias As we actively re-phoned non-/late-respondents to fill out and return the questionnaire, we again consider the group of late-respondents to be equivalent with the group of non-respondents for purpose of non-response bias tests. An ANOVA analysis on the 30% earliest respondents with the 30% latest respondents of the number of employees and the turnover gave no reason to assume any form of non-response bias; see Figure 10-3 and Figure 10-4 in the appendix (page 266).

APS and ERP validity and APS adoption bias A reportedly adopted APS which turns out not to be a true APS undoubtedly harms the results of our analysis. To anticipate on this problem, we asked the respondent to indicate the vendor's name, which gave us the opportunity to check whether the system really is an APS system. A similar procedure was performed for ERP systems. Based on the outcome, we concluded that six organizations had not implemented a real APS system. One respondent proved to be useless for this study, as he did not fill out the primary question whether the firm had adopted an APS system or not. These organizations were removed from the sample for the statistical analysis of our hypotheses, but not for construct reliability analysis. In all, we had 129 responses, from which 19 had adopted a real APS system, which is 14.7% of the respondents. We calculated the percentage of APS adopters of the respondents for all questions separately, and found that these percentages varied from 14.1% to 18.1%. As a result, we conclude that APS adoption does not cause any response bias of APS adopters and non-adopters.

5.3.3 Questionnaire development

In this study, we also used constructs that cannot be measured directly (i.e., latent variables); hence, they had to be operationally defined, by one or more observed items [88]. Content validation was assessed through the theoretical basis for the items in literature, and through pre-testing of the preliminary draft of the questionnaire in five organizations that had adopted an APS system. Furthermore, we followed the guidelines for writing questions presented by Fink and Kosecoff [71]. For all questions, we used 5-point scales as much as possible to facilitate the use of statistical analysis without recoding. To prevent a respondent from skipping a question or randomly ticking an answer because he does not know the answer, we once and a while included the option 'Not known'. Note, however, that this option also provides an easy escape for more difficult questions. The same holds for the option 'Not applicable', which we also occasionally used. Furthermore, we occasionally allowed the respondents to give multiple answers. Finally, we developed a comprehensive questionnaire of 74 items to represent all constructs and to check for response bias and authenticity of APS and ERP adoption. We divided the questionnaire into six parts, each concerned with a different topic. The first four parts were used to profile the respondents; the first part contained questions regarding general information about the firm, the second part contained questions about the market in which the firm operates, the third part contained questions about the manufacturing processes in the firm, and the fourth part contained questions about the way of planning in the firm. In the fifth part, the respondent had to indicate which arguments play a role in the decision to adopt an APS system. In the sixth part, the respondent had to fill out in which way he/she agrees with a number of propositions.

5.4 Operational definitions

Most constructs in this study are abstractions in the theoretical domain. As these constructs are not directly observable, we had to provide operational definitions that are observable. All operational definitions, or items, have been transformed into single questions or statements in the questionnaire. To increase reliability, existing items previously reported in the literature were used as much as possible.

Pearson's correlation coefficient, which is a measure of linear association between two variables, is usually calculated to test the correlation among the items of a construct. The absolute value of this correlation coefficient indicates the strength of the linear relationship between the items, with larger absolute values indicating stronger relationships. The sign of the coefficient indicates the direction of the relationship. However, Pearson's correlation coefficient assumes two interval or ratio-scaled items. As our multiple-item constructs consist of items with an ordinal scale, we *also* tested for correlation among the items of each construct by calculating Spearman's ρ (or Spearman's rank correlation coefficient) that is calculated by applying the Pearson correlation formula to the ranks of the data rather than to the actual data. Note, however, that this procedure is actually a large sample test. For ordinal-scaled items, there is no numerical test of internal consistency, such as Cronbach's alpha for interval scaled items. However, since (i) the significance levels of all correlation coefficients appeared to be the same for all items treated as ordinal-scaled (as measured by Spearman's ρ) and (ii) Likert-type scales are frequently considered in the literature to represent underlying continuous variables [134], we only present reliability analysis based on Pearson correlation coefficients and Cronbach's alpha to evaluate internal reliability of operational definitions. That is, we accept operational definitions of a multi-item scale straightaway if the value of Cronbach's alpha is higher than .60 [238]. Obviously, this procedure is consistent with the procedures for reliability analysis undertaken in Chapter 3.

5.4.1 Items for the innovation constructs

Compatibility *Compatibility* has been used in many studies on technological innovations. Operationalizations frequently used by researchers are: 'compatibility of the innovation with existing systems and infrastructure' [89][163][207], 'compatibility with existing practices of the adopter' [173][227], and 'compatibility with the values and believes or norms of the adopter' [89][227]. In addition, Tornatzky and Klein [227] also include an item that measures to what extent the innovation differs from former work methods. Hence, we operationalize *compatibility* by: 1) 'the degree of compatibility of an APS system with the existing firm's culture', and 2) 'the degree of compatibility of an APS system with the current way of planning'. With a value of .6451 for Cronbach's alpha, this operationalization is sufficiently reliable; see Table 5-3.

** Significant at $p < .05$, *** Significant at $p < .01$

Items	Spearman's ρ		Pearson correlation		Mean	S.D.	Cronbach's alpha
compatibility with firm's culture	1.000		1.000		4.1078	.9740	.6451
compatibility with current way of planning	.463***	1.000	.476***	1.000	3.6373	1.0029	

Table 5-3: Operational definition of *compatibility*.

APS complexity *Complexity* of an innovation is another construct that has frequently been used in previous studies [89][185][231]. Occasionally, however, it is named *ease of use* with corresponding items [185][231]. In addition, Grover [89] uses the items 'we believe that the system is complex to use', and 'we believe that system development is a complex process'. As a result, we distinguish two categories of these items; understanding the innovation and using the innovation. We, therefore, operationalize *APS complexity* by the items 1) 'the ease to understand an APS system', and 2) 'the ease to use an APS system'. Given the value of .7795 for Cronbach's alpha, this operationalization is sufficiently reliable; see Table 5-4.

*** Significant at $p < .01$

Items	Spearman's ρ		Pearson correlation		Mean	S.D.	Cronbach's alpha
ease to understand an APS system	1.000		1.000		4.3981	.6618	.7795
ease to use an APS system	.688***	1.000	.649***	1.000	4.5534	.5553	

Table 5-4: Operational definition of *APS complexity*.

Adaptation We operationalize the *adaptation* of an APS system by 1) 'the ease to adapt an APS system to changing circumstances', 2) 'the possibility to run what-if analysis with an APS system', and 3) 'the possibility to (manually) adapt the results generated by an APS system by hand'. Given the value of .6147 for Cronbach's alpha, the operationalization is sufficiently reliable; see Table 5-8.

Observability *Observability* is also called *result demonstrability* and corresponding operationalizations are proposed, for instance, by Moore and Benbasat [173] and Venkatesh and Davis [231]. Based on their operational definitions, we operationalize *observability* by the items 1) 'the ease to demonstrate results of an APS system', and 2) 'the ease to demonstrate advantages of an APS system'. Given a value of .8928 for Cronbach's alpha, this operationalization is sufficiently reliable; see Table 5-8 (p. 141).

*** Significant at $p < .01$

Items	Spearman's ρ		Pearson correlation		Mean	S.D.	Cronbach's alpha
ease to demonstrate advantages	1.000		1.000		3.4951	.9169	.8928
ease to demonstrate results	.812***	1.0000	.807***	1.000	3.6893	.8859	

Table 5-5: Operational definition of *observability*.

Other users' opinions This construct is measured by a single item, as we asked the respondents how important they consider other users' opinions about the APS system.

Relative advantage Tornatzky and Klein [227] state that 'being better' is such a general notion that the measurement of *relative advantage* cause several operationalization problems. For instance, Grover [89] needs 14 items to operationalize the construct *relative advantage*, among which 'improved performance', 'increased productivity', 'enhanced effectiveness', and 'general usefulness' [173][231][252]. We operationalize *relative advantage* by the items 1) 'the ease and agility of generating a plan with an APS system', 2) 'reduction in throughput time by the implementation and use of an APS system', 3) 'increase in delivery reliability by the implementation and use of an APS system', 4) the 'reduction in stock by the implementation and use of an APS system', 5) 'increase in utilization rates by the implementation and use of an APS system', 6) 'reduction in production cost by the implementation and use of an APS system', and 7) 'the feasibility of production plans created with an APS system'. Internal reliability of the scale is acceptable given the value of .7134 for Cronbach's alpha; see Table 5-8 (p. 141). However, as *relative advantage* is a multi-item construct, we performed a factor analysis on these seven items, for which the rotated factor solution is displayed in Table 5-6. Note that five items load on factor 1, and two items load on factor 2. Hence, the items of the scale of *relative advantage* measure two distinct dimensions of *relative advantage*. As the five items that load on factor 1 indicate the logistics-related advantage of an APS system, we name factor 1 *OM/logistics-related advantage*. The last two items in Table 5-6 that load on factor 2 reflect the *package-related advantage* of working with an APS system.

Items	***Factor 1: OM/logistics-related advantage***	***Factor 2: package-related advantage***
increase in utilization rates	.775	
reduction in cost	.620	
reduction in stock	.578	
increase in reliability	.442	.370
reduction in throughput time	.442	.354
feasibility of created planning		.737
agility of creating a planning		.505
Cronbach's alpha	.7353	.7138
OM/logistics-related advantage	.831	
package-related advantage	.024	.995

Table 5-6: Rotated factor matrix (varimax; cutoff = 0.3) of *relative advantage* and factor score covariance matrix.

Total cost of ownership The cost of an innovation is generally operationalized by 'initial purchase cost of an innovation' [84][227]. However, expected implementation costs of most technical innovations are equally important for adoption. As a result, we operationalize total cost of ownership with the items 1) 'purchase cost of an APS system', and 2) 'implementation cost of an APS system'. With a value of .8951 for Cronbach's alpha, the operationalization is sufficiently reliable; see Table 5-7.

*** Significant at $p < .01$

Items	**Spearman's ρ**		**Pearson correlation**		**Mean**	**S.D.**	**Cronbach's alpha**
purchase cost of an APS system	1.000		1.000		3.8283	.8576	.8951
implementation cost	.791***	1.000	.811***	1.000	3.9697	.8138	

Table 5-7: Operational definition of *total cost of ownership*.

Trialability Following Zhao and Co [252], who operationalize *trialability* by 'degree to which organizations obtained experience through a pilot project before implementation', we operationalize it by 'the possibility to experiment with an APS system before purchasing'.

Vendor support *Vendor support* has been studied by many researchers [84][252]. Based on the operationalizations found in literature, we decided to operationalize *vendor support* by the items 1) 'vendor support during the implementation of an APS system', and 2) 'the offering of training programs by the vendor of an APS system', which is reliable given the value of .7488 for Cronbach's alpha; see Table 5-8 (p. 141).

5.4.2 Items for organizational constructs

ERP usage To differentiate between ERP users and non-users, we simply asked if the organization used an ERP-system or not. However, we also asked for the vendor's name to verify that the system is indeed an ERP system.

External communication The operationalization of *external communication* proposed by Zmud [253] showes that it is about interpersonal communication channels and active information seeking employees [38][191]. However, researchers occasionally use the term *cosmopolitanism* for this construct [21][132][163] and the corresponding operationalizations are 'conferences attended', 'summer institutes attended', and 'journals are read regularly'. Since many of these items are concerned with information gathering by employees, we operationalize *external communication* by the following three items: 1) 'frequency of employees' visits to production and logistics seminars', 2) 'employees' reading of production and logistics literature', and 3) 'employees' attendance of logistics training'. With a value of .7797 for Cronbach's alpha, the internal reliability of this operationalization is sufficient; see Table 5-8 (p. 141).

Innovation experience Grover [89] uses the construct *technology policy* of which several items refer to our construct *innovation experience* (e.g., 'our organization has a long tradition of being the first to try new methods and technologies', and 'our organization spends more than others in the industry in developing new technology products'). However, we claim that the degree of success of past innovations in an organization positively influences the willingness to adopt future innovations. Therefore, we use the items 1) 'in our firm we frequently implemented new applications/innovations', and 2) 'the implementation of an innovation is generally successful' to operationalize *innovation experience*, which is reliable given the value of .7572 for Cronbach's alpha of; see Table 5-8 (p. 141).

** Significant at $p < .05$, *** Significant at $p < .01$

Items		Cron-bach's alpha	Pearson correlation							Mean	S.D.	alpha if item deleted
vendor support	vendor support during implementation	.7488	1.000							4.5196	.5401	-
	offering of training programs by vendor		.608***	1.000						4.3137	.6446	-
adaptation	ease to adapt to changing circumstances	.6147	1.000							4.3333	.6389	.5857
	possibility to run what-if analysis		.228**	1.000						3.9596	.7944	.5660
	possibility to adapt the results by hand		.402***	.414***	1.000					4.2020	.7690	.3641
relative advantage	agility of creating a planning	.7134	1.000							3.8854	.9389	.7025
	reduction in throughput time		.225***	1.000						4.2708	.7466	.6728
	increase in reliability		.168**	.479***	1.000					4.4583	.7387	.6704
	reduction in stock		.069	.182**	.203**	1.000				4.0938	.9742	.7164
	increase in utilization rates		.281***	.331***	.339***	.437***	1.000			4.0938	.9186	.6380
	reduction in cost		.262***	.333***	.368***	.324***	.549***	1.000		4.2917	.7802	.6423
	feasibility of created planning		.388***	.199**	.243**	−.082	.086	.254**	1.000	4.4479	.6628	.7127
external communication	employees frequently visit seminars	.7797	1.000							2.8099	1.075	.6231
	employees read literature		.624***	1.000						3.2066	.9909	.7030
	employees attend logistics training		.544***	.453***	1.000					2.5455	.9916	.7669
OM/logistics-related sophistication	number of employees with a BSc. degree on OM/ logistics	.7074	1.000							2.3056	1.308	.7199
	number of employees with a MSc. degree on OM/ logistics		.540***	1.000						1.3426	.7632	.6703
	hiring external OM/logistics consultants		.222***	.142	1.000					1.7778	.8790	.6917
innovation experience	organization frequently implements innovations	.7572	1.000							3.4609	1.011	-
	the implementation of innovations is generally successful		.620***	1.000						3.4174	.8375	-

Table 5-8: Operational definitions of *vendor support*, adaptation, relative advantage, external communication, OM/logistics-related sophistication, and innovation experience.

Functional differentiation Damanpour [55] uses the item ‘total number of units under the top management/chief executive level’, to operationalize *functional differentiation*. Kimberly and Evanisko [132] operationalize it by ‘number of different subunits’. In concurrence with this operational definition, we also use the item ‘number of different departments’. Furthermore, we asked respondents whether the following functional departments were present: ‘a planning/logistics department’, ‘an IT department’, and ‘an R&D department’. From these three dichotomous variables, we computed a new variable (with a 4-point scale) indicating ‘the degree of functional differentiation’. The value of this variable is 1 if the respondent indicated that his organization had none of these departments, 2.33, 3.67, and 5, respectively, if the respondent indicated that his organization had one, two respectively all three of these departments. As a result, we initially operationalize *functional differentiation* by 1) ‘number of different departments’, and 2) ‘the degree of functional differentiation’. Unfortunately, the value of Cronbach’s alpha is only .5631, which is insufficient to pass this scale as reliable. As a result, we only use the item ‘the number of different departments in the organization’. Possible relationships between the items ‘existence of a planning/logistics department’ and ‘existence of an IT department’ and APS adoption are analyzed separately.

Internal communication Damanpour [55] operationalizes *internal communication* by ‘number of committees in an organization’, ‘frequency of committee meetings’, ‘number of contacts among people at the same and different levels’, and ‘degree to which units share decisions’. Grover [89] operationalizes a related construct *integration* with the items ‘joint development of projects occurs frequently with other departments’, ‘applications are often shared between departments’, ‘our organization encourages exchange of ideas between departments’, ‘data are often shared between departments’, and ‘projects are often initiated through joint interaction between departments’. All these items focus on the extent of interaction between departments. However, we consider the smoothness of the interdepartmental communication more important than the frequency of interdepartmental actions. Hence, we operationalize *internal communication* by the item ‘in our firm the communication between departments is good’.

Management support *Management support* has frequently been used in previous studies on innovation adoption and implementation [55][163][187][226]. Damanpour [55], for instance, operationalizes it as ‘managerial attitude toward change’. As a result, we operationalize *management support* by ‘managerial attitude toward innovation’.

Size The construct *size* is generally measured by ‘number of employees’, ‘turnover’, and ‘number of end-products’ [21][226][253]. In this second survey, *size* was operationalized by the items 1) ‘the total number of employees of the firm’ and 2) ‘the average number of end-products’. Unfortunately, the value of Cronbach’s alpha is only .2246, which is far too low to indicate this scale as reliable. As a result, we only use the item ‘total number of employees of the firm’ and analyze the item ‘number of end-products’ separately.

OM/logistics-related sophistication *Sophistication* is generally used as a determinant of adoption and implementation in innovation studies. Zhao and Co [252], for instance, measure *technical knowledge* by ‘general knowledge of employees’ and ‘continued knowledge updating’. In addition, McGowan and Madey [163] ask for the existence of an ‘expert’. Furthermore, Bigoness and Perrault [33] use the items: ‘sophistication of line managers’ and ‘existence of an internal technical group’. Damanpour [55] operationalizes *sophistication* by ‘number or percentage of professional staff members with certain educational backgrounds’, and ‘degree of professional training of organizational members’. Zmud [253] uses the items ‘number of professionals possessing bachelor degrees’, and ‘number of professionals possessing master degrees’. Kimberly and Evanisko [132] and Brancheau and Wetherbe [38] ask for the level and substance of education of respondents. We operationalize *OM/logistics-related sophistication* by the items 1) ‘number of employees with a bachelor degree in OM/logistics’, 2) ‘number of employees with a master’s degree in OM/logistics’, 3) ‘frequency of hiring external logistics consultants’. With a value of .7074 for Cronbach’s alpha, this operationalization is reliable; see Table 5-8 (p. 141).

5.4.3 Remaining items

The rejection of some operational definitions because of a low value of Cronbach’s alpha, left us with some ‘remaining’ items for which we analyze the possible relationship with APS adoption separately: 1) ‘existence of an IT-department’, 2) ‘existence of a planning/logistics department’, and 3) ‘number of end-products'. In addition, there are two new multi-item constructs: *OM/logistics-related advantage*, and *package-related advantage*. We assume that these constructs and the remaining items are positively related to APS adoption.

5.5 Results: testing for associations with non-parametric tests

The constructs used in this study primarily have ordinal scales and occasionally nominal scales that, strictly speaking, require specific statistical procedures to falsify our hypotheses (i.e., to test for relationships between the constructs and their directions). While the basic premise of this thesis is that these variables are representations of their underlying continuous variables, for which we apply parametric procedures, we include this section to show the implications of using non-parametric test procedures. We briefly discuss the results of a non-parametric statistical analysis to test for association between the ordinal and nominal constructs, as well as for possible spurious relationships. The objective of this section is to develop data-driven but theoretically consistent conceptual APS adoption models.

5.5.1 Correlation between the constructs and items

APS adoption is a nominal-scaled variable. To test for association between this nominal-scaled variable and an ordinal-scaled variable, we use the Mann-Whitney test and the Wilcoxon rank sum test. That is, we analyze the group of APS adopters versus the group of non-adopters on these ordinal-scaled variables. The cases of both groups are combined and ranked; ties are assigned according the average rank. Subsequently, the rank sum is calculated for both groups. From these rank sums, a test variable U (for the Mann-Whitney test) and a test variable W (for the Wilcoxon rank sum test) is calculated. Subsequently, the significance level (i.e., the *p*-value) is determined to investigate whether the null hypothesis 'there is no association' is to be rejected ($p < .05$) or accepted ($p \geq .05$). In short, we test for association between two variables with the help of the Mann-Whitney and Wilcoxon rank sum tests. If there is a relationship between two variables, we try to test the direction of this relationship with the help of cross-tabulation. Although we tested all hypothesized relationships between all ordinal-scaled constructs and *APS adoption*, we only present the significant results of these Mann-Whitney and Wilcoxon rank sum tests; see Table 5-9.

	Adopters	**Non-adopters**	**Test statistics**			**Exact sig. (2-tailed)**	**Adopt-ers**	**Non-adopt-ers**
Construct	**Mean rank**	**Mean rank**	**Mann Whit-ney *U***	**Wil-coxon *W***	***Z***		**Cross-tab**	
management support	81.31 (18)	56.20 (101)	525.5	5676.5	– 3.133	.002	4.50	3.88
other users' opinions	32.89 (18)	51.53 (77)	421.0	592.0	– 2.710	.006	2.79	3.57
number end-products	82.13 (19)	61.43 (109)	70.5	6695.5	– 2.606	.008	4.79	3.87
innovation experience	7.56 (16)	51.71 (92)	479.0	4757.0	– 2.262	.023	3.84	3.37

Table 5-9: Results of Mann-Whitney, Wilcoxon rank sum tests and cross-tab for *APS adoption*.

From Table 5-9, we observe that the constructs *management support*, other users' opinions, *number of end-products*, and *innovation experience* are significantly related to *APS adoption*. However, as mentioned above, the Mann-Whitney and Wilcoxon rank sum tests do not account for direction. Therefore, we investigate the cross tabulation of *APS adoption* with these constructs; see rightside of Table 5-9. From this cross-tabulation, we observe that, except for *other users'* opinions, the means of all constructs for APS adopters is higher than the means of these constructs for non-adopters, which indicates a positive relationship between the constructs and *APS adoption*. From the differences in means of these constructs for APS adopters and non-adopters, we observe that the construct other users' opinions is negatively related to *APS adoption*. This indicates that firms that value other users' opinions about APS systems significantly adopt APS less often than firms that find these opinions not so important.

To test for a relationship between two dichotomous constructs, we use a φ-test (which is an option of the chi-square test within cross-tabulations in the software package SPSS, where φ is defined as a chi-square-based measure of association). Again, the null hypothesis is that the two constructs are independent. If the significance value of φ is smaller than .05, then the null hypothesis is rejected and we accept the alternative hypothesis that there is a relationship between the two constructs.

Construct	**φ Value**	**Exact. Sig.**
planning/logistics department	.212	.024
ERP usage	.175	.076
IT department	.146	.154

Table 5-10: φ values of *APS adoption* and dichotomous constructs.

There are several options for calculating the significance value of φ. We decided to use the exact method, as exact tests can obtain reliable significance levels without preliminary data requirements. The asymptotic method, in contrast, requires that cell frequencies in the contingency tables are not smaller than five. Unfortunately, the only nominal-scaled construct that appears to be significantly related to *APS adoption* is planning/logistics department; see Table 5-10.

The nature of the relationship between *APS adoption* and planning/logistics department is explained by the contingency matrix displayed in Table 5-11. We observe that planning/logistics department is positively related to *APS adoption*, since 19.6% of all respondents with a planning/logistics department had adopted an APS system. In contrast, only 2.8% of the respondents do not have a planning/logistics department.

	planning/logistics department				
↓ APS adoption	**Yes**		**No**		**Total**
Yes	18 (19.6%)	(94.7%)	1 (2.8%)	(5.3%)	19 (14.8%)
No	74 (81.4%)	(67.9%)	35 (97.2%)	(32.1%)	109 (85.2%)
Total	**92**	**(71.9%)**	**36**	**(28.1%)**	**128**

Table 5-11: Contingency matrix of *APS adoption* and *planning/logistics department*.

The results of our analysis are displayed in a conceptual/statistical model for *APS adoption*; see Figure 5-2(a). Note that the remarkable finding of this section is that ERP usage is only related to APS adoption at a significance level of $p < .1$, which obviously concurs with the ANOVA analysis of the same variables with the data of the first survey discussed in Chapter 4.

5.5.2 Spurious relationships

In the previous section, we found some significant relationships between the innovation and organizational constructs and *APS adoption* based on a non-parametric analysis. Nevertheless, we have to be cautious of possible spurious relationships. A spurious relationship refers to a situation in which measures of two or more variables are statistically related but not causally linked, usually because the statistical relationship is caused by a third variable. We, therefore, have to test all significant relationships on 'spuriosity' to obviate the effects of such a third variable. In Figure 3-9 (p. 104), it was believed that *supplier complexity* was a predictor for the adoption of an ERP system, while Figure 4-1 (p. 117), for example, shows that *supplier complexity* is not directly related to the use of an ERP system. Firms with high levels of *supplier complexity* significantly more often adopted an ERP system because these firms are large.

In the previous section, we found the ordinal-scaled constructs *innovation experience, management support*, *number of end-products*, and other users' opinions to be associated with *APS adoption*. If a relationship is spurious, there must be a 'lurking' variable. Generally, we have no prior knowledge of the lurking variables. We therefore consider all constructs to be potentially lurking. In case the lurking construct is ordinal-scaled, we divide the sample in two groups: one group of respondents with a 'low score' on the lurking construct and a group of respondents with a 'high score' on the lurking construct. Subsequently, we perform a Mann-Whitney test on both groups to test the relationship between the dependent and the independent construct. When this relationship is still significant for both groups, the relationship is 'autonomous', but when the relationship is not significant for one or both groups, the relationship might be spurious. However, the significance of the Mann-

Whitney test can also decrease because of a smaller sample size. Thus, we do not only have to test the significance of the correlation, as measured with the Mann-Whitney test, but we also have to test the extent of correlation. Since the dependent construct *APS adoption* is a nominal-scaled (i.e., dichotomous) construct, we have to test the correlation between a nominal-scaled (dependent) and an ordinal-scaled (independent) construct. However, to our best knowledge there is no numerical measure to test the extent of this type of correlation. To measure correlation between two ordinal-scaled variables, a Spearman's ρ test is generally used; to measure the correlation between two nominal-scaled variables a φ-test is generally used. We decided to use both tests to measure the extent of correlation for the different groups. When there is a difference for both groups that shows a *decrease* of at least 5% for both correlation measures, we indicate the construct to be lurking and the initial relationship between the independent and dependent construct as spurious. For possible nominal-scaled lurking constructs, we perform a similar procedure with the Mann-Whitney test for all options in the corresponding scale.

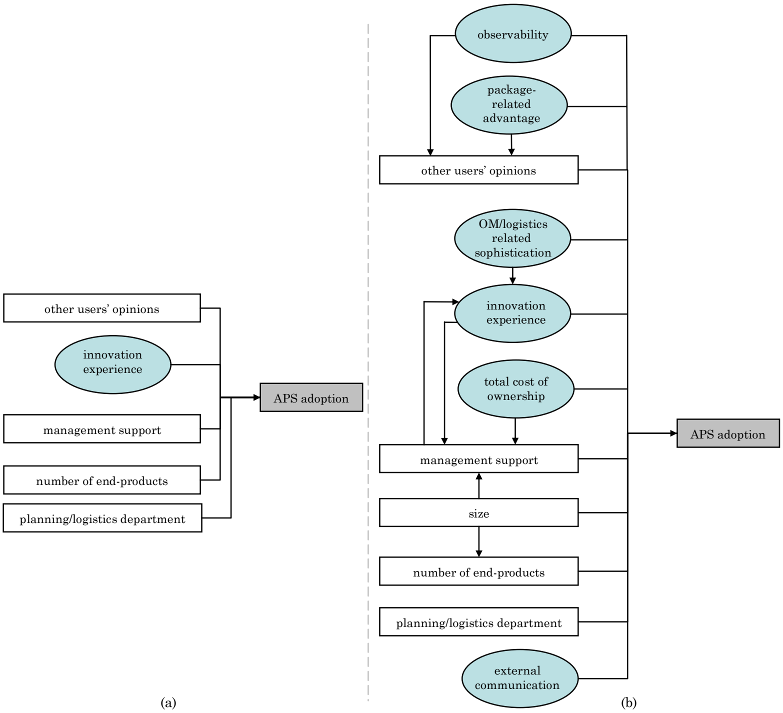


Figure 5-2: Data-driven conceptual models of APS adoption without (a) and with possible spurious relationships (b).

The results of these tests are graphically displayed in Figure 5-2 (b). *Innovation experience, size*, and *total cost of ownership* appeared to be possible lurking constructs in the spurious relationship between *APS adoption* and *management support*. *Observability*, and *package-related advantage* appeared to be possible lurking constructs in the relationship between *APS adoption* and other users' opinions. *Size* appeared to be a possible lurking construct in the spurious relationship between *APS adoption* and *number of end-products*. *Management support* and *OM/logistics-related sophistication* appeared to be possible lurking constructs in the spurious relationship between *APS adoption* and *innovation experience*. As a result, we obtained two data-driven conceptual models for *APS adoption*: one model without spurious relationships, and one model with spurious relationships; see Figure 5-2 (a) and (b).

5.6 Results: testing for relationships

With the help of a non-parametric statistical analysis, we obtained two data-driven conceptual models with significant associations between the independent constructs and the dependent variable *APS adoption*. Furthermore, we identified possible spurious relationships between these constructs and a number of 'lurking' variables. To analyze the causal effects displayed in these conceptual models and the presence of spurious relationships, we develop and analyze structural equations models of both conceptual models where we assume that the ordinal variables are representations of underlying continuous variables [231]. As mentioned in the previous chapters, this is common practice in the scientific survey literature and consistent with our approach in the previous chapters. For both data-driven conceptual models displayed in Figure 5-2, we developed and validated the measurement model first, which is evaluated like any other SEM model, using the goodness of fit measures χ^2/df ratio, CFI, NFI, TLI, and RMSEA; see Section 3.2, page 75. Subsequently, we analyze the path model (i.e., the structural equations model).

5.6.1 A structural equations model without spurious relationships

Initial measurement model We discuss the confirmatory factor analysis of the conceptual model of *APS adoption* without spurious relationships, i.e., model (a) in Figure 5-2. The corresponding measurement model displayed in Figure 5-3 fits the data according the fit indices df = 7, χ^2 = 10.819, p_{model} = .147, CFI = .998, NFI = .993, TLI = .993, and $\text{RMSEA}_{[0,.137]}$ = .065. Figure 5-3 displays squared multiple correlations (R^2) for each item, indicating the level of explained variance. Fortunately, the R^2-values are quite high. For example, this model explains 77% of the variance of the item ‘organization frequently implements innovations’.

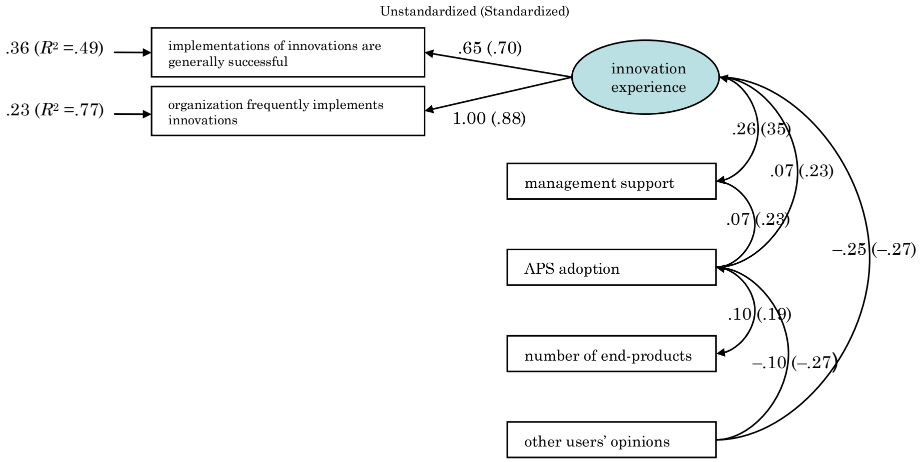


Figure 5-3: Initial measurement model of APS adoption (df = 7, χ^2 = 10.819, p_{model} = .147, CFI = .998, NFI = .993, TLI = .993, and RMSEA$_{[0,.137]}$ = .065).

We recall that the unstandardized factor loadings are interpreted as regression coefficients that indicate expected change in the item given a 1-point increase in the factor. For example, scores on the ‘implementations of innovations are generally successful’ are predicted to increase by .65 points for every 1-point increase in the *innovation experience* factor. Standardized loadings (in parenthesis) are interpreted as correlations and their squared values as proportions of explained variance. The standardized factor loading of the ‘implementations of innovations are generally successful’, for instance, is .70, which means that $.70^2$, or 49% of its variance is shared with the *innovation experience* factor. Given the reasonably high factors loadings convergent validity is acceptable. We, therefore, continue this section with the analysis of an initial structural equations model of *APS adoption*, based on this simple measurement model.

Structural equations model We discuss the structural equations model of the conceptual model of *APS adoption* without spurious relationships, i.e., model (a) in Figure 5-2. The structural equations model that is obtained after the removal of non-significant paths essentially reduces to a simple regression model displayed in Figure 5-4. This final structural equations model fits the data according to the fit indices $df = 3$, $\chi^2 = 2.398$, $p_{model} = .494$ (i.e., exact fit), CFI = 1.000, TLI = 1.000, NFI = .997, and $\text{RMSEA}_{[0,.137]} = .0$.

In Figure 5-4, the unstandardized beta coefficients and disturbances terms are represented as normal numbers; standardized beta coefficients are represented in parentheses. The disturbance term for the endogenous construct *APS adoption* indicates the unexplained variance in the endogenous variable due to all unmeasured causes, and the squared multiple correlation (R^2) indicates the level of explained variance by the model. Note that this model explains 17% of the variance of *APS adoption*.

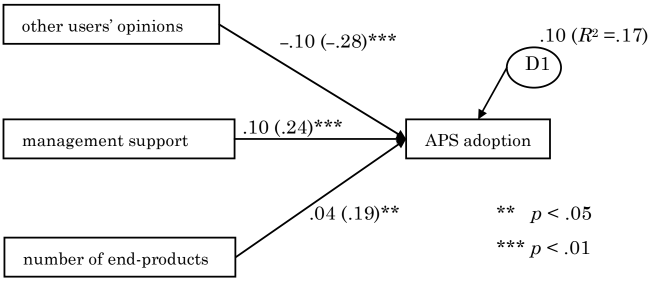


Figure 5-4: Final basic structural (regression) model of APS adoption ($df = 3$, $\chi^2 = 2.398$, $p_{model} = .494$).

5.6.2 Testing for spurious relationships

Measurement model of APS adoption with spurious relationships We briefly discuss the measurement model of the extended conceptual model of *APS adoption* with spurious relationships, i.e., model (b) in Figure 5-2. After elimination of non-significant factor loadings and covariances, we obtained the measurement model displayed in Figure 5-5. This measurement model fits the data according to the relative fit indices $df = 143$, $\chi^2 = 240.891$, $p_{model} = .000$, CFI = .985, NFI = .965, TLI = .969, and $\text{RMSEA}_{[.057,.089]} = .073$. The corresponding covariances between the factors are displayed in Table 5-12. In addition, given the sufficiently large factor loadings and low measurement errors of the items, convergent validity of this model is acceptable. Hence, we continue the analysis of a structural equations model based on this measurement model.

Note, however, that we analyzed the items of both *total cost of ownership* and *package-related advantage* independently as the factor loadings of the items were non-significant.

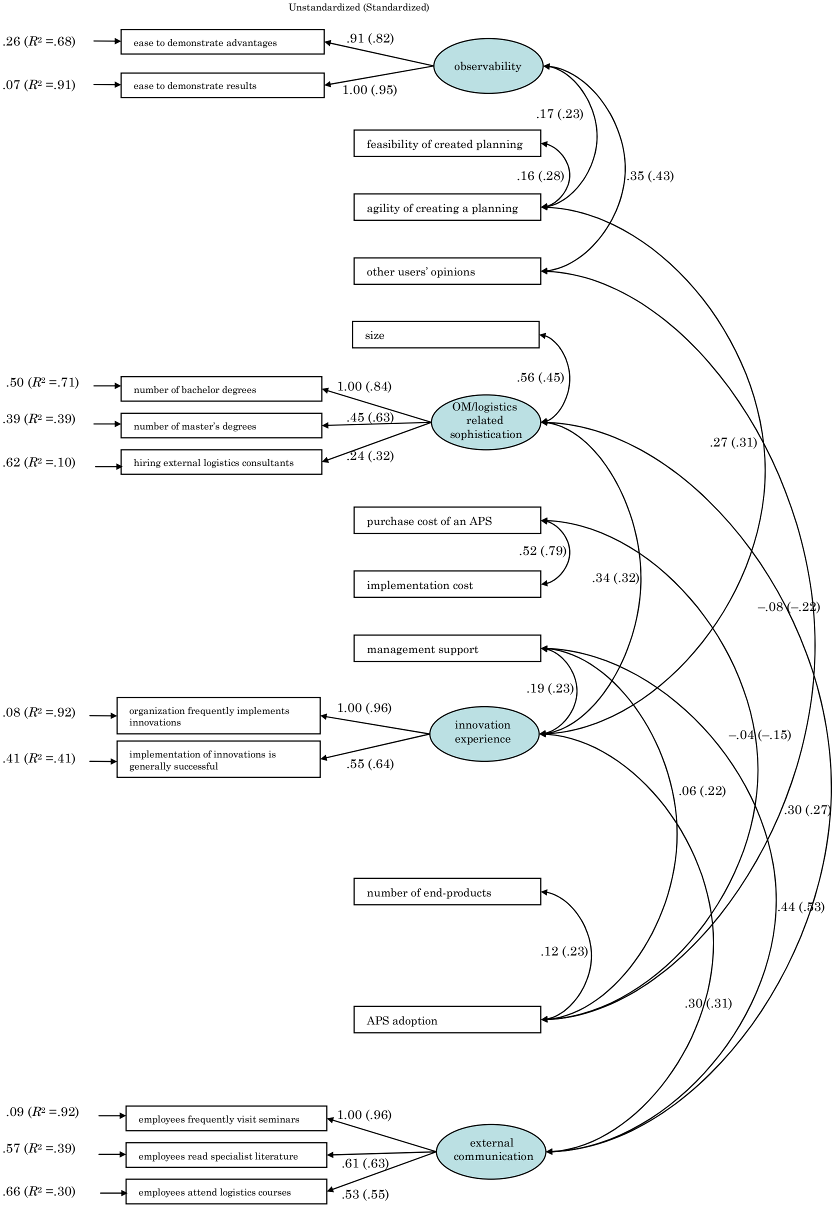


Figure 5-5: Measurement model of APS adoption with spurious relationships.

Construct 1	Construct 2	Covariance	*p*
innovation experience	*OM/logistics-related sophistication*	.345	.002
innovation experience	*external communication*	.300	.001
external communication	*OM/logistics-related sophistication*	.299	.003
agility of creating a planning	*observability*	.170	.014
other user's opinion	*observability*	.348	.000
agility of creating a planning	feasibility of created planning	.165	.005
agility of creating a planning	*innovation experience*	.274	.004
purchase cost	implementation cost	.516	.000
management support	*innovation experience*	.188	.009
management support	*external communication*	.442	.000
other user's opinion	*APS adoption*	− .077	.008
purchase cost of an APS system	*APS adoption*	− .043	.010
management support	*APS adoption*	.064	.003
APS adoption	number of end-products	.124	.006
size	*OM/logistics-related sophistication*	.559	.000

Table 5-12: Estimated covariances in the measurement model of APS adoption with spurious relationships.

Structural equations model of APS adoption with spurious relationships We discuss the structural equations model of the conceptual model of *APS adoption* with spurious relationships, i.e., model (b) in Figure 5-2. From the corresponding measurement model, we observe that *size* is only related to *OM/logistics-related sophistication* and, therefore, only indirectly related to *APS adoption*. Based on the covariances displayed in Table 5-12 and the directions of the paths in conceptual model (b) of Figure 5-2, we developed and analyzed structural equations models of *APS adoption* with spurious relationships. After the removal of non-significant paths, we obtained the final structural equations model displayed in Figure 5-6. This model fits the data according to the fit indices $df = 116$, $\chi^2 = 192.781$, $p_{model} = .000$, CFI = .984, TLI = .978, NFI = .960, and $\text{RMSEA}_{[.053,.092]} = .072$.

Note that this model displays direct relationships between the variables management support, purchase cost of an APS system, number of end-products, other users' opinions, and *APS adoption* and indirect relationships between *OM/logistics-related sophistication, external communication*, *innovation experience*, *observability*, and *APS adoption*. In addition, note that this model explains 21% of the variance of *APS adoption*.

From this final structural equations model, we observe that the more different end-products an organization manufactures, the more likely it is that it will adopt an APS system. In contrast, the higher the value of *purchase cost*, the lower the APS adoption rate. Furthermore, organizations that value other users' opinions about APS systems significantly adopt APS less often than organizations that consider these opinions not to be so important. This is strengthened by the levels of *observability*. Organizations that value the *observability* of APS systems (i.e., organizations that attach importance to the ease of demonstrating results and advantages of the APS system over the present way of working) also significantly adopt APS less often than organizations that consider *observability* less important.

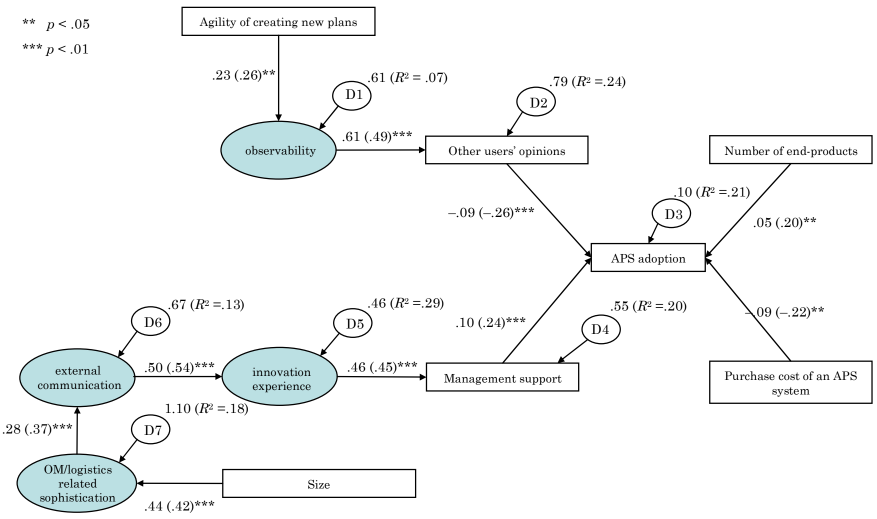


Figure 5-6: Final structural equations model of APS adoption (df = 116, χ^2 = 192.781, p_{model} = .000, CFI = .984, TLI = .978, NFI = .960, and RMSEA$_{[.053,.092]}$ = .072).

In concurrence with the general findings in innovation research, the structural equations model shows that *management support* of adopting innovations increases with higher levels of *innovation experience* [38][55][253]. The organizational level of *innovation experience* is partly determined by *external communication* and (indirectly) *OM/logistics-related sophistication*. This means that organizations with high levels of education and active information-seeking attitudes generally have high levels of innovation experience, which is in concurrence with the results of previous studies on adoption of innovations. Zmud [253], for example, found that subscriptions, a library, and the frequency of trainings are positively associated with innovativeness. Brancheau and Wetherbe [38] concluded that earlier adopters engage more frequently in external communication than late adopters. Furthermore, note that this model explains 29% of the variance of *innovation experience*, which is quite high since we primarily investigated the impact of innovation and organizational factors on the adoption of APS systems. Furthermore, note that there is no direct relationship between *APS adoption* and *size*. Nevertheless, *size* influences the level of *OM/logistics-related sophistication* and, hence, indirectly the adoption of APS systems.

5.7 Discussion, conclusions, and further research

5.7.1 Discussion

In this chapter, we have demonstrated that management support, cost of purchase, number of end-products, and other users' opinions are variables that directly influences the adoption of an APS system. In general, a supportive management attitude towards the innovation creates an internal climate conducive to innovation [55] and indirectly leads to higher rates of adoptions of innovations. This is supported by our findings, as *OM/logistics-related sophistication*, *external communications*, and *innovation experience* influence the level of *management support* ($R^2 = .20$), these variables indirectly influence APS adoption; see Table 5-13.

			Total direct effect	Total indirect effect	Total effect
other user's opinions	→	*APS Adoption*	−.26		−.26
observability	→	*APS Adoption*		(.49) (−.26) = −.13	−.13
number of end-products	→	*APS Adoption*	.20		.20
purchase cost of an APS system	→	*APS Adoption*	−.22		−.22
management support	→	*APS Adoption*	.24		.24
innovation experience	→	*APS Adoption*		(.24) (.45) = .11	.11
external communication	→	*APS Adoption*		(.24) (.45) (.54) = .06	.06
OM/logistics-related sophistication	→	*APS Adoption*		(.24) (.45) (.54) (.37) = .02	.02

Table 5-13: Total effects in the final path model.

Put differently, the more active information-seeking attitude the organization has, the higher the level of *innovation experience*; and the higher the management support, the higher the adoption rate of APS systems. This concurs with the findings of Damanpour [55]. In addition, Thong and Yap [226] state that businesses with CEOs who have a more positive attitude towards adoption of IT are more likely to adopt IT directly.

Cost of purchase has a negative effect on *APS adoption*. This concurs with the conclusions of Gerwin [84] and Tornatzky and Klein [227] that cost is negatively related to the adoption and implementation of innovations.

Another negative effect on *APS adoption* is the importance that organizations attach to other users' opinions. The more an organization values other users' opinions, the less likely it is that the organization adopts an APS system. In addition, *observability* has an indirect effect on *APS adoption* via other users' opinions. Thus, organizations that attach importance to the ease to demonstrate the results and advantages of an APS system also value other users' opinions about the APS system. An ANOVA analysis indicates that organizations with high scores on *innovation experience* have significant lower means of other users' opinions and *observability* compared to organizations with low scores on *innovation experience*. This indicates that organizations with less *innovation experience* perceive more uncertainty about a new technology, such as an APS system, have more negative attitudes towards the innovation, and attach greater importance to other users' opinions and the *observability* of the APS system.

OM/logistics-related sophistication indirectly influences *APS adoption,* which concurs with the findings of Zhao and Co [252] that general technical knowledge of employees is significantly associated with successful adoption of advanced manufacturing technology. Moreover, these findings are also supported by Dewar and Dutton [58] that extensive knowledge is important for the adoption of technical process innovations.

5.7.2 Insights and implications

If management wants to adopt an APS system successfully, it must create an internal climate conducive to the innovation by supporting the increase of external communication levels, such as in-house training programs, to enhance the *OM/logistics-related sophistication* in the organization. In addition, successful implementations of ERP systems require strong leadership, commitment, and participation by top management [149]. Based on the structural equations models, we postulate that this also holds for APS systems. Unfortunately, many chief executives make the mistake to view ERP as simply a software system and the implementation of the ERP system as a technological challenge [229]. APS implementation projects range from specific improvements on a functional level to large-scale change programs, involving the redefinition of the business strategy and redesign of the business [210] –which is quite similar as to ERP systems– where the role of executive management is to enable the change of procedures across multiple functional areas [64].

5.7.3 Limitations and directions for future research

From the results of the structural equations model, it appeared that *OM/logistics-related advantage*, *compatibility*, and *adaptation* are not significantly related to APS adoption. For the constructs *compatibility* and *adaptation*, this is probably due to the used operational definitions as it is commonly accepted that most technological innovations require mutual adaptation of the new technology to the organization and the organization to the technology [84][155], and for advanced software technology in particular [34][210].

However, relative advantage was initially operationalized into two dimensions: *OM/logistics-related advantage* and *package-related advantage*. The latter construct appeared to be a potential lurking construct in the relationship between *other users' opinion*s and *APS adoption*, displayed in Figure 5-2 (b), but this was not confirmed in the structural equations models. However, these types of advantages may impact the successful implementation of APS in a similar fashion as for the successful implementation of ERP systems

[109][209]. Indeed, this study only concerns APS adoption, not implementation. Future research could focus on other stages of the stage model of IT implementation, such as acceptance, routinization, and infusion [52][144].

There are various other directions for further research, among which the investigation of the impact of other factors on APS adoption. Recall that the variable 'number of end-products' directly influences the adoption of APS in this survey data at $p < .05$, while in the data of the first survey there was only an association at the $p < .1$ significance level. Since the unexplained variance of the variable APS adoption due to all not-included factors in the structural equations model displayed in Figure 5-6 is 79%, exploratory analysis of other factors that might influence APS adoption seems justified. Furthermore, it is required to study APS justification [242] by investigating the operational and financial benefits of using an APS system.

6 APS adoption and manufacturing layout

Manufacturing firms can be characterized by their type of manufacturing strategy, i.e., the strategic focus on specific competitive priorities, and the customer order decoupling point (CODP) that dictates the interaction between the manufacturing system and the market, i.e., the extent by which customer orders penetrate the manufacturing system: an engineer-, make-, assemble-to-order, or make-to-stock strategy. This point also determines the control requirements of the specific manufacturing environment [101].

In general, firms tend to move their CODP's towards earlier stages of their manufacturing systems to enable mass customization and to offer a larger variety and better service. However, putting the CODP further upstream generally entails an increase in uncertainty of customer order controlled manufacturing processes. As we mentioned in the previous chapters, there are several strategies to cope with this increasing uncertainty (e.g., Galbraith [81]), among which the two seemingly opposite strategies: 1) to 'put the decisions where they belong' [164] through decentralization, i.e., implementing more or less self-contained resource groups or cells, preferably in a product-oriented manufacturing setting [212], or 2) to expand communication channels and the use of decision support by implementing intelligent production planning and control systems that simultaneously support material coordination and planning and scheduling of scarce resource capacity.

In general, these strategies are considered to be opposites. Implementing groups, cells, or teams all aim to reduce complexity and corresponding control requirements to gain simplified *decentralized* production planning and control processes. Enlargement of communication channels and the addition of decision support tools to smooth hierarchical decision processes may be achieved by the adoption and implementation of Advanced Planning and Scheduling (APS) systems. APS systems receive a lot of attention, especially from the larger, global manufacturing firms that generally have process layouts or repetitive batch flow lines, for example in the food, automotive, and consumer products industry [210].

The finding of Chapter 3 is that the use of an ERP system is an important determinant for a more centralized operational planning decisions structure. In addition, it turned out that *complexity,* unlike *rate of change*, causes the customer order processing decisions to be more centralized but the operational planning structure (i.e., locus of short-term planning decisions) to be more decentralized. In addition, we know from the findings of Chapter 4 that the *rate of change* of PMT characteristics does generally not discriminate users of various production planning and control tools from non-users; only the construct *end-product change* is negatively related to the use of an APS system. The case study at Urenco Aerospace discussed in Chapter 2, showed that the decision to use a specific production planning and control system does not depend on the choice for a specific manufacturing layout. Indeed, the decision for a specific production planning and control system was primarily determined by the personal preference of the OM manager. In this chapter, we address the question whether the dominant type of manufacturing layout, in particular a functional layout or a cellular layout, is correlated to the adoption of an APS system: "Are APS systems more frequently adopted by traditionally organized discrete parts manufacturers than by discrete parts manufacturers that are organized in cellular layouts?" Furthermore, this chapter addresses the issues of OM/logistics-related sophistication and external communication channels in relation to APS adoption for both cellular layout and non-cellular layout adopters. "Do firms that are organized in cellular layouts solely focus on control complexity reduction and corresponding socio-technical management issues, or do they also develop a clear understanding of the recent developments with respect to APS systems?" The main objective of this chapter is to provide an overview of the status quo of APS adoption in relation to various types of manufacturing layouts and manufacturing strategies, i.e., the position of the customer order decoupling point.

The outline of this chapter is as follows. In Section 6.1, we briefly recall the discussion on cellular manufacturing. From this theoretical rationale, we derive in Section 6.2 propositions that harmonize with the commonly accepted view that cellular manufacturers have simpler production planning and control processes than traditionally organized manufacturers. In Section 6.3, we briefly describe the research method and analysis undertaken to test these propositions with the help of the data of the second survey as discussed in Chapter 5. Finally, Sections 6.4 and 6.5 discuss the study's results, the implications, and avenues for future research.

6.1 Decentralized manufacturing

A number of different types of cells, groups, and teams can be found in manufacturing environments, which can be classified based on the autonomy continuum; see for instance Banker et al. [22]. Well-known grouping approaches are the Group Technology (GT) / Cellular Manufacturing (CM) approach, and the modern (Dutch) Socio-Technical Systems (STS) approach. These approaches have in common that they both advocate the reduction of logistical complexity by product-orientation, dedication, and decision autonomy; the higher the dedication and autonomy of cells are, the lower the overall production planning and control complexity of the manufacturing system is.

Cellular manufacturing is, strictly speaking, an application of Group Technology where a part of a firm's manufacturing system has been converted to cells [118][236]. It is a manufacturing approach that advocates simplification of similar entities (parts, assemblies, and process plans) to reduce complexity and to achieve economies of scale effects in batch manufacturing. In this approach, a manufacturing cell is a cluster of dissimilar machines or processes located in close proximity and dedicated to the manufacture of a family of parts, i.e., a cell family. The aim of cellular manufacturing is to reduce set-up times (by using part family tooling and manual sequencing) and, therefore, to reduce inventories and market response times. For an extensive overview of other cell formation techniques in cellular manufacturing, we refer to Moodie et al. [172].

The (Dutch) *socio-technique* as an integrated organizational design methodology states that an organization must match its environment. The flow of orders from the environment determines the required cycle of activities, as it introduces the degree of diversity, rate of change, and complexity that is permitted to enter the organization. The STS approach, however, is to reduce control requirements by reducing input complexity and variety by 1) creating parallel flows and segments in the primary process, 2) the design of a production structure by a top-down approach, and 3) the design of a control structure by a bottom-up approach. Order flows are grouped in order families with common operations characteristics to create parallel flows. Subsequently, these parallel flows are segmented to create sensible groups. Finally, local control capacities of the groups are increased and the responsibilities of the tasks to complete parts of the order flows are given to these groups. Hence, design rules for socio-technical groups include elements as minimal labor division, internal coordination and control, team-based organization instead of individual-based organization, multi-skilled personnel, and acceptance of responsibilities [199].

Almost all other grouping approach aim to reduce the (logistical) complexity to improve performance by decentralization. Hence, they all advocate to simplify the overall production planning and control complexity by introducing local control cycles that can be performed with simplified systems [217]. The more autonomous the work group, the more simplified the overall production planning and control complexity, and the higher the performance of the cellular layout compared to its functional counterparts. In this thesis, we group all types of cells, groups, and teams under the veil of a cellular layout, and only distinguish between a fixed project layout, a functional layout, a cellular layout, and a product layout.

6.2 Propositions

6.2.1 Layout and APS adoption

Job shops are characterized by one-off and small batch discrete parts manufacturing of more or less unique products in a functional organizational setting. Due to a large degree of freedom, i.e., universal machines and generally highly skilled functional workers, the functional layout is extremely flexible to produce a large variety of parts. However, it also requires a great amount of planning and scheduling activities to keep work-in-process inventory and corresponding lead-times under control. In contrast, flow shops are characterized by medium-sized and large batch manufacturing of more or less standardized products on dedicated flow lines [99]. Flow shops generally require planning and scheduling for batching and set-up-time optimization issues: *When to produce what amount of products?*

A cellular layout is generally characterized as a hybrid layout, i.e., a combination of a functional layout and a flow line, where dissimilar machines are located in close proximity and dedicated to the manufacture of a family of parts. According to Suri [217], transforming a factory into a number of product-oriented cells allows the otherwise complex, centralized production planning and control system to be replaced with simpler local scheduling systems. The group operating the cell is given the delivery schedule for that cell's products, and the group then takes responsibility for deciding on actual equipment schedules, labor hours, and priorities. The idea is that the global production planning and control system (e.g., an ERP system) and the simplified structure of the cell allow manual scheduling and dispatching procedures in the cell. Then, the function of the aggregated production planning and control system becomes assigning overall delivery schedules, ordering and allocating material, and coordinating between cells if necessary. A survey of Wemmerlöv and Johnson [237] indicates that more than 60 percent of the firms that have installed cells had simplified production planning and control procedures. This also holds for STS groups, where production planning and control authority and responsibility is given to the groups as they have simplified self-contained control cycles and rely upon mutual adjustment modes [115][119]. Accordingly, firms that work in groups, from either a CM or STS perspective, do not need advanced centralized APS systems that prescribe what and when exactly to produce. Thus, we hypothesize that firms with a cellular layout generally do not adopt APS systems. In contrast, due to the high production planning and control complexity and corresponding control requirements of the functional layout, we expect that especially these 'traditionally' organized, and generally centrally controlled discrete parts manufacturers adopt APS systems as these systems are centralized production planning and control systems in nature. This leads to the following proposition:

> **PROPOSITION 6-1:** *APS systems are adopted more frequently by 'traditionally' organized discrete parts manufacturers (and with functional layouts in particular) than by manufacturing firms that are organized in a cellular layout.*

6.2.2 Layout, sophistication, and communication channels

Sophistication has been proven to be positively associated with the adoption of technical innovations [33][163]. Furthermore, Chew et al. [50] conclude that know-how and know-why is required for the successful implementation of new technologies. In addition, according to several studies, early adopters are higher educated or have a greater knowledge about the innovations they adopted [38][132][191]. In addition, based on a study of the adoption and implementation of advanced manufacturing technologies (AMT), Zhao and Co [252] conclude that technical knowledge is a significant determinant of successful usage of the innovation. Hence, if an organization has one or more employees that are knowledgeable about an innovation, it is better equipped to deal with the issues of implementation. Furthermore, the diffusion theory of Rogers [191] suggests that firms that possess technical expertise are better equipped to identify and evaluate information communicated to the firm regarding the appropriateness of the innovations to the firm. From Chapter 5, we know that the innovational and organizational factors *observability*, *management support*, *innovation experience*, *external communication*, and *OM/logistics-related sophistication* relate to the adoption of APS systems. In concurrence with proposition 6-1 that firms with higher control complexity are inclined to adopt APS sooner than firms with lower control complexity, one may assume that firms that remain to have complex production planning and control issues must have more knowledge and expertise to deal with these planning problems to achieve acceptable performances to stay in business. In contrast, as firms that have adopted a cellular layout are expected to have low levels of control complexity and corresponding control requirements, we hypothesize that these firms do not prioritize the innovational and organizational factors that relate to APS adoption. More specifically, we hypothesize that these firms do not prioritize to have advanced OM/logistics-related sophistication levels and external communication levels, and certainly not of APS systems. Hence, we have the following proposition.

> **PROPOSITION 6-2:** *Traditionally organized manufacturing firms have higher Operations Management/logistics-related sophistication than firms with a cellular layout.*

Furthermore, we assume that this knowledge is generally gained with the help of external APS and OM/logistics-related communication channels. Hence, we also include the following proposition.

PROPOSITION 6-3: *Traditionally organized manufacturing firms have more external communication channels about APS systems than firms with a cellular layout.*

6.3 Research method and operational definitions

6.3.1 Research method

The study of the association between the dominant type of manufacturing layout and APS adoption and the related constructs *OM/logistics-related sophistication* and *external communication*, is conducted with the help of the data obtained from the second survey discussed in the previous chapter. Again, the analytic procedures in this study include the calculation of descriptive statistics, reliability analysis, and the analysis of differences in means between subpopulations for which we use the statistical software package SPSS 11.

6.3.2 Layout and manufacturing strategy

For the type of manufacturing layout, we explicitly asked respondents to indicate the *dominant* type of layout in their plant, where respondents could choose between 'a project layout (fixed position)', 'a functional layout (job shop)', 'a cellular layout (groups)', and 'a product layout (flow shop)'. In this survey, 48 respondents had indicated to use a functional layout and 47 respondents had indicated to use a cellular layout. The manufacturing strategy is operationalized as the CODP position, i.e., ETO, MTO, ATO, and MTS.

6.3.3 Sophistication and communications channels

Technical expertise is often indicated as a determinant of adoption. Since technical expertise is latent, not directly observable, we had to operationalize this construct. In a study on Advanced Manufacturing Technology (AMT) adoption, Zhao and Co [252] measured technical knowledge by 'general knowledge of employees' and 'continued knowledge updating'. They proved that 'general knowledge of employees' was significantly associated with successful AMT adoption. From the previous chapter, we know that something similar holds for the level of *OM/logistics-related sophistication* (i.e., the level of OM/logistics-related knowledge and expertise) on *APS adoption*. As *OM/logistics-related sophistication* is a complex, broad construct, we decided to include several questions that particularly ask for the level of APS knowledge and expertise as well as for the level of organizational education about operations management and logistics. The three items that measure the level of *OM/logistics-related sophistication* of an organization are: 1) 'number of employees with a bachelor degree in OM/logistics', 2) 'number of employees with a master's degree in OM/logistics', and 3) 'getting advice from external OM/logistics consultants'; see Table 5-8 (p. 141).

However, we also asked for the level of *APS familiarity*. The three items that measure the level of *APS familiarity* of an organization are: 1) 'familiarity with advanced planning techniques', 2) 'familiarity with the working, advantages and disadvantages of APS systems', and 3) 'existence of a specialist on APS systems'; see Table 10-1 (p. 257) in the appendix. Note that we did not account for the time-dependency (cause-effect relationship) of this type of sophistication. Firms may have high levels of *APS familiarity* without having adopted an APS system. In contrast, firms can have obtained higher levels of *APS familiarity* because of actual APS adoption and implementation. This is exactly the reason why we did not include the construct *APS familiarity* in the analysis of the impact of various factors on APS adoption in Chapter 5; it is, however, strongly related to actual APS adoption.

For *relative advantage*, we initially decided to operationalize *relative advantage* with 7 items using a five-point Likert-type scale. Respondents were asked to indicate the degree of emphasis their firms attach to the following items about APS adoption: 1) 'time required for making a production plan', 2) 'reduction in throughput time, 3) 'increase in reliability', 4) 'reduction in stock', 5) 'increase in utilization rates', 6) 'reduction in cost', and 7) 'feasibility of the production plan'; see the correlation matrix in Table 5-8. However, a factor analysis indicated that these items measured two dimensions of relative advantage: *OM/logistics-related advantage* and *package-related advantage*; see Table 5-6.

For *external communication*, we recall that we used the following variables: 1) 'employees' visits to seminars on production and logistics', 2) 'employees' reading of specialist literature on production and logistics', and finally 3) 'employees' attendance of logistics courses'; see Table 5-8.

6.4 Results

6.4.1 Layout and the position of the CODP

To gain insight into the association between the variables that measure 'dominant type of manufacturing layout' and 'position of the CODP', that measure the manufacturing strategy, we examined the contingency table of these two variables; see Table 6-1. It indicates that Dutch discrete parts manufacturing firms especially have an ETO/MTO strategy and work in a functional layout or a cellular layout. This concurs with the findings of Harvey [95] that manufacturing firms in Northern Europe produce in smaller batches than their US counterparts. We gain even more insight, if we give each layout a specific score, i.e., a weight, to construct a weighted frequency table. The number of firms working in (i) a functional layout is multiplied with weight 1, (ii) a cellular layout is multiplied by 2, and (iii) a product layout is multiplied by 3. From the means given in Table 6-1, we observe that firms with an ETO strategy have a slight tendency towards functional layouts, while firms with an ATO strategy have a tendency towards cellular layouts.

Note that these findings are in concurrence with both the group technology (GT) and socio-technical systems (STS) theory; an ETO strategy indicates the design and production of more or less unique products, an environment in which a cellular layout is generally not economically justified. In contrast, an ATO strategy aims to achieve a large number of product variants from a few standard modules; these modules may be manufactured in a cellular layout to achieve economies of scale effects. However, a peculiar finding is that six ETO firms had indicated to use a flow shop layout, which might imply that these firms engineer products to order, subcontract the production of parts, and subsequently assemble the end-products in house.

	Job shop	**%**	**Group lay- out**	**%**	**Flow shop**	**%**	**Total**
Engineer to order	14	(46.7)	10	(33.3)	6	(20.0)	30
	(29.8)		(21.3)		(20.0)		(24.2)
Make to order	25	(41.0)	21	(34.4)	15	(24.6)	61
	(53.2)		(44.7)		(50.0)		(49.2)
Assemble to order	5	(23.8)	11	(52.4)	5	(23.8)	21
	(10.6)		(23.4)		(16.7)		(16.9)
Make to stock	3	(25.0)	5	(41.7)	4	(33.3)	12
	(06.4)		(10.6)		(13.3)		(9.7)
Total	**47**	**(37.9)**	**47**	**(37.9)**	**30**	**(24.2)**	**124**

Frequency counts shown as cell values, with percentage of row totals and column totals given in parentheses

Scores →	**1**	**2**	**3**	
	Functional layout	**Cellular layout**	**Product layout**	**Means**
Engineer to order	14	20	18	1.733
Make to order	25	42	45	1.836
Assemble to order	5	22	15	2.000
Make to stock	3	10	12	2.083

Table 6-1: Contingency matrix and weighted frequencies and means of 'dominant type of manufacturing layout' related to 'position of the CODP'.

6.4.2 Layout and APS adoption

Proposition 6-1, which deals with the association between APS adoption and the type of manufacturing layout, can be tested by evaluating the contingency matrix of the two variables 'dominant type of manufacturing layout' and 'APS adoption'; see Table 6-2. This table is composed of 128 respondents, since one non-APS user had not filled out the question of the dominant type of manufacturing layout, and six respondents had indicated to have adopted an APS system, but actually had adopted an ERP system or a planning system without advanced decision support.

	APS user		Non-APS user		Total	Missing
Functional layout	5	(11.4)	39	(88.6)	44	4
	(26.3)		(35.8)		(34.4)	
Product layout	4	(13.8)	25	(86.2)	29	1
	(21.1)		(22.9)		(22.7)	
Fixed position layout (project)	0	(00.0)	9	(100.0)	9	
	(00.0)		(08.3)		(07.0)	
Cellular layout	10	(21.7)	36	(78.3)	46	1
	(52.6)		(33.0)		(35.9)	
Total	**19**	**(14.8)**	**109**	**(85.2)**	**128**	

Frequency counts shown as cell values, with percentage of row totals and column totals given in parentheses

Table 6-2: Contingency matrix of the variables 'dominant type of manufacturing layout' and 'APS adoption'.

Table 6-2 indicates that APS is only adopted by 14.8% of the respondents, which is common for a new technology like APS. More firms in the sample (59%) had adopted an ERP system; see Table 6-3.

	ERP user		Non-ERP user		Total
Functional layout	29	(60.4)	19	(39.6)	48
	(36.7)		(34.5)		(35.8)
Product layout	16	(53.3)	14	(46.7)	30
	(20.3)		(25.5)		(22.4)
Fixed position layout (project)	3	(33.3)	6	(66.7)	9
	(03.8)		(10.9)		(06.7)
Cellular layout	31	(66.0)	16	(34.0)	47
	(39.2)		(29.1)		(35.1)
Total	**79**	**(59.0)**	**55**	**(41.0)**	**134**

Frequency counts shown as cell values, with percentage of row totals and column totals given in parentheses

Table 6-3: Contingency matrix of the variables 'dominant type of manufacturing layout' and 'ERP adoption'.

A remarkable finding from the contingency matrix is that more than half of all APS adopters (52.6%) appear to work in a cellular layout, which is 21.7% of all respondents with a cellular layout. In contrast, only 11.4% of the firms with a functional layout and only 13.8% of the firms with a product layout had adopted an APS system. In addition, none of the respondents with a fixed position layout, i.e., project layout, had adopted an APS system. While not significant, similar results were obtained for the data of the first survey discussed in Chapter 3.

Irrespective of statistically significance, these findings contradict our proposition that predominantly more non-cellular layout adopters would adopt an APS system. Hence, we cannot confirm proposition 6-1; in fact, the proposition is deemed to be rejected. As a result, we conclude that even more APS users may work in a cellular layout than in a functional layout.

Similar findings were obtained for ERP adoption. Table 6-3 indicates that 39.2% of the ERP users work in a cellular layout, while 36.7% of the ERP users work in a functional layout, and even 20.3% in a product layout.

6.4.3 Layout, sophistication, and communications channels

The remarkable finding that more APS adopters appear to work in a cellular layout instead of a functional layout is also confirmed by the differences in *OM/logistics-related sophistication* and *external communication* channels for firms that work in a cellular layout versus firms that do not. An ANOVA analysis indicates that firms with a cellular layout have significant ($p < .05$) higher means for both *OM/logistics-related sophistication* and *external communication* than firms that do not have a cellular layout; see Table 6-4.

Effect Size as measured by Cohen's *d*

Characteristic	Cellular layout	Non-cellular layout	Significance	E.S.
OM/logistics-related sophistication (2.07)	2.26	1.97	.045	.48
External communication (2,85)	3.11	2.71	.026	.76

Table 6-4: Differences in *OM/logistics-related sophistication* and *external communication* for cellular/non-cellular layouts.

This means that firms with a cellular layout have generally more sophistication and external communication channels about the recent developments in OM/logistics-related issues than traditionally organized firms. This could be the reason why more respondents with a cellular layout had adopted APS than respondents with a non-cellular layout. However, during the analysis we questioned whether the product layout was a bias in these findings. Hence, we constructed a similar table for cellular layout versus functional layout; see Table 6-5.

Note that the means and significance levels in Table 6-4 are somewhat different compared to Table 6-5, because Table 6-4 also comprises respondents with a product layout or fixed-position layouts. The significant difference of the means for *OM/logistics-related sophistication* for firms with a cellular layout versus firms with a functional layout indicates that firms with a cellular layout have predominantly more *OM/logistics-related sophistication* than firms with a functional layout. For the construct *external communication*, it appeared that firms with a cellular layout have higher means than firms with a functional layout. This means that cellular layout users have more external communication channels about this topic than firms with a functional layout. Hence, we have to reverse the statements of both propositions 6-2 and 6-3:

> **PROPOSITION 6-4:** *Firms with a cellular layout are more sophisticated on OM/logistics-related issues and have more external communication channels about APS systems than firms with a functional layout.*

Effect Size as measured by Cohen's d

Characteristic		**Cellular layout**	**Functional layout**	**Significance**	**E.S.**
sophistication	APS	2.96 (N=8)	2.08 (N=4)	.073	1.36
	Non-APS	2.13 (29)	1.88 (32)	.094	.44
	Total	2.31 (37)	1.90 (36)	.008	.65
APS familiarity	APS	3.63 (8)	2.67 (4)	.170	.91
	Non-APS	2.27 (30)	2,05 (33)	.265	.29
	Total	2.55 (38)	2.12 (37)	.040	.48
OM/logistics-related sophistication	APS	2.15 (9)	1.60 (5)	.284	.71
	Non-APS	1.98 (33)	1.64 (35)	.049	.48
	Total	2.02 (42)	1.63 (40)	.018	.49
external communication	APS	3.33 (9)	2.27 (5)	.074	1.14
	Non-APS	3.08 (32)	2.78 (35)	.132	.37
	Total	3.14 (41)	2.72 (40)	.027	.50
Competitive position	APS	1.29 (7)	2.00 (5)	.064	− 1.17
	Non-APS	1.94 (32)	2.46 (26)	.041	− .54
	Total	1.82 (39)	2.39 (31)	.012	− .61
relative advantage	APS	4.30 (8)	3.93 (4)	.333	.57
	Non-APS	4.36 (29)	4.12 (28)	.043	.54
	Total	4.35 (37)	4.10 (32)	.027	.53
logistics-related advantage	APS	4.23 (8)	3.85 (4)	.408	.48
	Non-APS	4.41 (30)	4.14 (29)	.061	.50
	Total	4.37 (38)	4.10 (33)	.053	.47
package-related advantage	APS	4.39 (9)	4.10 (5)	.392	.48
	Non-APS	4.15 (29)	4.12 (29)	.846	.04
	Total	4.21 (38)	4.12 (34)	.543	.14
size	APS	3.78 (9)	3.20 (5)	.392	.45
	Non-APS	3.67 (36)	3.38 (39)	.239	.28
	Total	3.69 (45)	3.36 (44)	.143	.32

Table 6-5: Comparison of APS adoption issues compared for cellular layout versus functional layout.

Table 6-5 also displays the variable 'competitive position' (which is coded from 1 = very good to 5 = very poor); the values of this variable indicate that firms with a cellular layout have, on average, a better competitive position than firms with a functional layout ($p < .05$). For non-APS adopters this difference is significant. This means that non-APS adopters with a functional layout have on average a poorer competitive position than non-APS adopters with a cellular layout. Furthermore, we notice that firms that had adopted APS and simultaneously work in a cellular layout had indicated to have, on average, the highest competitive position. In all, as the number of APS adopters is too small to find a significant difference –if we discriminate them as users of a cellular layout versus users of a functional layout–, we postulate that firms with a cellular layout have a better competitive position than traditionally organized firms. This is, however, not necessary the result of the type of manufacturing layout. However, these findings do strengthen proposition 6-4.

In addition, further support for this proposition stems from a close examination of the relationship between the construct *relative advantage* (attached to an APS system) and the dominant type of manufacturing layout, as this indicates the underlying reasons for adopting an APS system. From Table 6-4, we notice that firms with a cellular layout have a higher score on *relative advantage* ($p < .05$) than firms with a functional layout. This means that firms with a cellular layout attach greater importance to the relative advantage an APS system may offer, than firms with a functional layout, especially when these firms had not actually adopted an APS system. This contradicts with general group theory that group users try to overcome planning complexity by reduction, i.e., decentralization, and not by the (possible) implementation of an advanced planning system. In other words, our study shows that firms with a cellular layout attach importance to APS systems to achieve reduction in throughput, inventory, and cost, as well as gaining plans faster and simultaneously achieve higher utilization rates and delivery reliability even though these advantages are theoretically the driving force to initiate the implementation of cellular layouts.

Because of the findings of the case study at Urenco Aerospace, see Chapter 2, plus the findings of this chapter, we conclude that decentralization does not necessarily lead to a reduction of production planning and control requirements. That is, the findings support our claim that groups are not implemented to overcome the planning complexity per se. Note that this is in concurrence with a study of De Leede and Stoker [153] that concludes that although groups in The Netherlands are generally created from Dutch sociotechnical theory ideas, only few groups in The Netherlands are completely autonomous. They also found that many are trying to move in that direction and only few organizations claimed to have completed the design and implementation of groups. Surprisingly, it appeared that there was no relationship between the design of the groups and the nature of the order flow, and accordingly, production planning and control requirements may still be present. This is also confirmed by the study of Riezenbos [189].

6.5 Conclusion and future research

The purpose of this study was to empirically examine the relationship between the dominant type of manufacturing layout and APS adoption among Dutch discrete parts manufacturing firms. While, theoretically, the implementation of a cellular layout is aimed for a reduction of the production planning and control complexity, the remarkable finding of this study is that APS systems are predominantly more adopted by firms working in a cellular layout than 'traditionally' organized firms. This finding also holds for the adoption of ERP systems, which is remarkable, only in the context of our finding from the analysis in Section 3.5.1 (p. 104), that the use of an ERP system is an important determinant for a more centralized operational planning decisions structure. We, therefore, investigated whether *size* was a 'lurking' variable, since larger firms predominantly more often use ERP than smaller firms. However, it appeared that *size* did not affect the findings discussed in this chapter; see Table 6-5.

From the findings of Chapter 5, we know that there is a significant relationship between *OM/logistics-related sophistication*, *external communication* and *APS adoption*. Indeed, firms that have high levels of *OM/logistics-related sophistication* also have high levels of *external communication*. In concurrence with these findings, we found that firms with a cellular layout have significantly higher levels of *OM/logistics-related sophistication* and *external communication* (channels) about OM/logistics-related topics than firms with a functional layout. This difference is, however, not significant if both type of firms had adopted APS. It also turned out that firms that had adopted APS and simultaneously work in cellular layouts have, on average, the best competitive position of all respondents.

In concurrence with these remarkable findings, we expect that groups in The Netherlands are particularly implemented from a social perspective, i.e., to enrich and enlarge jobs, to increase worker involvement and commitment, and to provide responsibility to shop floor employees, and not so much to reduce production planning and control requirements by making groups as dedicated as possible. However, while it is consistent with our findings that various groups still require an overall APS system, future research must confirm this expectation, because of potential bias in the findings due to the single-rater characteristic of the survey. Indeed, future research is necessary to affirm the following proposition that stems from the findings of this exploratory chapter:

> **PROPOSITION 6-5:** *Firms with a cellular layout are more developed about OM/logistics-related issues than traditionally organized discrete parts manufacturing firms.*

However, some remarks must be made. First, APS is a relatively young technology that has only recently gained a lot of attention. Although analysis indicates some significant relationships between firms with a cellular layout and firms with a functional layout, we expect that there are more APS adoption-related differences between these types of firms, but for which we could not find sufficiently significant differences in means because of the small sample.

Second, for firms with a cellular layout, we did not ask for their experiences with the specific grouping approach. Furthermore, we are not aware of the average period these firms already employ a cellular layout. Although not very likely, firms that had both adopted a cellular layout and an APS system might have adopted the cellular layout only recently, or it might be that some firms are not yet convinced that the cellular layout may lead to a reduction of the planning complexity, and subsequently adopt an APS system. Furthermore, future research is necessary to investigate the breadth and depth of APS adoption, that is, how large and deep the innovation penetrates in an organization, and to what extent the adoption and implementation of an APS system impacts the work methods in an organization.

7 Manufacturing layout, PMT-uncertainty, and strategic focus

Well-known grouping approaches are the Group Technology (GT) / Cellular Manufacturing (CM) approach, and the modern (Dutch) Socio-Technical Systems (STS) approach. These approaches have in common that they both advocate the reduction of logistical complexity by product-orientation, dedication, and decision autonomy; the higher the dedication and autonomy of cells are, the lower the overall production planning and control complexity of the manufacturing system is. However, a number of different types of cells, groups, and teams can be found in manufacturing systems, which can be classified based on the autonomy continuum; see for instance Banker et al [22]. Autonomous cells are indicated as *real* cells in which work tasks and those who perform them are connected through time, space, and information [120]. Configurations not adhering to the discipline of time, space, and information may be classified as *latent* or *virtual* cells, and may be expected to underperform [120]. Nevertheless, numerous cells in practice do not fully meet the requirements of real cells; this is particularly true for the Dutch discrete parts industry [189]. However, based on a socio-technical approach to cell design, Hyer et al. [119] proposed a comprehensive model that contrasts previous models proposed in the literature. Exceptionally remarkable is its emphasis on the strategic context, as most existing models for cell design assume that the decision to implement cells has already been taken; all that is necessary is simply to design them. In fact, the model of Hyer et al. [119] emphasizes the important link between organizational strategy and design objectives, acknowledging that one must first determine that cells make sense as an organizational response. Indeed, most publications on cellular manufacturing systems have a primary technical/tactical orientation; see for instance Moodie et al. [172] and Hyer and Wemmerlöv [120]. The relationship between design and implementation of cells, and the alignment of a manufacturing strategy's imperative to derive a sustainable competitive advantage, is still underexposed. What is more, most grouping approaches lack an explicit market focus to adapt to uncertainty and hostility.

It is commonly accepted that functional layouts are extremely flexible to manufacture a huge variety of different products and features, and to adapt to the ever-changing needs of customers in environments where order sizes are small or even of a one-of-a-kind production. Cellular layouts are considered to be economically feasible only if the organization faces a sufficiently large and relatively stable demand. In addition, variability should be reduced as much as possible to prevent loss of pooling synergy [214]. Hence, to change from a functional layout to a cellular layout successfully, firms should not only evaluate the advantages of smaller batch sizes and set-up time reduction that generally correspond with the implementation of cells, but they must find ways to reduce variability. This would, however, imply that cellular manufacturing is not a panacea for uncertain and hostile environments per se, because of reduced requisite variety; from a systems perspective, the creation of autonomous flows through parallelization and subsequently the creation of dedicated cells through segmentation reduces the number of degrees of freedom to cope with complexity and to adapt to uncertainty. Cells must be embedded within a relatively stable manufacturing environment to work properly and efficiently [206]. Indeed, other organization structures are more appropriate to function in uncertain and hostile environments, for instance, adhocracies, virtual and network based structures, or even functional resource and competence groups.

Nevertheless, the relationship between PMT-uncertainty, the extent of customer influence on the productmix, customer's vendor-switching possibilities, and the decision to implement a cellular layout or maintaining a functional layout is underexposed in literature: do firms with a cellular manufacturing structure differ with respect to PMT-uncertainty (i.e., complexity and rate of change) from firms with a functional layout? Do firms with a functional layout face higher levels of customer-related hostility in that customers exert influence on the productmix and that they have ample vendor-switching possibilities than firms with a cellular layout? Do firms with a functional layout have a different strategic focus than firms with a cellular layout? That is, do they focus on different competitive priorities? In this chapter, we address the question whether firms with a cellular layout differ on these aspects from firms with a functional layout. After all, an objective of adopting a cellular layout is to achieve the benefits, commonly associated with mass production, in less repetitive batch manufacturing environments [202].

The plan of this chapter is as follows. In Section 7.1, we hypothesize the differences between the PMT-uncertainty-related constructs *complexity* and *rate of change* for firms with a cellular layout versus firms with a functional layout. However, we also introduce new constructs related to a firm's focus on competitive priorities. In this chapter, we also explore the differences in these constructs for firms with a cellular layout versus firms with a functional layout. In Section 7.2, we briefly discuss the research method and the operational definitions of the constructs. In Section 7.3, we present the results of hypothesis testing with the help of the data of the first survey as discussed in Chapter 3. In Section 7.4, we discuss our findings. However, this chapter ends with a supplement (i.e., Section 7.5) containing a brief discussion of the relationships between the competitive priorities.

7.1 Propositions

7.1.1 Differences in PMT-uncertainty

We continue this chapter with the assumption that firms that have adopted a cellular layout try to make these cells as dedicated and self-contained as possible to reduce the (logistical) complexity and to achieve the advantages of real cells [120]. This may result from the introduction of flow within such dedicated cells to reduce set-up times and to achieve economies of scale effects in small batch manufacturing [43]. Subsequently cross-trained cell workers are empowered with local control cycles to achieve higher overall performance [115]. However, we assume that this may only be economically feasible, i.e., lead to sufficiently high utilization of resources within a cell without ample inter-cell movements, if production variability is relatively low. Otherwise, the performance of the shop deteriorates due to the loss of pooling synergy [214]. That is, the firm has to manufacture a sufficiently large number of similar orders for similar products or parts within a family in such a way that complete and reasonable cells can be formed; see for instance Flynn and Jacobs [73][74]. In contrast, the functional layout has the required flexibility to adapt to PMT-uncertainty despite its complexity; hence, this type of manufacturing layout is appropriate for uncertain manufacturing environments. From this discussion, we derive the proposition that firms with a cellular layout face lower levels of rate of change than firms with a functional layout.

> **PROPOSITION 7-1:** *Firms with a cellular layout face lower levels of environmental rate of change than firms with a functional layout.*

Operations technology complexity generally originates from the division of labor. The manufacturing system then becomes a complex network of workers and machines that are mutually dependent and among which various interactions occur. If the complexity of a system increases, the control of the system becomes more difficult and laborious. Indeed, the simplification of this complexity is exactly the reason to implement cells in the first place. Hence, we hypothesize that firms with a cellular layout face lower levels of environmental complexity than firms with a functional layout.

> **PROPOSITION 7-2:** *Firms with a cellular layout face lower levels of environmental complexity than firms with a functional layout.*

Mintzberg [169] also states that an organization's environment can range from munificent to hostile. Hostility affects the organization through the predictability of the work to be done; hostile environments are unpredictable. In addition, Mintzberg [169] states that its relationship with the speed of response is of greater interest, since very hostile environments generally demand fast reactions by the organization. Slomp et al. [206] state that CM-systems in the Dutch discrete industry are primarily applied in 'stable' and friendly environments. Hence, we have the following proposition.

> **PROPOSITION 7-3:** *Firms with a cellular layout face lower levels of environmental hostility than firms with a functional layout.*

7.1.2 Differences in the focus on competitive priorities

Contingency theory suggests that environmental and structural contingencies cause some manufacturing strategies to be more effective than others, see for instance Lawrence and Lorsch [151]. The strategic emphasis on developing certain manufacturing capabilities that may enhance a plant's position in the marketplace is reflected by the competitive priorities. In addition, manufacturing strategy and focus are two general concepts that have emerged to convey the need of the internal consistency and unity of purpose among operations decisions [101][107][205]. Such emphasis may guide decisions regarding production process, capacity, technology, planning, and control. Put differently, focus begins with decisions on key competitive priorities (cost, flexibility, time, and quality), which in turn guide decisions on the production system [100][204][235]. In addition, Kotha and Orne [139] state that manufacturing structures (product-line complexity, process-structure complexity, and organizational scope) also implicitly represent generic manufacturing strategies.

However, many see process choice as a pivotal element in manufacturing strategy and in achieving focus [99][194]. Process choice can be viewed as a reference point for bringing about consistency across operations decisions. A process focus (i.e., the functional layout) is intended for producing low-volume, customized products. In contrast, a product focus (i.e., a product layout) is intended for producing high-volume, standardized products. Some manufacturing firms use both types of processes even within the same plant [30][235]. Ward et al. [235] state that manufacturers who value flexibility greatly will tend to use job shop type processes and those who value low cost manufacturing will tend to choose flow line processes. Based on a survey of 114 U.S. manufacturing firms in the Midwest and Northeast, they found a significant relationship between competitive priorities and process choice; the importance of cost as a competitive priority increases as process choice moves from the job shop setting to the flow shop setting. In a separate analysis, Safizadeh et al. [194] observed similar relationships between competitive priorities and process choice. In addition, Slomp et al. [206] found that Dutch discrete parts manufacturing firms with a functional layout have higher levels of focus on flexibility than firms with a cellular layout. Hence, we hypothesize that firms with a functional layout have higher levels of strategic focus on flexibility than firms with a cellular layout.

> **PROPOSITION 7-4:** *Firms with a functional layout have higher levels of strategic focus on flexibility than firms with a cellular layout.*

Reorganizing work processes into cells, simultaneously from both a technical and a social perspective, has helped many organizations to streamline their operations, to shorten lead-times, to increase quality, and to decrease costs [120]. Taylor and Felten [221] state that such socio-technical cells benefit only if the firm also focuses on total quality management issues. On the other hand, they also state that TQM institutes, nowadays, have embraced socio-technical systems theory as a methodology to enhance the potential of TQM. These statements concur with the statement of Klein [133] that the primary long-term benefit of TQM is, nevertheless, its potential to increase collaborative learning among teams. In highly empowered work settings, individuals and teams learn, but organizations as a whole are often unable to take advantage of synergy across teams [1]. In addition, Manz and Stewart [162] state that the introduction of any type of groups without the inclusion of quality-based process-orientation, such as in TQM practices, may fail because change efforts are discontinued when social and technical coordination problems harm short-term performance. Based on this brief theoretical rationale, we hypothesize that firms with a cellular layout have higher levels of strategic focus on quality than firms with a functional layout.

> **PROPOSITION 7-5:** *Firms with a cellular layout have higher levels of strategic focus on quality than firms with a functional layout.*

Buchanan [42] states that Just-In-Time principles encourage a move away from functional plants to the use of manufacturing work cells in which the focus is on faster and more reliable delivery. Hence, we include the following proposition.

> **PROPOSITION 7-6:** *Firms with a cellular layout have higher levels of strategic focus on delivery performance than firms with a functional layout.*

7.2 Research method and operational definitions

The examination of the difference between firms with a cellular layout and firms with a functional layout on PMT-uncertainty and the strategic focus on competitive priorities, is conducted with the help of the data obtained from the first survey discussed in Chapter 3. Again, the analytic procedure used in this study aims to test for differences in means for subpopulations, namely firms with a cellular layout versus firms with a functional layout, for which we use the statistical software package SPSS 11.

7.2.1 Layout

We recall that, for the type of manufacturing layout, we asked respondents to indicate the dominant type of layout in their plant, where respondents could choose between a project layout (fixed position), a process layout (functional, job shop layout), a cellular layout (group-based manufacturing), and a product layout (flow shop). 66 respondents indicated to use a functional layout and 52 respondents indicated to use a cellular layout.

7.2.2 PMT-uncertainty

In this chapter, we use the PMT-uncertainty-related constructs operationalized in Chapter 3, in particular *customer order complexity*, *end-product complexity, operations technology complexity*, and *supplier complexity*; see Table 3-4, p.83. In addition, we use the second order construct *rate of change*; see Figure 3-4, p.91. However, in this study we also aimed to operationalize a customer-behavior related construct *hostility*, with the items 1) 'Percentage of seasonal products in product mix', 2) 'Influence of customers on product mix', and 3) 'vendor switching possibilities'. However, since the value of Cronbach's alpha for this construct was far too low, we only use these items separately.

7.2.3 Competitive priorities

Hill [107] argues that there is a strong relationship between manufacturing tasks and customer needs. Manufacturing tasks were defined as those capabilities that are critical to winning customer orders. In addition, most researchers view manufacturing strategy as defined by the relative weights of manufacturing capabilities, including low cost, quality, flexibility, and delivery performance. Although some conceptual studies suggest innovativeness and customer service as other important priorities, empirical research and strategy theories consistently stress the four basic capabilities; see for instance Schmenner and Swink [196] and Ward et al. [235]. Similarly, there is general agreement that the effectiveness of an operations strategy is determined by the degree of consistency between emphasized competitive priorities and corresponding decisions regarding operational structure and infrastructure [36]. As a result, we operationalize the competitive priorities according to the strategic focus on cost, (product-) quality, delivery performance, and flexibility.

***Strategic focus on cost* (*SF-C*)** We operationalize the *strategic focus on cost* with the single item 'low cost is a strategic priority'.

***Strategic focus on product quality* (*SF-PQ*)** We operationally define the *strategic focus on product quality* by the items 1) high product quality is a strategic priority' and 2) 'high product reliability is a strategic priority', for which we obtain a sufficiently large value of Cronbach's alpha of .8107; see Table 8-1 (p. 190).

***Strategic focus on delivery performance* (*SF-D*)** We operationally define the *strategic focus on delivery performance* by the items 1) 'strategic importance of quick supply', 2) 'short lead-times is a strategic priority', and 3) 'strategic importance of high delivery reliability'. As a result, we obtain a value of Cronbach's alpha of .6753; see Table 8-1 (p. 190).

Strategic focus on flexibility (SF-F) We operationally define the *strategic focus on flexibility* by the items 1) 'strategic importance of short lead-times to gain flexibility', 2) 'strategic importance of mix flexibility', and 3) 'strategic importance of volume flexibility', for which we obtain a Cronbach's alpha with value of .7836; see Table 8-1 (p. 190).

However, note that in the scale of *strategic focus on flexibility*, we ask for the strategic importance of short lead-times to gain flexibility and in the scale of *strategic focus on delivery performance*, we ask the respondent to indicate the extent to which short lead-times is a strategic priority in itself. As a result, these scales are suspicious to measure the same construct. Therefore, we perform a factor analysis (KMO = .719) to explore the number of 'independent factors' in the items of both scales. As presented in Table 7-1, we obtain two separate but related constructs.

Variables (items)	***Flexibility* (*SF-F*)**	***Delivery performance* (*SF-D*)**
the strategic importance of volume flexibility	.735	
the strategic importance of mix flexibility	.860	
the strategic importance of short lead-times to gain flexibility	.556	.380
the strategic importance of quick supply	.352	.427
short lead-times is a strategic priority		.884
high delivery reliability is a strategic priority		.604
Cronbach's alpha	.7836	.6753
***Strategic focus on flexibility* (*SF-F*)**	.817	
***Strategic focus on delivery reliability* (*SF-D*)**	.53	.819

Table 7-1: Rotated factor matrix (varimax; cutoff = 0.3) of *SF-F* and *SF-D* and factor score covariance matrix.

7.2.4 Secondary constructs

In this chapter, we also use the constructs *size* and *financial performance*, because we also aim to investigate 1) spurious relationships between possibly causal effects of the 'primary' constructs, dominant type of layout (i.e., process choice), and strategic focus on competitive priorities, and *size*, and 2) the effect of a specific type of layout in uncertain and certain environments on *financial performance*; see Table 3-9 (p. 89).

7.3 Results

We discuss the results of hypothesis testing with the help of an ANOVA analysis to explore differences in means on the constructs, items, and statements for firms with a cellular layout versus firms with a functional layout. Hence, we only use respondents who indicated to use a functional (66 respondents; 32.2%) or a cellular layout (52 respondents; 25.4%).

PMT-uncertainty-related constructs A first remarkable finding was that, in our sample, there are no significant differences in all constructs related to the external environment; see Table 7-2. Put differently, firms with a cellular layout do not differ on the constructs related to complexity and rate of change compared with firms with a functional layout. Thus, we cannot confirm propositions 7-1 and 7-2. Furthermore, note that firms with either a cellular layout or a functional layout do not differ in *size* or *financial performance*.

Effect Size as measured by Cohen's *d*

Statements	Cellular layout	Functional layout	Significance	E.S.
customer order complexity (3.08)	3.08 (N_i = 20)	3.08 (29)	.963	− .01
end-product complexity (3.29)	3.02 (17)	3.47 (26)	.200	− .41
operations technology complexity (3.16)	3.11 (19)	3.20 (24)	.491	− .31
supplier complexity (2.97)	3.10 (21)	2.87 (30)	.165	.01
rate of change (3.31)	3.29 (21)	3.34 (26)	.742	.01
size (3.20)	3.05 (21)	3.30 (30)	.297	− .30
financial performance (2.71)	2.82 (14)	2.66 (28)	.596	.18

Table 7-2: Differences in means on the PMT-uncertainty-related constructs for firms with a cellular layout versus firms with a functional layout.

Effect Size as measured by Cohen's *d*

Statements	Cellular layout	Functional layout	Sign.	E.S.
Percentage of seasonal products in product mix (1.45)	1.24*** (N_i = 51)	1.63 (64)	.008	− .53
Influence of customers on the product mix (3.19)	2.9** (52)	3.42 (64)	.011	− .48
Vendor switching possibilities (3.09)	2.9** (52)	3.25 (65)	.034	− .41

Table 7-3: Differences in means on customer-related hostility items for firms with a cellular layout versus firms with a functional layout.

However, both types of firms do differ on the single customer-related hostility items; see Table 7-3. Firms with a functional layout have on average a higher percentage of seasonal products in their product mix; their customers have more influence on the product mix. Their customers have also more switching possibilities and hence, firms with a functional layout operate in more hostile environments. This requires firms with a functional layout to have more mix-flexibility. This concurs with the claim that functional layouts are extremely flexible to manufacture a huge variety of different products and features; and to adapt to the ever changing needs of customers in environments where order sizes are small or of a one-of-a-kind production. Based on these findings we confirm proposition 7-3 that firms with a cellular layout have lower levels of customer-related hostility than firms with a functional layout.

Competitive priorities Firms with a cellular layout have higher levels of *strategic focus on quality* and higher levels of *strategic focus on delivery performance* than firms with a functional layout; see Table 7-4. Since the effect sizes, as measured by Cohen's *d* is sufficiently large, these results confirm propositions 7-5 and 7-6. In addition, firms with a cellular layout also have higher delivery reliabilities and less waiting times within their lead-times than firms with a functional layout; see Table 7-5. For s*trategic focus on cost* and *strategic focus on flexibility,* we found no significant differences between firms with a cellular layout and firms with a functional layout. Thus, proposition 7-4 cannot be confirmed based on this study.

Effect Size as measured by Cohen's *d*

Statements	**Cellular layout**	**Functional layout**	**Sign.**	**E.S.**
Strategic focus on delivery performance (2.43) ***	2.55	2.33	.009	.57
Strategic focus on flexibility (2.11)	2.21	2.04	.177	.38
Strategic focus on quality (2.68)***	2.80	2.24	.010	.53
Strategic focus on price (2.21)	2.17	2.24	.558	.04

Table 7-4: Differences in means on the competitive priorities for firms with a cellular layout versus firms with a functional layout.

Effect Size as measured by Cohen's *d*

Statements	**Cellular layout**	**Functional layout**	**Sign.**	**E.S.**
High product quality is an order winner (2.67)	2.85** ($N_i = 20$)	2.55 (29)	.029	− .68
High product reliability is an order winner (2.65)	2.70** (20)	2.61 (28)	.042	.19
High delivery reliability is an order winner (2.57)	2.80** (20)	2.41(29)	.020	.71
Short Lead-times is an order winner (2.28)	2.53** (19)	2.11 (28)	.020	.71
High utilizations is an order winner (1.56)	1.78* (18)	1.40 (25)	.096	.52
Small lot sizes is a strategic priority (3.70)	3.45* (20)	3.90 (28)	.079	− .52

Table 7-5: Differences in means on the single items of the competitive priorities for firms with a cellular layout versus firms with a functional layout.

7.4 Conclusion

Firms with a functional layout are no different from firms with a cellular layout with respect to PMT-uncertainty, except the strong dependency of firms with a functional layout on the supplier switching behavior of customers. It concurs with the statement that firms with a functional layout make whatever type of order drops in, even one-off prototyping orders. This is typical of engineer-and-make-to-order firms; MTO firms generally sell capacity. Thus, they generally have a comprehensive part production and assembly department in which they produce and assemble a high diversity of end-items in small and medium-sized batches, *often* in functional organizational manufacturing settings, i.e., job shops. Indeed, firms with a cellular layout rated 'small lot sizes' as less strategic than firms with a functional layout; see Table 7-5. However, from Table 6-1, we also know that MTO firms may also adopt the cellular layout, irrespective of the PMT-uncertainty; see Table 7-2.

Effect Size as measured by Cohen's *d*

Statements	**Cellular layout**	**Functional layout**	**Sign.**	**E.S.**
Delivery reliability - on time orders as percentage of total number of orders (4.15)	4.30* (*Ni* = 46))	4.03 (63)	.071	.35
Processing time as percentage of total lead-times (3.05)	3.35** (38)	2.83 (63)	.039	.39
I think lead-times are too high (3.05)	2.80** (21)	3.26 (29)	.015	− .35
I think delivery reliability is too low (2.50)	2.25** (21)	2.71 (30)	.024	− .35

Table 7-6: Differences in means on opinions and statements for firms with a cellular layout versus firms with a functional layout.

In addition, from Table 7-6 we observe that firms with a cellular layout have higher delivery reliability and lower waiting times (i.e., higher score on processing time as percentage of total lead-times). It concurs with the finding in the previous chapter –which was based on another survey– that firms with a cellular layout have a better competitive position than firms with a functional layout.

Furthermore, firms with a cellular layout indicated to be more satisfied with their delivery lead-times and delivery reliability. In all, we conclude that firms with a cellular layout obtain better logistical performance, indifferent of the level op environmental complexity and rate of change. This strengthens our claim, as discussed in the previous chapter, that firms with a cellular layout are more developed on OM/logistics-related issues.

Reorganizing work processes into cells has helped many organizations to streamline operations, to shorten lead-times, to increase quality, and to lower costs. Cellular manufacturing is a powerful concept that is simple to understand; however, its ultimate success depends on deciding where cells fit into the organization, and then applying the know-how to design, implement, and operate them. Firms that work with a cellular layout have higher levels of *strategic focus on delivery performance* and *strategic focus on quality* than firms that work with a functional layout.

7.5 The relationship among competitive priorities

While the general framework for manufacturing strategy and competitive priorities (i.e., cost, quality, flexibility, and delivery performance) has now been fairly well defined, it is still unclear what the relationships between the competitive priorities are [235]. The trade-off model is the most established perspective, first proposed by Skinner [204]. It states that firms must make choices regarding which competitive priority to give the greatest investment of time and resources; manufacturing systems should focus on one priority at a time, because cost, flexibility, and delivery performance require different operational structures and infrastructures for support. In contrast, proponents of the cumulative model claim that trade-offs are irrelevant in a world of intense competition and advanced manufacturing technologies [53][70]. Competitive priorities are considered complementary rather than mutually exclusive, as an existing capability (e.g., quality) may aid the development of other capabilities (e.g., flexibility).

Two-tailed; Pearsons correlation coefficients

	F1	***F2***	***F3***	***F4***	***F5***
Strategic focus on flexibility (F1)	1				
Strategic focus on delivery performance (F2)	.534***	1			
Strategic focus on quality (F3)	.119	.275***	1		
Strategic focus on cost (F4)	.207***	.207***	− .266***	1	
Strategic focus on quick product introduction / innovations (F5)	.262***	.160**	.057	− .039	1

Table 7-7: Correlations among the (strategic focus on) competitive priorities.

The results from Table 7-1 and the finding that firms with a cellular layout have simultaneously higher levels of *strategic focus on delivery performance* and *strategic focus on quality* suggest that the competitive priorities are related to some extent; more specifically, there is a correlation between the constructs *strategic focus on delivery performance* and *strategic focus on flexibility*. Accordingly, this suggests support for the integrative and the cumulative models—only a longitudinal research method can resolve this issue. Consequently, we analyzed potential correlation between the competitive priorities in more detail; Table 7-7 shows that quality is positively related to delivery performance, which is again positively related to flexibility. In addition, the importance of low cost is positively related to delivery performance and flexibility but negatively related to quality.

8 Line management's support of individual competencies and financial performance

More than ever before, the processes of world-class manufacturers must be fast, fluid, and flexible. This can be achieved only by implementing innovative manufacturing concepts and harnessing the full potential of new technologies and concepts. Agility is such a manufacturing management concept;. It is the organizational capability to re-engineer and adjust to continuous change by empowering employees, generally in a decentralized organizational setting. Process management plays an important role in agile manufacturing. Process management practices underpin a continuing progression of quality-related initiatives over the past two decades, including Total Quality Management (TQM), the International Organization for Standard's ISO 9000 program, and Six Sigma. These programs share a core set of activities to map, improve, coordinate, and adhere to organizational processes; e.g., [29][55][96]. Hence, lean manufacturing related concepts and methods like Just-In-Time philosophy, kanban control systems, Total Quality Management, Statistical Process Control, and Six Sigma are extremely important [61][158].

As the workforce is a key source of agility [110] agile organizations, highly decentralized as they are, have 'flexible, dynamic, pluralistic, and deliberate' structures [2] to foster the individual competencies to respond quickly to competitive threats and market opportunities. Speed and competencies are key to becoming agile; the ability of an organization to quickly offer renewed customer service, with renewed product-attributes and manufacturing processes to seize momentary opportunities, is a measure of its agility. Agility affects the strategic and operational way of doing things. It is not only largely dependent on the capabilities and competencies of both managers and workers, to learn and evolve with change, but also on the interactions between the technological capabilities and the capabilities of the employees working with the technology [110]. In this perspective, technical skills encompass knowledge of a particular functional discipline and the capability to apply that knowledge [101]. In addition, control skills, or management skills, are needed to make sure that activities can be performed. However, it is well known that these types of skills will not lead to a sustainable distinctive competitive advantage [183][184]. As a result, the presence of the required skills and knowledge on its own, at a specific point in time, is momentary, and hence insufficient for sustained agility. Unfortunately, it remains unclear how to manage employees in the process towards agility. If agility is largely dependent on the capability and competence of its workforce to cope with uncertainty, how should both managers and workers be managed to learn and evolve with change? Which individual characteristics must be emphasized?

A stream of research has emerged in the strategy literature, as well as in the human resource management literature, that postulates that inimitable and valuable organizational and individual resources, competencies, capabilities, knowledge, culture, and skills are key aspects of a firm's sustain competitive advantage [23][137][145][186][195][213]. Competence management comprises the integral management of strategic, organizational, and individual competencies. A central theme in competence management is the ability to learn, unlearn, and relearn on all levels of an organization. Hence, competence management appears to be appropriate to provide directions and guidelines for the creation of an agile organization.

The management of individual competencies is considered to be part of a High-Performance Work System that is, in theory, positively related to financial performance [27]. They also stipulate that capabilities of human resources staff are an important determinant of this relationship. However, while numerous authors claim that modern management methods must be embedded throughout the organization [101], the impact of line management's role on the relationship between individual competence management and financial performance is still unclear. Even stronger, the CEO and senior line managers in numerous firms are at best skeptical of HRM's role in a firm's success [27], let alone that they acknowledge the strategic role and financial impact of individual competence management. However, recent research shows that managing people must become an integral part of the job of line managers in manufacturing and service operations; it is no longer the domain of the HRM 'staff function' only [37][228]. In this chapter, we address this issue, investigating the question whether firms in which line management values individual competencies outperform firms in which this is not the case. In addition, we aim to explore whether line management's support of individual competencies relates to a firm's strategic focus on agile manufacturing priorities.

The contribution of this paper is twofold. First, with the help of a structural equations model, we demonstrate 1) that firms in which line management values individual competencies are indeed outperformers, and 2) a relationship between management's support of individual competencies and agile manufacturing concepts,. Second, we demonstrate that firms that undervalue individual competencies focus less on the agile competitive priorities speed and flexibility.

The outline of this chapter is as follows. In Section 8.1, we discuss dynamic competence management, and especially the management of individual competencies that enables learning to adapt to change. From this theoretical rationale, we derive in Section 8.2 propositions that harmonize with the commonly accepted view that strategic competence management leads to higher financial performance. However, we demonstrate that there is also a relationship between line management's support of individual competencies and financial performance. We discuss the results of hypothesis testing in Section 8.4. Finally, in Section 8.5, we end this chapter with a discussion, managerial implications, and we give avenues for future research on this topic.

8.1 Dynamic competence management

8.1.1 Organizational competencies

The resources of a firm, are all assets, capabilities, organizational processes, firm attributes, information, and knowledge controlled by the firm, enabling it to conceive and implement strategies that improve its efficiency and effectiveness [23]. In concurrence with this perspective, Sanchez et al. [195] define organizational capabilities as repeatable patterns of action in the use of assets to create, produce, and/or offer products to a market. In addition, they define competence as an ability to sustain the coordinated deployment of assets in a way that helps a firm achieve its goals. Organizational capabilities indicate the repeatable patterns of organizational actions and processes, within and among these subsystems, in the use of organizational resources to create, produce, and/or offer special product-attributes to a market. As specific organizational routines they are special types of assets. Moreover, it is the organizational ability to deploy individual capabilities and technological capabilities in such a way that the organization achieves its internal organizational goals. The speed and dexterity with which groups of organizational members, or even individual members, deploy technological capabilities determine the effectiveness of organizational capabilities.

8.1.2 Management of individual competencies

Individual competence management is based on the notion that individual behavior can be managed and that management and control of individual behavior may lead to desired patterns of individual action. In addition, an HRM system will gain, develop, and motivate behaviors necessary to enhance financial performance [123][183][198]. Individual behavior results from individual motivation, the way things are perceived, the way of learning, and individual talents in which motivation and perception are based on personality and attitude [190]. These variables directly determine behavior. Attitudes are based on, and influenced by norms and values, which are cultural variables. As a result, values and attitudes are hard to imitate, but also hard to change and difficult to manage. The same holds for personality characteristics. If distinctive core-competencies are based on personality characteristics, a competitive advantage is durable, at least in static environments, as these variables are hard to imitate. However, in extremely hostile and dynamic environments such firms can be trapped by these types of assets; their validity is momentary, and the management of these more or less static variables leads to slow adaptation of newly desired individual behavior. In other words, problems may arise if a changing environment demands other personality characteristics that can generally be obtained only at extremely high costs (e.g., firing and hiring).

In our view, individual capabilities comprise the knowledge, talents, skills, *and* competencies of individual employees. Some individual competencies are *representativeness (*i.e., the degree to which an individual is representative), *information inquirement* (i.e., the degree to which an individual is able to collect information), *information transfer* (i.e., the degree to which an individual is able to transfer information), *co-operativeness* (i.e., the degree to which an individual is able to cooperate with other individuals and business systems), *independent functionality* (i.e., the degree to which an individual is able to function independently), *initiativeness* (i.e., the degree to which an individual is able to develop initiatives), and *change and improvement willingness* (i.e., the degree to which an individual is able to handle, support, and initiate change, renewals and improvements).

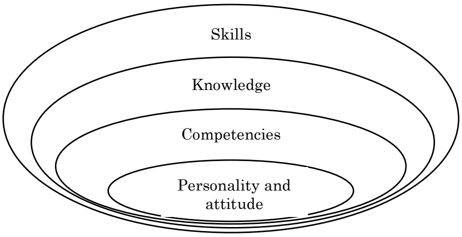


Figure 8-1: Hierarchy of individual capabilities [7].

Talent, skills, knowledge, and competencies are developed by learning and doing, and are therefore manageable. However, the management of individual competencies, i.e., building, leveraging, and deploying individual competencies, underpinning the framework for learning, is a prerequisite for the development of skills and knowledge. Note that with our notion of individual competencies, they are much closer to individual personality and attitude than skills and knowledge, but they are less static, hence better manageable than individual personality characteristics; see Figure 8-1. Consequently, individual competencies are more difficult to change and hence more difficult to manage but also more difficult to imitate than knowledge and skills. Nevertheless, individual competencies influence individual behavior more than skills and knowledge. Moreover, individual competencies form the basis for the development of skills and knowledge [130]. Hence, the causal relationships and linkages between individual competencies (and consequently the present set of knowledge and skills, but also the future knowledge and skills achievable with current resources) and organizational competencies can be characterized as mechanisms of distributed organizational knowledge that represents the present assets and future strategic options. These causal relationships and linkages indicate the way an organization deals with knowledge, expertise, and learning. It indicates the learn-ability of all organizational resources. Thus, knowledge and expertise is evolved and stored in the organizational knowledge system (i.e., organizational procedures and routines, manufacturing technology, and management information and communication systems).

Organizational learning is not simply the sum of each member's learning [201]. Organizations, unlike individuals, develop and maintain learning systems that not only influence their immediate members, but also others [75][103]. As a result, adequate transfer and information channeling throughout the organization is extremely important. Renewed individual capabilities and functional technological capabilities in these types of environments evolve in a renewed organizational capability by learning, which is greatly facilitated if it is embedded in an innovative and flexible, hence agile organizational infrastructure and knowledge system. Nevertheless, it would also be greatly facilitated if employees were highly capable to cooperate with these organizational systems as well as with other individuals, and if they were highly capable of independently collecting and transferring information. Hence, the individual competence to convert data into meaningful information, to turn information into intelligence related to a business issue, and to share that intelligence with others, become crucial to thrive in a competitive market. Management imperative is to put useful data at the fingertips of its human capital on a timely basis and to train them how to use such data [76].

8.2 Propositions

8.2.1 Individual competencies and financial performance

Numerous authors have demonstrated that the strategic management of core competencies leads to higher financial performance [186][213][195], and that there is a hierarchy of core competencies, organizational competencies, and individual competencies. The resource-based view of the firm suggests that a firm’s pool of human capital can be ‘leveraged’ to provide a source of competitive advantage [116][246]. Indeed, Huselid et al. [117] demonstrate that there is a relationship between the capabilities of HRM staff and the effective implementation of HRM policies and practice on the one hand, and financial performance on the other hand. Hayes et al. [101] state that effective management of a factory's human resources requires the distribution of HRM policies throughout the organization. Building the organizational capability requires that both line and HRM managers support the strategic role of HRM [26]. Simply put, to gain a competitive advantage and higher financial performance based on human capital, line management must adopt and support HRM policies, such as individual competence management. We claim therefore that there is a positive relationship between line management's support of individual competence management and financial performance; firms that value individual competencies will achieve higher financial performance than firms that do not value individual competencies.

> **PROPOSITION 8-1:** *Line management's support of individual competencies is positively related to financial performance.*

8.2.2 Individual competencies and agile manufacturing priorities

Hayes et al. [101] state that a manufacturing organization must be able to identify and solve problems rapidly to guarantee a low work-in-process, short cycle, high quality production system. Manufacturing employees, including engineers, line operators, and supervisors, must all be able to diagnose problems as they occur and solve them quickly. The workforce must be able to collect and transfer information fast, as the speed of information that must be shared between all organizational resources is critical for time compression. Indeed, they must be able to cooperate smoothly with each other and with the business systems, and at the same time develop initiatives to solve problems independently. The workforce must adapt to change by initiating ideas for improvement and renewal. Furthermore, they must be service sensitive for speed and at the same time be highly stress-resistant.

These time-based individual competencies must be embedded in an innovative flexible organizational infrastructure, i.e., an agile decentralized organizational structure, with smooth and flexible information and communication systems. Effective integral management of time-based competencies is a primary condition for effective agile management, which is essentially process management oriented. Indeed, a process management focus on enhancing and refining existing capabilities is expected to lead to improvements in efficiency, speed to market, and ultimately, competitiveness [82]. As management's support of individual competencies also underpin theories of organizational development and learning, we claim that there is a relationship between the value that line management of a firm attaches to individual competencies and the strategic focus on agile manufacturing priorities. Hence, we have the following proposition.

> **PROPOSITION 8-2:** *Line management's support of individual competencies is positively related to the strategic focus on agile manufacturing priorities.*

8.2.3 Individual competencies and PMT-uncertainty

It remains unclear which individual competencies need to be emphasized to obtain suitable patterns of individual actions. If agile management is the right premise, then we need to emphasize competencies related to speed and flexibility. However, the level of PMT-uncertainty also dictates the need to emphasize specific individual competencies. The lack of information before actually performing a task is considered to be the key issue, where uncertainty is the difference between the amount of information required to perform tasks and the amount of information already possessed by the organization [62][80]. Hence, information reduces uncertainty. As a result, the individual competencies of the speed of information processing, and the dexterous way of collecting and transferring information during actual task execution are emphasized in uncertain environments. However, for dynamic environments the time-based dexterous individual competencies (i.e., the willingness to change and the ability to learn fast) are also emphasized to adapt to change. We claim that there is a relationship between the emphasis on specific individual competencies and the type of uncertainty of the situation in which the individual operates.

> **PROPOSITION 8-3:** *The emphasis on particular individual competencies in a specific manufacturing environment is related to the level of complexity and rate of change (of that specific manufacturing environment).*

8.3 Research method and operational definitions

The examination of the impact of line management's support of individual competencies on the strategic focus on agile manufacturing priorities and financial performance is conducted with the help of the first survey data discussed in Chapter 3. We followed the survey methodology proposed by Flynn et al. (1990) and Malhotra and Grover (1998). In this section we operationally define the constructs, analyze internal reliability of the scales, and present a full measurement model. The analytical procedures used include the calculation of descriptive statistics, reliability analysis, and factor analysis.

8.3.1 Importance attached to individual competencies

Van Assen [7] proposes 10 basic individual competencies: representativeness, information collection, information and knowledge transfer, co-operativeness, independent functionality, initiativeness, change and improvement willingness, service sensitiveness, problem solvingness, and stress tolerance. Other individual competencies may be identified, but we claim that they are covered by the above set of basic competencies. Innovativeness (i.e., the degree to which an individual initiates, implements, realizes, or early adopts change, improvement, and renewals), for instance, can be accommodated by initiativeness, change and improvement willingness, and problem solvingness.

We operationally define the construct *importance attached to individual competencies* (*IA-IC*) by the 5-point Likert scaled items: 1) 'It is important that operators keep their work place neat', 2) 'It is important that operators quickly signal problems', 3) 'It is important that operators solve problems independently', 4) 'It is important that operators show initiative', 5) 'It is important that operators are willing to change', 6) 'It is important that operators independently collect information and seek for knowledge', 7) 'It is important that operators independently transfer information and knowledge', and 8) 'It is important that operators independently gain process related knowledge'; see Table 8-1. With a value of .8734 for Cronbach's alpha, this scale is sufficiently reliable. Factor analysis (varimax rotation) gave only one factor with 'eigenvalue' larger than 1, and hence, these items measure up one construct.

8.3.2 Strategic focus on agile manufacturing priorities

Agility builds upon the fundamental concepts of advanced manufacturing technology and lean manufacturing. However, to consider agile manufacturing as just another way of describing lean production, flexible manufacturing or CIM is a misconception generally made [127][128]. Although technology plays an important role, agility is about the basis of competition, business practices, and corporate structures in the 21st century, not about developing more technology. As agile manufacturing is an evolving strategic manufacturing paradigm, we consider the following four agility-related strategic priorities to be essential: 1) *use of Japanese manufacturing philosophies*, 2) *strategic focus on Advanced Manufacturing Technology*, 3) *strategic focus on delivery performance*, and 4) *strategic focus on flexibility.* Since we also used the latter two constructs in the previous chapter, we only discuss the operational definitions of 1) *use of Japanese manufacturing philosophies* and 2) *strategic focus on Advanced Manufacturing Technology.*

Construct	Cron-bach's alpha	Variables (items)	Pearson correlation								Mean	SD	Alpha if item deleted
IA-IC	.8734	It is important that operators keep their work place neat	1.000								4.3631	.6508	.8610
(*N* =179)		It is important that operators quickly signal problems	.651	1.000							4.5140	.5645	.8572
		It is important that operators solve problems independently	.373	.401	1.000						4.1508	.7225	.8599
		It is important that operators show initiative	.504	.591	.510	1.000					4.4246	.5889	.8517
		It is important that operators are willing to change	.406	.472	.525	.617	1.000				4.3631	.6244	.8558
		It is important that operators independently collect information and seek for knowledge	.346	.357	.505	.405	.477	1.000			4.0335	.6943	.8599
		It is important that operators independently transfer information and knowledge	.453	.430	.504	.529	.458	.622	1.000		4.1844	.6488	.8533
		It is important that operators independently gain more process related knowledge	.433	.443	.382	.424	.395	.452	.434	1.000	4.0615	.6374	.8645
JMP	.6194	use of the JIT/lean concept	1.000								.2647	.4423	.4764
(*N* = 204)		use of kanban	.469	1.000							.2402	.4283	.4753
		use of Six Sigma	.217	.253	1.000						.2059	.4053	.6336
		use of TQM principles	.343	.294	.171	1.000					.0931	.2913	.5806
SF-AMT	.5691	the use of AMT is a strategic priority	1.000								1.9759	.7703	.3543
(*N* = 166)		recent developments on AMT are closely monitored	.461	1.000							3.7289	.9039	.3926
		rate of change and renewal of AMT technology within the firm	.280	.235	1.000						1.6988	.5556	.5389
		use of an FMS system	.206	.245	.092	1.000					.0602	.2387	.5908
SF-D	.6753	the strategic importance of quick supply	1.000								2.4064	.5917	.6923
(*N* = 187)		short lead-times is a strategic priority	.396	1.000							3.9733	.9184	.4474
		high delivery reliability is a strategic priority	.304	.535	1.000						4.4011	.7996	.5302
SF-F	.7836	the strategic importance of short lead-times to gain flexibility	1.000								2.2024	.6433	.7935
(*N* = 168)		the strategic importance of mix flexibility	.510	1.000							2.1131	.6958	.6345
		the strategic importance of volume flexibility	.467	.658	1.000						2.1190	.7160	.6745
SF-PQ	.8107	high product quality is a strategic priority	1.000								2.644	.502	
(*N*=188)		high product reliability is a strategic priority	.274	1.000							2.670	.383	

Table 8-1: Operationalization of *importance attached to individual competencies* and the factors related to *agile management*.

Use of Japanese manufacturing philosophies (JMP) As mentioned before, agile manufacturing management builds on process management practices of continuous progression of quality-related initiatives over the past two decades, including Total Quality Management (TQM) and Six Sigma [51][96]. Hence, we operationally define the *use of Japanese manufacturing philosophies* by the items 1) 'use of the JIT/lean concept', 2) 'use of kanban', 3) 'use of TQM principles', and 4) 'use of Six Sigma', for which we obtain a value of .6194 for Cronbach's alpha, which indicates that this scale is sufficiently reliable; see Table 8-1.

Strategic focus on Advanced Manufacturing Technology (***SF-AMT***) Kidd [127][128] states that AMT technology will play a strategic role for agile manufacturers. We therefore operationally define the *strategic focus on Advanced Manufacturing Technology* by the items 1) 'use of AMT is a strategic priority', 2) 'recent developments on AMT are closely monitored', 3) 'rate of change and renewal of AMT technology in the firm', and 4) 'the use of an FMS system', for which we obtain a value of Cronbach's alpha of .5691 ($N = 166$). This value is too low to qualify the scale as reliable; see Table 8-1. The removal of the item 'the use of an FMS system' would increase the value of Cronbach's alpha to .5908 ($N = 166$). As this is close to the .60 threshold, we postpone the decision to accept or discard this scale until the analysis of the full measurement model in section 8.4.1, since we prefer to maintain this scale because of content validity.

8.3.3 Financial performance

Recall that in Section 3.3.9 (p. 94), we operationally defined the construct *financial performance* by the items 'market share', 'return on investment', 'return on sales', and 'growth of organizational turnover'. Table 3-9 (p. 89), shows that Cronbach's alpha for this operational definition is rather low, i.e., .5589, $N = 143$. Furthermore, although a factor analysis only leads to one factor, we omit the item 'market share' to obtain a value of Cronbach's alpha of .5901 ($N = 162$).

8.3.4 PMT-uncertainty

With respect to complexity, we only consider the constructs *customer order complexity* and *operations technology* complexity. The Cronbach's alpha values of are .7105 and .6410, respectively; see Table 3-4 (p. 83). For the rate of change of the PMT characteristics, we distinguish between *customer order change* and *end-product change* with Cronbach's alpha values of .5866 and .7164, respectively. Finally, we consider the construct *information deficiency* for which we recall to have a value of Cronbach's alpha of .7971; see Table 10-1 (p. 257).

8.4 Results

We tested our propositions by means of structural equations modeling, using the software package AMOS. We also performed cluster analysis of the respondents for their agile competitive priorities and subsequently explore differences in means of these and several other groups of respondents.

8.4.1 Individual competencies and financial performance

A measurement model We first discuss a first-order measurement model of the constructs related to the support of individual competencies and the strategic focus on agile manufacturing priorities. Figure 8-2 displays standardized (displayed in parentheses) and unstandardized estimates. Covariances displayed with normal arrows are significant; non-significant covariances are displayed with dotted arrows. Figure 8-2 also displays the squared multiple correlations (R^2) for each item, indicating the level of explained variance. They all are reasonably large, except for the items 'the use of an FMS system' and 'recent developments on AMT are closely monitored' of the construct *strategic focus on Advanced Manufacturing Technology*, for which only 10% respectively 16% of the variance are explained by this model. This model also only explains 13% of the variance of the item 'the use of TQM principles' of the construct *use of Japanese manufacturing philosophies*. However, since there are no commonly accepted cut-off values reported in the literature, we only remove the item 'the use of an FMS system', since it has both a low value of R^2 and a small factor loading. This concurs with the outcome of traditional reliability analysis based on Cronbach's alpha in the previous section. We, therefore, retain the other items for sake of construct validity.

The removing of all non-significant covariances resulted in a final measurement model that fits the data according to the relative fit indices (i.e., df = 237, χ^2 = 403.881, p_{model} = .000, CFI = .987, NFI = .969, TLI = .983, and $\text{RMSEA}_{[.048,.068]}$ = .058). From the analysis of this 1st-order measurement model, we observe that it is not sensible to construct and analyze a second-order measurement model that comprises the 2nd-order construct agility-related strategic focus. Hence, we proceed the analysis of causal effects (i.e., hypothesis testing) with the 1st-order constructs of the measurement model displayed in Figure 8-2.

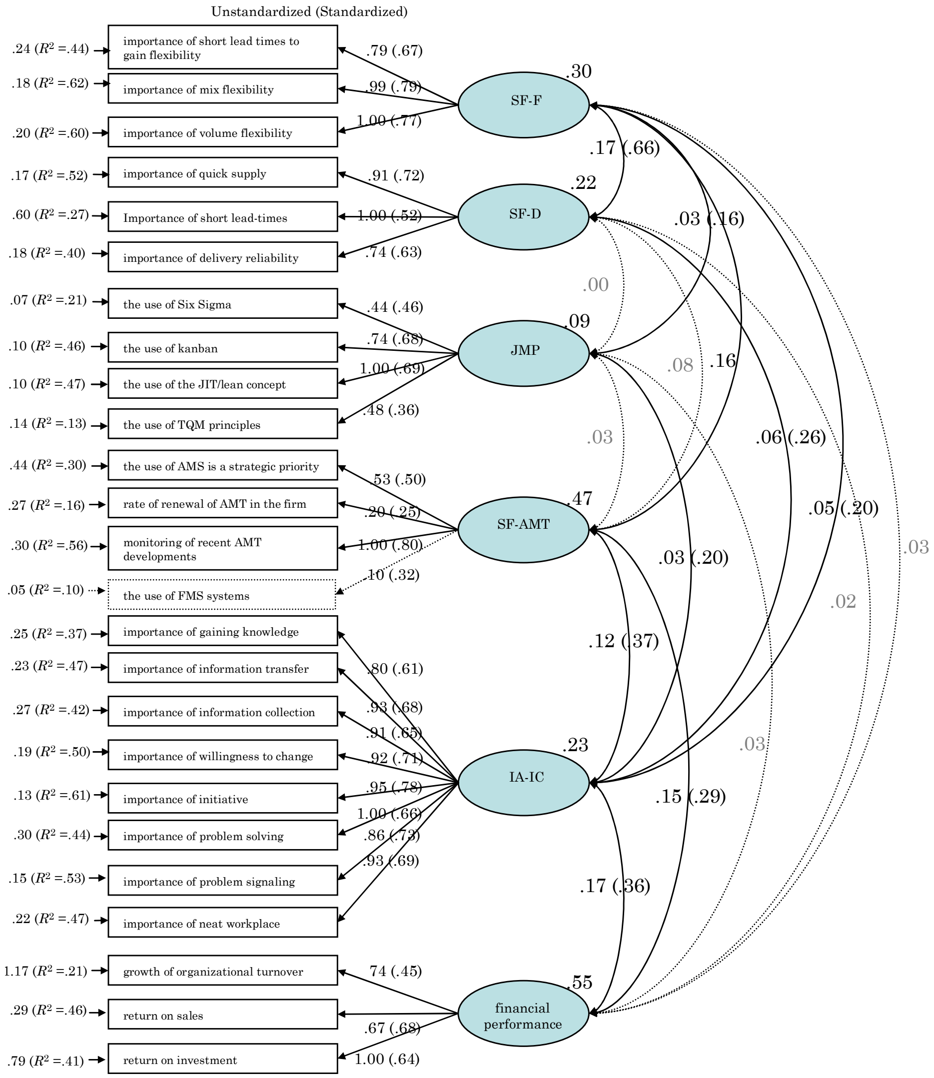


Figure 8-2: Full measurement model of all primary constructs (*df* = 237, χ^2 = 403.881, p_{model} = .000, CFI = .987, NFI = .969, TLI = .983, and RMSEA$_{[.048,.068]}$ = .058).

A structural equations model We discuss a structural equations model to test Propositions 8-1 8-2. The final model displayed in Figure 8-3 fits the data according to the relative fit indices (i.e., *df* = 247, χ^2 = 413.082, p_{model} = .000, CFI = .987, NFI = .968, TLI = .984, and RMSEA$_{[.047,.067]}$ = .057).

Figure 8-3 also displays unstandardized and standardized (in parenthesis) path coefficients, which are all significant. Also displayed in Figure 8-3 are the disturbance terms indicating the effects of unmeasured variables not included in the model (i.e., the unexplained variance in the latent endogenous variables due to all unmeasured causes) and the level of explained variances (i.e., R^2) for each endogenous construct. Note that the model explains 44% of the variance of the construct *strategic focus on delivery performance.*

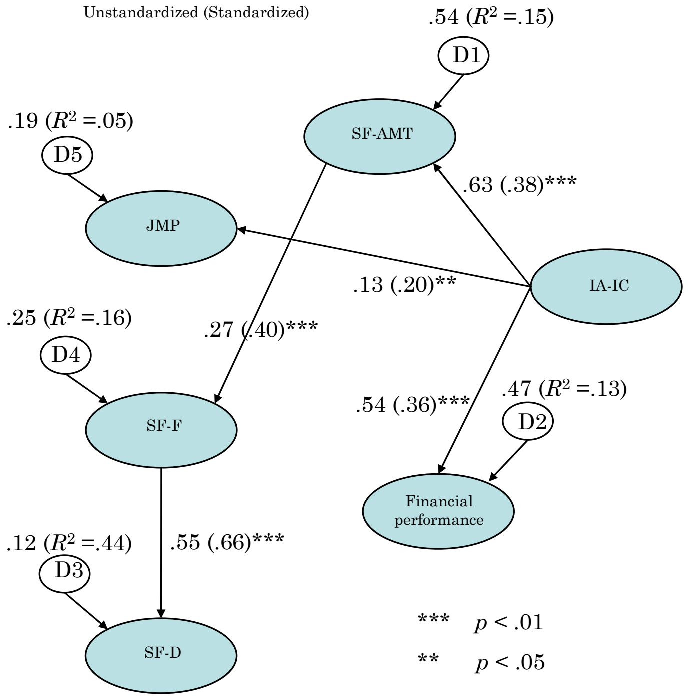


Figure 8-3: A path model of individual competence management and *financial performance* (*df* = 247, χ^2 = 413.082, p_{model} = .000, CFI = .987, NFI = .968, TLI = .984, and $\text{RMSEA}_{[.047,.067]}$ = .057).

We could not find direct significant relationships between the constructs *strategic focus on delivery performance*, *strategic focus on flexibility*, and *financial performance*. Furthermore, the direct paths from *IA-IC* to *strategic focus on flexibility* and *strategic focus on delivery performance*, respectively, are not significant and were, therefore, removed from the model. Furthermore, we observe that the path coefficients from the constructs *importance attached to individual competencies* (*IA-IC*) to *use of Japanese manufacturing philosophies* and *strategic focus on Advanced Manufacturing Technology* are .13(.20) and .63(.38), respectively.

There are, however, indirect relationships between *IA-IC* and *strategic focus on flexibility* and *strategic focus on delivery performance* with a total standardized effect of .15 (i.e., .38 times .40) and a total standardized effect of .10 (i.e., .15 times .66) respectively, since there is a direct relationship between *strategic focus on flexibility* and *strategic focus on delivery performance.* The construct *importance attached to individual competencies* (*IA-IC*) predicts *financial performance* by .54 (.36), which indicates that a 1-point increase in the construct *importance attached to individual competencies* leads to an increase of the construct *financial performance* by .54. Of course, only 13% of the variance in the construct *financial performance* is explained by this model.

Based on this model, we conclude that competence management provides a fundamental guideline for agile manufacturing and its underlying constructs. Firms with line management supporting individual competencies have higher levels of *strategic focus on Advanced Manufacturing Technology*, *flexibility*, *delivery performance* (i.e., speed), and *use of Japanese manufacturing philosophies.* There are no relationships between the agility-related strategic priorities and *financial performance* in Figure 8-3. This model confirms Proposition 8-1, ‘line management’s support of individual competencies is positively related to financial performance’, and Proposition 8-2, ‘the value attached to individual competencies is positively related to the strategic focus on agile manufacturing’. Nevertheless, we want to analyze both relationships in more detail.

Analysis of differences between subpopulations We computed a variable *IA-IC*, categorized it into two groups of respondents with high and low scores, indicated as the group of *IA-IC* firms and the group of non-*IA-IC* firms, respectively. We analyzed differences in means for various constructs, among which *financial performance*; see Table 8-2.

Only the differences in means for the construct *strategic focus on delivery performance* and the item ‘quick supply is a strategic priority’ are non-significant; three items are significant only at the .1 level, all other variables are significant at the .05 level. From this table, we conclude that *IA-IC* firms (i.e., firms in which line management values individual competencies) achieve significantly better *financial performance* than non-*IA-IC* firms (on all items of *financial performance*). Obviously, *IA-IC* firms attach significantly higher importance to the management (i.e., planning and control) of individual competencies (i.e., statement 3 in Table 8-2: ‘It is important that I can plan and control employee competencies’). In addition, *IA-IC* firms have significantly higher means on the construct *strategic focus on flexibility* (*SF-F*) and its items, as well as on the single *strategic focus on delivery performance* (*SF-D*) related items ‘short-lead-times is a strategic priority’ and ‘high delivery reliability is a strategic priority'. In other words, firms that value individual competencies have better *financial performance* and higher scores on the agility-related strategic priorities.

Effect Size as measured by Cohen's *d*

Factors and Statements	Non *IA-IC firms*	*IA-IC* firms	Total	sign.	E.S.
organizational turnover	2.93	3.26	3.11	.028	– .50
financial performance (F6)	2.18	2.59	2.40	.003	– .51
BP: return on investment	2.04	2.54	2.31	.010	– .44
BP: return on sales	*2.4*	*2.62*	*2.52*	*.054*	– .31
BP: growth of organizational turnover	2.73	3.26	3.01	.005	– .45
it is important that I can plan and control employee competencies	3.69	4.11	3.91	.000	– .58
our firm gained improvement from more rigorous improvement steps (BPR)	1.82	1.68	1.74	.037	.33
information availability of the product	1.68	1.46	1.56	.047	.31
strategic focus on flexibility	1.97	2.23	2.10	.001	– .30
SF-F: the strategic importance of volume flexibility	*2*	*2.22*	*2.11*	*.053*	– .31
SF-F: the strategic importance of mix flexibility	1.96	2.24	2.11	.010	– .42
SF-F: the strategic importance of short lead-times to gain flexibility	2.07	2.32	2.2	.012	– .39
quality is a strategic priority	4.38	4.69	4.55	.002	– .47
strategic focus on delivery performance	2.31	2.43	2.38	n.s.: >.1	– .06
SF-D: quick supply is a strategic priority	2.38	2.42	2/4	n.s.: >.1	– .07
SF-D: short lead-times is a strategic priority	3.79	4.12	3.97	.016	– .36
SF-D: high delivery reliability is a strategic priority	4.13	4.59	4.38	.000	– .57
small lot sizes is a strategic priority	*3.43*	*3.75*	*3.61*	*.076*	– .28
strategic focus on AMT	*1.78*	*1.91*	*1.85*	*.064*	– .31
SF-AMT: recent developments on AMT are monitored	3.54	3.84	3.7	.024	– .34
the use of FMS	.01	.08	.05	.034	– .33

Table 8-2: Differences in means for *IA-IC* firms versus non-*IA-IC* firms.

In addition, we performed an analysis of differences in means for *financial performance* for respondents categorized on high versus respondents categorized on low levels of the constructs *strategic focus of Japanese manufacturing philosophies* and *strategic focus on Advanced Manufacturing Technology*, respectively, but we did not find significant differences—this would confirm the direction of the path between *IA-IC* and *SF-AMT,* and the direction of the path between *IA-IC* and *JMP*. Nevertheless, to analyze the directions of the structural equations model in more detail we use cluster analysis based on the constructs *strategic focus on flexibility* and *strategic focus on delivery performance* and perform an analysis of differences on the *IA-IC* related items and *financial performance.*

8.4.2 Individual competencies and agile manufacturing priorities

Cluster analysis Cluster analysis is a group of multivariate techniques whose primary purpose is to assemble objects (i.e., respondents), so that each respondent is similar to others in the cluster for a predetermined selection criterion, but exhibit high external (between-cluster) heterogeneity [262]. Hair and Black [92] state that internal validity is a minimum condition to prove the quality of a typology based on cluster analysis. For the constructs *strategic focus on flexibility* and *strategic focus on delivery performance*, we used both the hierarchical Centroid method and Ward's method to establish the appropriate number of clusters (i.e., two or three clusters), profiled the cluster centers, and explored for any obvious outliers. Subsequently we used a nonhierarchical method (*k*-means clustering) with the hierarchical results as the initial seeding points, to fine-tune the results by allowing the switching of cluster membership. Finally, we have chosen to maintain two separate clusters.

*** significant at $p < .01$.

	Cluster 1 ($N = 80$)	Cluster 2 ($N = 86$)	$N = 166$
SF-D	2.07***	2.69***	2.39 ($N = 180$)
SF-F	1.62***	2.58***	2.11 ($N = 170$)

Table 8-3: Cluster analysis on the agility-related strategic priorities *SF-D* and *SF-F*.

Based on an ANOVA analysis, we observe that the two clusters differ significantly on the variables used to identify the clusters; see Table 8-3. Cluster 2 comprises respondents that have a strategic focus on both agility-related strategic priorities that corresponds with the focus on speed, while respondents of cluster 1 attach much less importance to these priorities. The latter firms are more oriented towards traditional issues like efficiency and quality.

Differences in means on the IA-IC items and financial performance between the clusters Next, we analyze differences in means on the items of the constructs *importance attached to individual competencies* and *financial performance* for both clusters. From Table 8-4, we observe that cluster 2 respondents, i.e., the respondents that have a focus on the two agility-related strategic priorities, attach greater importance to the individual competencies than respondents of cluster 1. In addition, respondents of cluster 2 also indicate that their employees organize their workplaces more neatly. Finally, from Table 8-4, we observe that there is no significant difference in *financial performance* between these clusters.

Effect Size as measured by Cohen's *d*

Statements	**Cluster 1**	**Cluster 2**	**Total**	**sign.**	**E.S.**
It is important that operators keep their work place neat	4.28	4.48	4.38	.044	− .31
It is important that operators quickly signal problems	4.43	4.61	4.52	.037	− .31
It is important that operators solve problems independently	3.93	4.27	4.10	.003	− .46
It is important that operators show initiative	4.34	4.51	4.43	.069	− .29
It is important that operators are willing to change	4.26	4.47	4.37	.031	− .34
It is important that operators independently inquire for information and knowledge	3.91	4.13	4.02	.042	− .32
It is important that operators independently transfer information and knowledge	4.11	4.26	4.19	.155	− .23
It is important that operators independently gain more process related knowledge	3.99	4.18	4.09	.061	− .29
financial performance	2.34	2.44	2.39	.450	− .05
It is important that I can plan and control employee competencies	3.77	4.07	3.93	.007	− .42
I think our operators organize their work place neat	3.30	3.61	3.46	.025	− .61
I think lead-times are too high	3.13	2.67	2.89	.005	− .45
Our firm invests a lot in quality improvement programs	1.24	1.12	1.18	.039	.32
Our firm stimulates continuous improvement	1.12	1.01	1.06	.005	.45
Our firm gains compatitive advantage with specific skills of staff	1.49	1.31	1.40	.020	.37

Table 8-4: Differences in means on statement for both clusters.

Differences in means on financial performance for IA-IC firms versus non-IA-IC firms in cluster 2. The analysis whether *IA-IC* firms that also have higher levels of *strategic focus on delivery performance* and *strategic focus on delivery performance* (i.e., the firms in cluster 2 in which line management values individual competencies) obtain higher scores on *financial performance* and related items than non-*IA-IC* firms in cluster 2, only shows significant differences in means on 'growth of organizational turnover' at $p < .1$; see Table 8-5. Interestingly, however, *IA-IC* firms in cluster 2 show a higher level of 'organizational turnover' and *end-product change* than non-*IA-IC* firms in cluster 2.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$;
Effect Size as measured by Cohen's *d*

Constructs	**Non- *IA-IC***	***IA-IC***	**E.S.**
financial performance	2.37	2.43	− .08
Growth of organizational turnover	2.62*	3.14*	− .45
Organizational turnover	2.61**	3.20**	− .61
Component & part change	2.94**	3.42**	− .57

Table 8-5: Differences in means on *financial performance* for Non-*IA-IC* firms versus *IA-IC* firms in cluster 2.

Differences in means on financial performance for IA-IC firms with a high score versus a low score on SF-AMT and JMP, respectively To analyze whether *IA-IC* firms that emphasize the agility-related strategic priority *SF-AMT* or *JMP* achieve higher *financial performance* than *IA-IC* firms that do not, we devided *IA-IC* firms in high/low scores on the variables *strategic focus on Advanced Manufacturing Technology* and *use of Japanese manufacturing philosophies*, respectively. Table 8-6 shows that *IA-IC* firms that have a high level of *strategic focus on Advanced Manufacturing Technology* and/or a high level of *use of Japanese manufacturing philosophies* do not significantly achieve higher *financial performance* than *IA-IC* firms with no such focus. This confirms the directions of the paths in the structural equations model presented in Figure 8-3. Note, however, that *IA-IC* firms that value individual competencies and simultaneously have a high level of *strategic focus on Advanced Manufacturing Technology* and/or focus on *use of Japanese manufacturing philosophies* do have significant higher organizational turnovers. This suggests that size may have an influence on our results (i.e., a spurious relationship). Consequently, we analyzed the path analytic model for large and small firms, separately, but we did not find any bias compared to the findings in Figure 8-3. We also tested a structural equations model in which the construct *size* was included, but we found only non-significant relationships with this construct. In addition, we analyzed differences in means for *financial performance* related variables for large and small-sized firms that value individual competencies; see Table 8-6.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$; Effect Size as measured by Cohen's d

Constructs	***SF-AMT***			***JMP***			***size***		
	Low	**High**	**E.S.**	**Low**	**High**	**E.S.**	**Low**	**High**	**E.S.**
financial performance	2.54	2,67	.04	2.54	2.63	.06	2.62	2.55	.07
Return of sales	2.65	3.64	.07	2.62	2.63	.05	2.59	2.66	.10
Return on investment	2.44	2.68	.08	2.47	2.61	.07	2.65	2.44	.06
Growth of organizational turnover	2.29	3.21	.17	3.24	3.27	.04	3.15	3.36	.07
Organizational turnover	3.08***	3.48***	.39	2.89***	3.72***	.57	2.50***	4.06***	.67

Table 8-6: Differences in means on *financial performance* for *IA-IC* adopters categorized in high/low scores on *SF-AMT*, *JMP,* and *size*.

Based on these findings, we conclude that line management's support of individual competencies is positively related to *financial performance* (as shown in statement 2 in Table 8-2). In addition, we conclude that individual competence management (or at least line management's support of individual competencies) is a prerequisite for agility; the strategic focus on agile manufacturing priorities is not a predictor of higher financial performance per se. Finally, based on these findings we confirm the directions of the paths in the structural equations model, and we confirm Proposition 8-2, i.e., 'line management's support of individual competencies is positively related to the strategic focus on agile manufacturing priorities'.

8.4.3 Individual competencies and PMT-uncertainty

To explore whether *IA-IC* firms emphasize particular individual competencies differently given the situational characteristics of PMT-uncertainty (i.e., *complexity*, *rate of change*, and *information deficiency*), we explore the differences in means on the single *IA-IC* items for *IA-IC* firms that are split in groups of high/low *financial performance,* high/low *information deficiency*, high/low *customer order complexity*, high/low *operations technology complexity*, high/low *end-product change*, and high/low *customer order change*, respectively; see Table 8-7 that only displays significant values.

Financial performance Table 8-7 shows that *IA-IC* firms with high *financial performance* attach more importance to the individual competence attribute 'willingness to change' (i.e., a mean value of 4.82 in the 9th statement in Table 8-7) than *IA-IC* firms with low *financial performance*, and to the individual competence attribute 'the capability to independently inquire information and knowledge'.

Information deficiency We observe from the second column of Table 8-7, that *IA-IC* firms with high levels of *information deficiency* also attach more importance to the individual competence attribute 'willingness to change' (i.e., a mean value of 4.79 in the 9th statement in Table 8-7) compared to *IA-IC* firms having low levels of *information deficiency*. Furthermore, *IA-IC* firms with high levels of *information deficiency* also prioritize high efficiency, high delivery reliability, and quality improvement programs.

Customer order complexity *IA-IC* firms that have high levels of *customer order complexity* emphasize high utilization to a smaller degree than *IA-IC* firms with low levels of *customer order complexity*. Interestingly, the latter firms prioritize high delivery reliability more than *IA-IC* firms with higher levels of *customer order complexity*. Furthermore, there is no difference in the emphasis on particular individual competencies.

Operations technology complexity *IA-IC* firms with high levels of *operations technology complexity* attach more importance to neatness of the shop floor (probably to create better overviews) and to the individual capability to signal problems quickly than *IA-IC* firms with low levels of *operations technology complexity*.

End-product change *IA-IC* firms with high levels of *end-product change* attach more importance to the individual willingness to change than *IA-IC* firms with low levels of *end-product change*. Furthermore, they have a higher *strate-*

gic focus on flexibility as they attach greater importance to short lead-times and small lot sizes as strategic priorities.

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$; Effect Size as measured by Cohen's d

Constructs		***financial performance***	***information deficiency***	***customer order complexity***	***technology complexity***	***end-product change***	***customer order change***
High utilization	Low			1.85**			
	High			1.49			
	Total			1.68			
High efficiency is a strategic priority	Low		3.91***				
	High		4.42				
	Total		4.19				
Quick supply	Low						2.24**
	High						2.54
	Total						2.41
High delivery reliability is a strategic priority	Low		4.40**	4.74**			
	High		4.75	4.4			
	Total		4.59	4.58			
Short Lead-times is a strategic priority	Low					3.93*	3.87**
	High					4.30	4.34
	Total					4.10	4.14
Small lot sizes is a strategic priority	Low					3.40**	
	High					4.03	
	Total					3.68	
It is important that operators keep their work place neat	Low				4.47***		
	High				4.83		
	Total				4.63		
It is important that operators quickly signal problems	Low				4.72**		
	High				4.94		
	Total				4.82		
It is important that operators are willing to change	Low	4.6**	4.58**			4.60**	4.55**
	High	4.82	4.79			4.81	4.78
	Total	4.70	4.68			**4.70**	4.68
It is important that operators independently collect information and knowledge	Low	4.28*					
	High	4.52					
	Total	4.38					
Our firm gains competitive advantage from specific processes	Low					1.36*	1.33**
	High					1.56	1.60
	Total					**1.45**	1.49
Our firm gains competitive advantage from specific operator skills	Low						1.39**
	High						1.63
	Total						1.53
I think our operators show initiative	Low		3.33*		3.30**		
	High		3.63		3.71		
	Total		3.46		**3.48**		
Our firm invests a lot in quality improvement programs	Low		1.08**				
	High		1.24				
	Total		1.15				
It is important that I can plan and control employee competencies	Low	4.29*					
	High	3.94					
	Total	4.13					

Table 8-7: Differences in means on the single *IA-IC* items for *IA-IC* firms that are subsequently split in two groups of high/low on various PMT-uncertainty related factors.

Customer order change *IA-IC* firms with high levels of *customer order change* attach more importance to the individual willingness to change than *IA-IC* firms with low levels of *customer order change*. Furthermore, they have a higher *strategic focus on delivery performance*, as they attach greater importance to short lead-times and quick supply as strategic priorities. In addition, they indicate to gain a competitive advantage from both specific processes and specific skills of operators.

From Table 8-7, we also note that *IA-IC* firms that face dynamic environments (regardless the type of *rate of change*) had indicated to gain competitive advantage with specific processes, and that they strategically prioritize short lead-times. We, therefore, conclude that *IA-IC* firms that face high levels of PMT-uncertainty emphasize speed and flexibility. In addition, these organizations attach greater importance to the individual capability to handle change.

8.5 Discussion and future research

A skilled and motivated workforce providing the speed and flexibility required by today's dynamic manufacturing environments has increased the strategic importance of human resource management [26]. Consequently, managing people must become an integral part of the job of line managers in manufacturing operations, not simply the domain of the HRM 'staff function' [37][228].

Line management's support of individual competencies and financial performance An important HRM practice that needs to be adopted by line management is individual competence management. This concurs with the findings of Becker and Huselid [25] who state that, driven by market imperatives to develop more efficient organizational structures and practices (e.g., decentralization by implementing empowered manufacturing teams), there is an increasing emphasis among academics and practitioners on behavioral competitive strategies that rely on core competencies and capabilities among employees, not only because they provide the most effective response to market demands, but also because they cannot easily copied by competitors [186][213].

This research provides evidence that firms where line management supports individual competencies obtain higher financial performance than firms in which line management does not value individual competencies. It concurs with the theoretical debate that management's attention for HRM activities that enhance competency accumulation and exploitation may facilitate the development of organizational competencies to achieve sustained competitive advantage and financial performance [146]. Accordingly, firms that are capable of incorporating a strategic perspective on competence management throughout the management structure outperform competitors that do not.

The relationship between support of individual competencies and the strategic focus of agile manufacturing priorities Our study provides evidence that line management's support of individual competencies is positively related to *the strategic focus on agile manufacturing priorities*. This finding concurs with the objective of agility, with the workforce as a key source of agility [109]. Firms that support individual competencies also have higher levels of *strategic focus on flexibility*, which concurs with the statement of Hayes et al. [101] that manufacturing flexibility can provide a competitive advantage if there is a proper fit between variables, such as competitive environment, strategy, organizational attributes, technology, and the human capital. In addition, Upton [230] states that manufacturing flexibility much more depends on people than on technical factors.

In the contingency approach to strategic human resource management, the impact of individual competence management on financial performance is generally conditioned by an organization's strategic position. More specifically, organizations that focus on individual competence management through acquiring, developing, and utilizing employees with particular knowledge, skills, and abilities exhibit higher performance if this HRM practice is consistent with the organization's current strategies [244][248] and vice versa [208]. If employee behaviors produced by a specific HRM practice are increasingly appropriate for the implementation of a firm's manufacturing strategy, external fit improves.

This study provides empirical support that there are relationships between line-management's support of individual competencies and strategic focus on agile manufacturing priorities, and line-management's support of individual competencies and financial performance, respectively. However, support for the general assumption that superior performance may result from the fit between line management's support of individual competencies and strategic focus is relatively weak, as cluster 2 firms (i.e., the group of firms with a strategic focus on flexibility and delivery performance) that value individual competencies do not exhibit higher *financial performance* than cluster 2 firms that do not support individual competencies. Nevertheless, cluster 2 firms that value individual competencies have higher levels of growth of organizational turnover. Put differently, the fit between 'line-management's support of individual competencies' as an HRM practice, strategic focus on agile manufacturing priorities, and financial performance is moderate. However, this study contributes to the body of knowledge on the external fit hypothesis, as our findings suggest that line management's support of individual competencies is a prerequisite for agility; the strategic focus on agile manufacturing priorities is not a predictor of higher financial performance per se.

Emphasis of individual competencies and situational complexity and change Closely related to the claim of external fit of HRM practice and strategy is the alignment of a firm's environment (i.e., change and complexity) and the support of individual competencies. This study found that firms that operate in uncertain manufacturing environments (i.e., have higher levels of information deficiency and high levels of change), and in which line management supports individual competencies, emphasize change-related individual competences. Simply put, the individual competencies to proactively adapt to change (i.e., the individual willingness to change) are of major importance in uncertain environments. This concurs with the statements of Lawler [150] that job-based management approaches become disfunctional and inappropriate in rapidly changing environments; in dynamic environments individuals require the capability to change work methods, routines, and skills rapidly to adapt to changing circumstances. The alternative to job-based management is one in which the capabilities of individuals are the primary focus and that need to be managed in a way that facilitates the firm to develop organizational capabilities that provide competitive advantage and higher levels of economic rents [150].

9 Epilogue: complementary and further research

Since most of the previous chapters already contained a discussion and a future research section, we confine ourselves to a brief summary of the findings in Section 9.1. We discuss an ongoing complementary research project of ours in which a prototype manufacturing planning and control system for decentralized manufacturing environments is under development in Section 9.2.

9.1 Summary

9.1.1 Cellular manufacturing

The contribution of this thesis lies in the building, testing and modification of theory in the research domain of discrete parts manufacturing operations management. We showed that there are considerable planning and control requirements in cellular manufacturing systems, for instance because of intercell movement. While ERP systems are used in cellular manufacturing systems to plan and control on a global level (i.e., to determine the delivery schedule for each cell's products), cells are left the responsibility to manage various other production planning and control issues. We found that, in general, the use of an ERP system is an important determinant for a more centralized operational planning decisions structure. Many firms with a cellular layout adopted ERP systems. Surprisingly, we found that APS systems are predominantly more adopted by firms working in a cellular layout than 'traditionally' organized firms. We also found significant relationships between OM/logistics-related sophistication and external communication on the one hand, and APS adoption on the other hand. Indeed, firms that have a high level of OM/logistics-related sophistication also have a high level of external communication. In concurrence with these findings, we found that firms with a cellular layout have significantly higher levels of OM/logistics-related sophistication and external communication channels about OM/logistics-related topics than firms with a functional layout.

We postulate that in The Netherlands, groups are particularly implemented to enrich and enlarge jobs, to increase worker involvement and commitment, and to provide responsibility to shop floor employees, and much less so to reduce (production planning and control) complexity.

9.1.2 Complexity, rate of change, and information deficiency

In Chapter 3, we found that the different dimensions of PMT-uncertainty affect the locus of production planning and control differently. Environmental complexity, and in particular customer order complexity, leads to a decentralization of the operational planning and control decision structure but at the same time a centralization of the customer-order processing (COP) decision structure. We found that firms with high levels of customer order complexity have low frequency of production planning and control meetings and more centralized COP decision structures. In contrast, firms with high levels of end-product complexity have a high frequency of production planning and control meetings but more decentralized COP decision structures. In addition, the impact of the environmental rate of change and information deficiency on the locus of production planning and control is small. Another interesting finding with managerial implications is that firms with a high score on financial performance appeared to have a lower level of customer order complexity and more decentralized COP decision structures than firms with a low score on financial performance. Organizations that decentralize their structure to cope with PMT-uncertainty would be well-advised to reduce customer order complexity first.

We explored the impact of information deficiency, rate of change, and complexity on the use of various production planning and control tools (i.e., kanban control, conventional plan board, spreadsheet, ERP, and APS) in Chapter 4. We found that the impact of PMT-uncertainty on the adoption of these production planning and control tools is only small; route complexity, for instance, does not discriminate users from non-users of different types of production planning and control tools at all. Product change, the only rate of change related factor with some impact, is even negatively related to the adoption of an APS system. Furthermore, it turned out that a lack of information forces firms to use spreadsheets. Finally, we found that size is negatively related to the use of a conventional plan board; however, it turned out to be a stronger predictor of the adoption of a kanban control system than PMT-uncertainty.

We also obtained evidence that any decision to decentralize (the locus of production planning and control) is primarily based on other than logistical considerations, such as social issues. The results indicate that there is no direct relationship between the rate of change of a manufacturing environment and the operational planning decisions structure and the COP decision structure, respectively. By the same token, there is no relationship between information deficiency and the operational planning decisions structure. We also did not find a relationship between uncertainty in the PMT characteristics and the frequency of production planning and control meetings.

9.1.3 Innovation and organizational factors and APS adoption

The main finding of chapter 3 is that complexity, unlike rate of change, leads to a centralization of the customer order processing decisions structure but a decentralization of the operational planning structure (i.e., locus of short-term planning decisions). In addition, we found that the rate of change of PMT characteristics does not discriminate users of various production planning and control tools from non-users. And if we contemplate on the case study at Urenco Aerospace, it appears that the decision to use a specific production planning and control system is not affected by the choice for a specific manufacturing layout.

We found that management support, purchase cost, number of end-products, and other users' opinions are factors that directly influence the adoption of an APS system. In addition, OM/logistics-related sophistication, external communications, and innovation experience influence the level of management support, which is a prerequisite for adopting any technical innovation. Indeed, we found that the more active information-seeking attitude a firm has, the higher its level of innovation experience is, the higher management support is, and the higher its rate of APS adoption is. In contrast, we found that the more a firm values other users' opinions, the less it adopts an APS system. In addition, observability has an indirect effect on APS adoption via other users' opinions. Thus, organizations that attach importance to the ease to demonstrate the results and advantages of an APS system also value other users' opinions about the APS system. An ANOVA analysis indicates that organizations with high scores on innovation experience have significant lower means of other users' opinions and observability compared to organizations with low scores on innovation experience. This indicates that organizations with less innovation experience perceive more uncertainty about a new technology, such as an APS system, have more negative attitudes towards the innovation, and attach greater importance to other users' opinions and the observability of the APS system.

9.1.4 Line management's support of individual competencies

This research provides evidence that firms where line management supports individual competencies obtain higher financial performance than firms in which line management does not value individual competencies. This finding concurs with the theoretical debate that management's attention for HRM activities that enhance competency accumulation and exploitation may facilitate the development of organizational competencies to achieve sustained competitive advantage and financial performance [146]. Accordingly, firms that are capable of incorporating a strategic perspective on competence management throughout the management structure outperform competitors that do not.

This study also indicates that line management's support of individual competencies is positively related to the strategic focus on agile manufacturing priorities. This finding concurs with the objective of agility of allowing an organization to thrive in an environment of constant and unpredictable change, with the workforce as a key source of agility [109]. Firms that support individual competencies also have a strategic focus on flexibility, which concurs with the statement of Hayes et al. [101] that manufacturing flexibility can provide a competitive advantage if there is a proper fit between variables, such as competitive environment, strategy, organizational attributes, technology, and the human capital. In addition, Upton [230] states that manufacturing flexibility much more depends on people than on technical factors.

9.2 Complementary research

Parallel with the research discussed in the previous chapters, a complementary research project is running for the development of a prototype manufacturing planning and control system for decentralized manufacturing systems. In fact, the thesis project started as an application-oriented study on resource loading in decentralized manufacturing environments, and the machine shop of the manufacturing division of Urenco Nederland BV in particular in 1997. However, the complementary development project discussed in this chapter primarily focuses on serial make-to-order multi-stage discrete parts manufacturing environments, but the results can easily be applied for assemble-to-order and make-to-stock environments as well. In this complementary research project, we assume that each manufacturing stage consists of a group of operators and one or more machine groups. Following socio-technical systems design principles, these manufacturers do not require detailed scheduling systems that prescribe exactly when operations have to be performed. However, from Chapter 2 we know that group workers need the guarantee that planned orders can actually start on the predetermined times without unexpected delays due to material unavailability. Indeed, resource groups need a decentralized Manufacturing Planning and Control System (MPCS) based on tactical finite capacity planning and workload control with which each stage can grant commitment to the completion of a specific workload, against predetermined deadlines and in production cost margins. As a result, such an MPCS must include an effective and flexible customer order processing module to establish or verify reliable delivery dates (due-date assignment) and prices that form the basis of these deadlines. Customer orders with imposed fixed delivery dates have to be accepted or rejected. Alternatively, appropriate workload dependent delivery dates have to be determined. This is, however, not new. The crux is that it must be done in ever faster changing, hostile, and complex supply chains. In this chapter, we discuss the concept of a dynamically modified-hierarchical multi-agent MPCS for these types of multi-stage manufacturing environments.

9.2.1 Pull and push

The planning syndrome is particularly the result of the infinite capacity assumption of MRP, and its push characteristic, in which orders are released independent on the actual status of the shop floor. Orders are released simply when calculated start times commence. These timings of orders are determined by off-setting the due dates of various end items by planned lead-times.

An opposite system of push is pull. Hall [94] states that 'material in a pull system is drawn or sent for by the users of the material as needed'. In addition, Schonberger [197] states that pull systems are solely related to the Toyota-style kanban system, i.e., the traditional kanban system. In fact, kanban is the material replenishment method that manages and ensures the success of Just-In-Time manufacturing via manufacturing control cards or containers. In the traditional kanban system, work for a machine is only released and actual production at a machine is only started at the arrival of a kanban, after a corresponding product at a successive machine, i.e., upstream machine, is used.

In pure pull systems, it holds that inventory remaining at the point of triggering must be enough to cover demand until replenishment. Hence, pure pull is essentially a *replenishment* system. As a result, pull systems are not straightforward in highly custom-engineer-to-order manufacturing environments, as it starts with the sale of a product already in stock and then works its way back upstream through replenishment of inventories, which simply cannot exist in a custom-engineered environment. In addition, for a factory that custom-designs and fabricates each product, the final product is defined only after the design is specified by the customer order. There are no predefined finished goods before receipt of the customer order and subsequently, one cannot store inventories at the output of each workstation [217].

However, pull maintains to be advantageous, as the underlying cause of the key benefits of pull systems is that *there is a limit on the maximum amount of inventory in the system*—no matter what happens on the shop floor, the WIP level cannot exceed a prespecified limit. Hence, the magic of pull is the *WIP cap*, not the pulling process or resident WIP. It still holds that if WIP is capped, then disruptions in the shop (e.g., machine failures, shutdowns due to quality problems, slowdowns due to product mix changes) do not cause WIP to grow beyond its predetermined level [110]. Note that in a pure push system, no such limit exists. If an MRP-generated schedule is followed literally (i.e., without adjustment for plan conditions), then the schedule could get arbitrarily far ahead of production and thereby bury the manufacturing system in WIP, causing a *WIP explosion* [110]. This is the earlier mentioned *lead-time syndrome* or *planning loop* that may also occur in MRP systems. Hence, we conclude that due to the (long-term) benefits of pull control, aspects of pull should be incorporated into manufacturing planning and control systems. Unfortunately, from a planning perspective, there is also a drawback to pull, as a pull system is inherently rate driven: we set the *WIP cap* and let the system run. However, while a rate-driven system is logistically appealing, there is no natural link to customer delivery dates in a pull system. Customers pull what they need, and signals (e.g., cards or kanbans) trigger replenishments. However, until the demand actually occurs, the system offers no information about customer orders. Hence, a pull system provides no inherent mechanism for planning raw material procurement, staffing, and so on. Hopp and Spearman [110] show that although push systems can be logistic nightmares, they are extremely well suited to planning, as there is a simple and direct link between customer delivery dates and order releases in a push system. The question, then, is whether we can obtain the logistic benefits of pull and still develop a coherent planning structure.

Of course, most real world systems have aspects of both push and pull, and there have been various attempts to formally combine push and pull into hybrid systems; see for instance Hall [94]. A well-known approach to combining push and pull mechanisms is to add a push component to a pull system through setting of control parameters in the pull system. Whenever a safety stock level, base stock, or reorder point is changed based on forecasts, a push element has been added to the pull system; see for instance Karmarkar [124].

9.2.2 A generic modified-hierarchical MPCS architecture

The prototype MPCS integrates the advantages of both push and pull, and is based on the modified-hierarchical manufacturing planning and control reference architecture of Van Assen et al. [6], that satisfies the planning and control requirements of decentralized manufacturing; see Figure 9-1. In this architecture, a decentralized planning and control system for each stage performs capacity adjustment decisions locally as problems occur, based on local and global information. In other words, each decentralized system is designed to help in solving disturbances in the manufacturing process when and where they arise, in a timely fashion. However, local decisions not necessarily lead to a satisfactory overall solution. Therefore, the MPCS encompasses a centralized aggregated capacity planning and workload control system that counts for the overall coordination of the material flow between the stages as well as the use of the aggregate resource capacity, i.e., the stages as a whole. On this planning level, typical decisions include staffing decisions, e.g., the determination of the required work-force by hiring temporal personnel. Thus, the reference architecture exhibit great resemblance with the architectures proposed by Bertrand et al. [31] and Zijm [254]. However, there are some important differences, which become clear in the next sections. For more information on these architectures we refer to the above-mentioned papers.

Based on an aggregate process plan, each customer order is divided into a set of work-packages, each corresponding with a specific stage. Next, based on the customer delivery date an authorization time fence is assigned to each work-package in which it must be completed.

In the decentralized manufacturing planning and control systems, a detailed process plan is determined for each stage, in which work-packages are divided into jobs. Initially, these jobs must then be completed in the corresponding stage before or on the deadlines imposed by the authorization time fence. If a local disturbance occurs, it has to be solved locally in the stage with the help of the detailed resource loading module and/or the multi-resource scheduling module of the specific decentralized system. Nonetheless, the architecture is designed so that consequences of a local decision in one stage for other stages are taken into account.

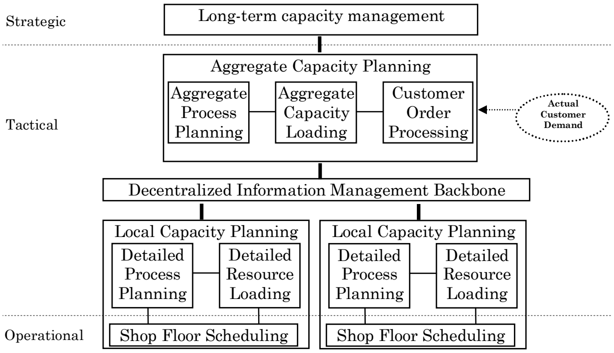


Figure 9-1 : Part of the modified-hierarchical MPCS architecture (Van Assen et al. [6]).

However, in case the manufacturing system consists of consecutive stages, it might occasionally be better to solve a problem that occurs in a specific stage in a succeeding stage. If, for example, the manufacturing system has a production stage with relatively expensive highly skilled workers and a common assembly stage with a relatively low cost structure, then it might be better (i.e., more cost effective) to become late in the production stage and catch up in the assembly stage by adding overtime capacity. For a more detailed discussion of the functional aspects of this architecture, we refer to Van Assen et al. [6]. In this chapter, we primarily aim to discuss the concepts of the architecture implemented as a multi-agent research prototype MPCS, in which an overall pull mechanism to control workload (of the supply chain stages by controlling work-package releases and setting work in process caps) is combined with local push controlled mechanisms (i.e., detailed resource loading) in the supply chain stages.

In the multi-agent MPCS, we distinguish a central staff agent that is responsible of the overall coordination of the manufacturing system, i.e., the coordination of orders among the various stages, as well as customer order processing and due date determination. We also distinguish local agents, each representing a specific stage. These local agents aim to support the stages with short-term capacity adjustment decisions, if necessary, to complete their work in time, even if disturbances (such as temporarily machine breakdowns) have occurred. Therefore, each local agent is facilitated with a detailed resource loading system. The central staff agent, on the other hand, is facilitated with an aggregated stage loading system that is based on the concept of the Generalized Kanban Control System (GKCS); see also Figure 9-1. Accordingly, the MPCS incorporates aspects of the Generalized Kanban Control System (GKCS), resource loading, and agent-based coordination of the various software modules.

9.2.3 A GKCS-based aggregated stage loading system

In this complementary research project we have adopted the concept of the *Generalized Kanban Control System* (GKCS); see for instance Buzacott and Shantikumar [45]. In the GKCS system, a workload control rule is imposed on each stage by limiting the amount of work-in-process to a certain number of virtual kanbans, i.e., a work-package is only allowed to enter a stage when a virtual kanban is available. After each stage an order-up-to, or base stock level can be defined for the output buffer of that stage. The system will then strive to reach this stock level. The generalized kanban system has both the *classic kanban system* and the *base stock system* as limiting cases. Indeed, if the workload control rules are released a GKCS reduces to a base stock system. In contrast, if the number of kanbans is equal to the base stock level a GKCS reduces to a classic kanban system. Accordingly, the generalized kanban system can model a range of systems varying from *make-and-assemble-to-stock* to *make-to-order* systems; see Figure 9-2, in which we display a queuing network model of a 3-stage single-class GKCS system.

In fact, a GKCS is a base stock system with a workload control rule for each stage. The workload control rule is imposed on each stage by limiting the number of products in each stage by a fixed number of virtual kanbans. A production request can only be taken into production when a virtual kanban is available. For a stage that manufactures 'to-order' the base stock level is zero by definition.

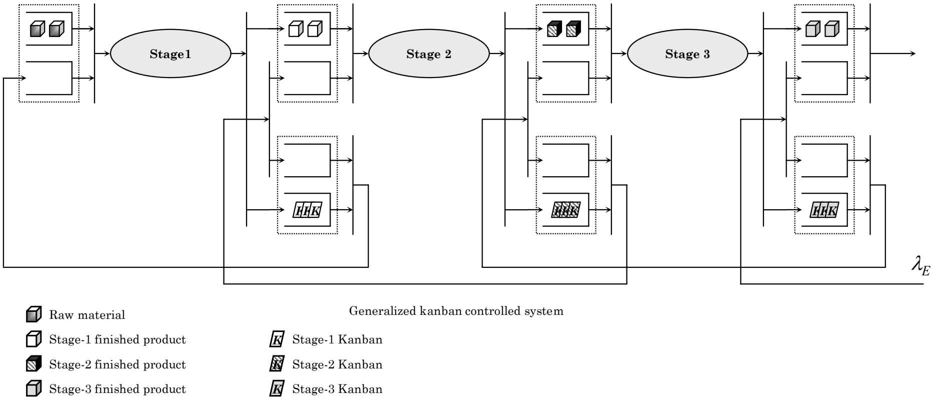
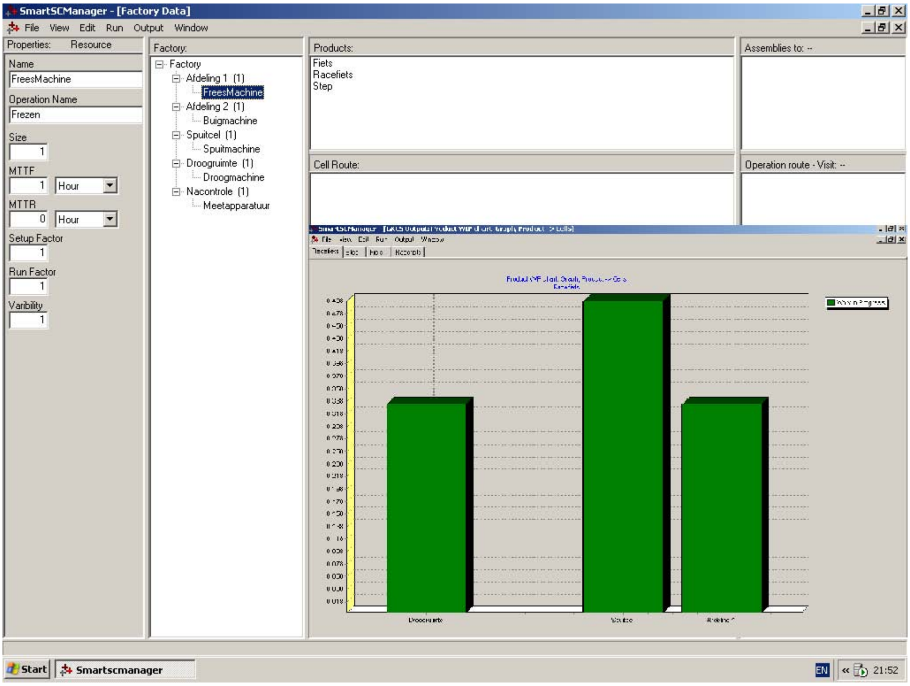


Figure 9-2: Queuing network model of a 3-stage single-class GKCS system (Wormgoor [244]).

With a GKCS based *performance evaluation system*, used in a generative mode, it is possible, though still time-consuming, to find parameter combinations, i.e., workload norms and base stock levels, for which a certain demand and desired market service levels can be met while minimizing inventory carrying costs. The system capacity obtained is the *effective system capacity* based on the nominal resource capacity and workload norms. Subsequently, and especially under an *assemble- and make-to-order* strategy, one may decide to 'temporarily' increase the nominal resource capacity by adding extra non-regular capacity, to increase the effective system capacity; hence, to speed up processes. In the traditional view of operations research, such questions are classified as *aggregate finite capacity loading*.

The framework presented by Buzacott and Shantikumar [45] does not allow multiple part types. This framework is, however, extended during our research project, see for instance Wormgoor [244] and Van 't Klooster [136], to allow multiple part types to be produced in the same stage, where each part type satisfies a class-dependent workload norm and has its own base stock level. Furthermore, during our project several practical extensions for the GKCS models have been proposed and implemented. First, the method is extended to allow arbitrary routing of the part types over the stages which also allows repeat visits to a previous stage. Subsequently an approximate method is developed to model converging flows, for example in assembly systems, as an exact method is computationally unattractive. Finally, we accounted for scrap since then the throughput of an upstream stage may be higher than in a downstream stage. The other group of extensions is concerned with modeling shop floor dynamics. Some of these dynamics, such as set-ups, rework, and failures can be accounted for by *inflating* the first and second moment of the service times, see for instance Hopp and Spearman [110]. Finally, methods are proposed to incorporate operator capacity in each stage as a secondary resource since that will also limit throughput in a manufacturing system.

The dual resource-constrained multi-stage multi-item GKCS offers an elegant workload control mechanism that makes use of two parameters for each product class and for each stage of the manufacturing system: the number of kanbans and the base stock levels. In addition, the required operator capacity has to be set as a third parameter for the stage. In this complementary project, the idea was to allow a staff agent to determine the 'optimal' operator capacity (regular operator capacity plus temporarily operator capacity by hiring extra personnel) required to meet market demand and corresponding market service levels in the near future. Note that especially in ATO manufacturing environments there is a trade-off between the cost of inventory and the cost of capacity adjustments to satisfy market demands. The specific values of these parameters have a high impact on the efficiency of the generalized kanban control policy, and are thus crucial for usage as an aggregate finite capacity planning system; see for instance Frein et al. [79], Duri et al. [63], and Liberopoulos and Dallery [157].



Name: FreesMachine
Operation Name: Frezen
Size: 1
MTTF: 1 Hour
MTTR: 0 Hour
Setup Factor: 1
Run Factor: 1
Varibility: 1

- Factory
  - Afdeling 1 (1)
    - FreesMachine
  - Afdeling 2 (1)
    - Buigmachine
  - Spuitcel (1)
    - Spuitmachine
  - Droogruimte (1)
    - Droogmachine
  - Nacontrole (1)
    - Meetapparatuur

Fiets
Racefiets
Step

Figure 9-3: A prototype GKCS-based performance evaluation system.

The idea is that the use of the multi-stage multi-item GKCS-based performance evaluation system, displayed in Figure 9-3, in generative mode allows us to determine workload dependent delivery dates in make-and-assemble-to-order systems, as well as corresponding internal authorization time fences for each work-package. Furthermore, we may determine the required total operator capacity and workload limits (i.e., the number of virtual kanbans) to control work-package releases to satisfy market service levels. Note, however, that the utilization levels (i.e., the optimal *WIPcap*) that belong to the optimal parameters and the total expected sojourn times of products determined by this aggregate loading module are of particular interest for the multi-agent MPCS. However, there are still numerous open questions to challenge. For instance: the analysis and optimization of large scale dual resource constrained multi-class multi-stage GKCS systems is still incomplete.

9.2.4 A detailed resource loading system for each stage

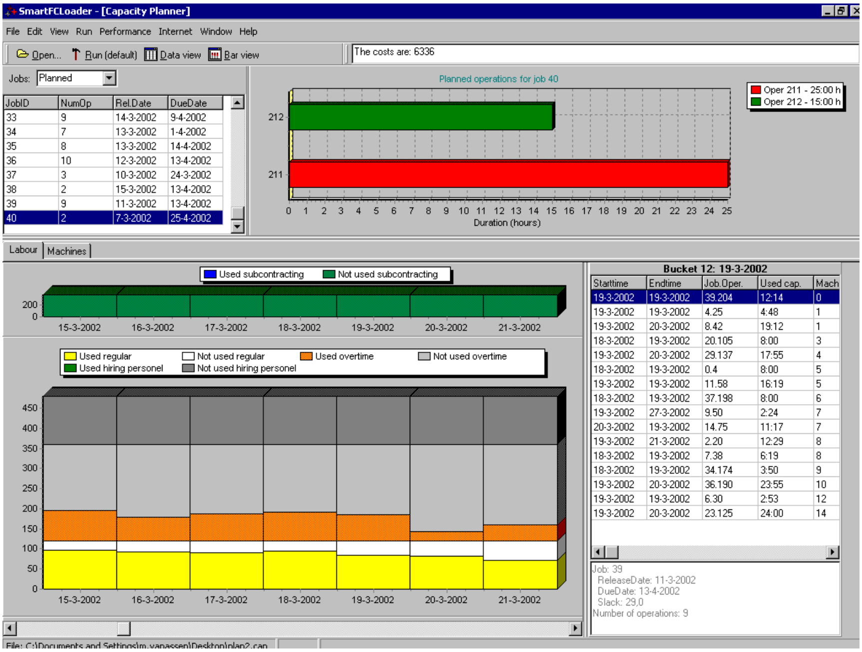
In the previous section, we discussed an aggregated loading system with a strong emphasis on coordination and workload control of various stages (i.e., the coordination of work-packages), in which the staff agent is facilitated with a generative GKCS-based performance evaluation system to set parameters for each stage to determine the *WIPcap* and to propose time fences. The question remains how a local agent should determine the usage of available capacity to complete work-packages in time even if local disturbances have occurred, e.g., machine breakdowns. To cope with such disturbances, each stage has the flexibility to adjust capacity, for instance, by adding overtime capacity. Hence, on a detailed resource level, the stage has some slack to catch up with short delays due to local disturbances. We, therefore, briefly discuss a heuristic for detailed resource loading to fill in the decentralized local resource loading modules of the MPCS framework in Figure 9-1, i.e., the planning tool for each local agent. We recall that in the decentralized manufacturing planning and control modules, a more detailed process plan is determined for each stage in which work-packages are divided into jobs. Note that these jobs may be further divided into operations on the scheduling and dispatching level. These jobs must then be completed in the corresponding stage before or on the deadlines imposed by the achievable authorization time fence. If any disturbances occur, they primarily have to be solved locally in the stage with the help of the resource loading module of the specific decentralized system.

The resource loading problem For a detailed problem description of resource loading, we refer to van Assen et al. [19] and Hans [95]. In this chapter, we will confine ourselves with a brief discussion of the problem taken from van Assen et al. [19]. Consider a stage, i.e., a group of operators and a variety of machine groups, to which a set of jobs corresponding to a set of work-packages has to be loaded over one or more discrete time-buckets, say days, within their authorization time fence. Hence, a work-package is subject to a release date and a deadline. A work-package consists of a sequence of jobs, where each job should be processed on a particular machine group. Thus, jobs are produced according to the sequence induced by the process plan and stated in the job-list of each work-package. We adopt the well-known and generally used step-per-period strategy because this ensures a feasible disaggregation of the resource loading plan into a detailed short-term schedule. Furthermore, for simplicity reasons, we assume that a job may not start processing before its predecessor is completed, i.e., batch overlap is not allowed. Job pre-emption is allowed, i.e., a job may be processed in several consecutive time-buckets.

Practically, machines are operated by operators, which, in general, have their own specific skills stated in a capability and competence matrix. However, for simplicity reasons we assume that operators are interchangeable. An operator is assigned to a job for the entire duration of its processing time. Processing times of jobs are considered deterministic and expressed in time units, say hours. Operators can work in regular as well as in overtime. While not used in this application, it is easy to incorporate the possibility that if there is insufficient operator capacity, the stage can hire temporary staff, or, when even temporary staff cannot cover the operator capacity problems, part of the job or even the entire job can be subcontracted; see Van Assen et al. [19]. For machine capacity, we assume that there is only regular capacity that cannot be expanded temporarily.

Hence, the resource loading problem essentially reduces to the assignment of jobs to one or more time-buckets, where jobs are subject to precedence constraints. We can assign a job for x hours to a day, when at least x hours of machine capacity as well as x hours of regular and irregular operator capacity is available. If there is insufficient regular or irregular capacity in a day, the options are to assign only a part of the job to this day, or to process the job in a different day.

A resource loading procedure determines if work-packages can be completed before their internal deadlines, using regular capacity as well as non-regular capacity, taking into account complex precedence relations between jobs. Furthermore, in each period there are upper bounds on the number of hours we can work in overtime. As a result, a resource loading plan then specifies the allocation of scarce regular and non-regular resource capacity to work-packages over time, taking into account the restricted availability of different types of important resources, i.e., machines and operators. Thus, a resource loading plan also specifies to what extent extra capacity, i.e., extra hours of capacity by working in overtime, is required to complete all work-packages in time. However, the use of non-regular capacity leads to extra costs. The objective is then to minimize the cost of adding non-regular capacity, under the restriction that all work-packages receive sufficient capacity, that precedence relations between jobs are met, that the upper bounds on each type of capacity in each planning period are not exceeded, and that deadlines are met.



The costs are: 6336

Jobs: Planned

JobID	NumOp	Rel.Date	DueDate
33	9	14-3-2002	9-4-2002
34	7	13-3-2002	1-4-2002
35	8	13-3-2002	14-4-2002
36	10	12-3-2002	13-4-2002
37	3	10-3-2002	24-3-2002
38	2	15-3-2002	13-4-2002
39	9	11-3-2002	13-4-2002
40	2	7-3-2002	25-4-2002

Bucket 12: 19-3-2002

Starttime	Endtime	Job.Oper.	Used cap.	Mach
19-3-2002	19-3-2002	39.204	12:14	0
19-3-2002	19-3-2002	4.25	4:48	1
19-3-2002	20-3-2002	8.42	19:12	1
18-3-2002	19-3-2002	20.105	8:00	3
19-3-2002	20-3-2002	29.137	17:55	4
18-3-2002	19-3-2002	0.4	8:00	5
19-3-2002	19-3-2002	11.58	16:19	5
18-3-2002	19-3-2002	37.198	8:00	6
19-3-2002	27-3-2002	9.50	2:24	7
20-3-2002	19-3-2002	14.75	11:17	7
19-3-2002	21-3-2002	2.20	12:29	8
18-3-2002	19-3-2002	7.38	6:19	8
18-3-2002	19-3-2002	34.174	3:50	9
19-3-2002	20-3-2002	36.190	23:55	10
19-3-2002	19-3-2002	6.30	2:53	12
19-3-2002	20-3-2002	23.125	24:00	14

Job: 39
ReleaseDate: 11-3-2002
DueDate: 13-4-2002
Slack: 29,0
Number of operations: 9

File: C:\Documents and Settings\m.vanassen\Desktop\plan2.can

Figure 9-4: A detailed resource loading system.

It is easy to recognize that the resource loading problem is NP-hard, as the decision problem that corresponds with the resource loading problem is NP-complete. This can be proven by reduction to the 3-machine job shop problem with unit processing times, which is proven to be NP-complete by Lenstra and Rinnooy Kan [154]. As a result, we expect that there is no polynomial optimization algorithm. Hence, one must use enumerative algorithms or integer linear programming algorithms to find optimal solutions, i.e., optimal resource loading plans, for instances of the problem. However, this may, especially for large real-life instances, require computation times that are unacceptably large. Hence, it is justified to use approximation algorithms that find good, but not necessarily optimal, solutions in reasonable times. For a Linear Mixed Integer Programming formulation of this problem that is solved by branch and price techniques, we refer to Hans [95]. However, in this complementary research project a fast practical heuristic for resource loading based on dynamic programming is developed [19] and incorporated in a real commercial software system; see Figure 9-4.

A dynamic programming approach The basic idea of our heuristic is to load work-packages one by one to build a (partial) loading plan consecutively. To load a single but complete work-package, that comprises a number of jobs, to optimality, given this partial resource loading plan, we have formulated a forward dynamic programming recursion on the problem. In this recursion, first all possible bucket sets to load the first job of the work-package are examined, and subsequently for successive jobs, until the last job of that work-package. Accordingly, solving the dynamic programming recursion for one work-package leads to an optimal plan for that specific work-package, given the partial resource loading plan at that time. The basic idea of our practical heuristic, however, is to solve w DP's to obtain a single feasible resource loading plan, as there are w work-packages that have to be loaded. In Van Assen et al. [19], we show that this DP-approach outperforms all multiple-priority-rules-based approaches commonly used in practice. In addition, the DP-approach performs even better in a multiple-pass mode. In addition, various practical extensions are developed, for instance time-driven and resource driven loading procedures and methods to account for competencies and skills. However, there are a number of challenging research directions, for instance the development of job-based heuristics for detailed resource loading instead of the work-package-based DP-heuristic discussed in this section. In addition, further research is required to incorporate methods to account for uncertainty in the detailed resource loading problem.

9.2.5 General working of the MPCS as a multi-agent system

Clarity and simplicity are central principles in the design and development of our research prototype, as the development of an advanced intelligent multi-agent system with new features that extend the body of knowledge of Distributed Artificial Intelligence (DAI) was not the ultimate goal of the complementary research project. To build a multi-agent system in which the agents 'do what they should do' generally turns out to be particularly difficult, and that entails the question "when and how should which agents interact to successfully meet their design objectives?". To keep this chapter concise, it is, therefore, justified to only conceptually discuss the general working of the system, the roles of various agents, and the way they interact.

The working of the system in a (serial) multi-stage make-to-order environment is as follows: at the arrival of a new customer request, the staff agent has to determine an appropriate workload dependent due-date and negotiates a price and delivery date with the customer. Occasionally, a rush order with a given (i.e., imposed) deadline may arrive that can only be accepted or rejected by the staff agent. All orders, however, are divided into work-packages corresponding to the various stages the orders have to visit. Initially, the staff agent determines appropriate authorization time fences for each work-package in which the corresponding jobs should be completed. The staff agent controls the timings of the work-package releases, and accordingly it controls the work-packages waiting in between the stages to enter a stage. Each local agent solely controls (the jobs of) the work-packages in a stage. The staff agent influences the operating space of these local agents by setting the workload norms for each stage as well as the determination of the maximum numbers of operators (i.e., regular operator capacity and non-regular operator capacity obtained by hiring temporal personnel) with which 'the stage' should complete all work-packages in portfolio.

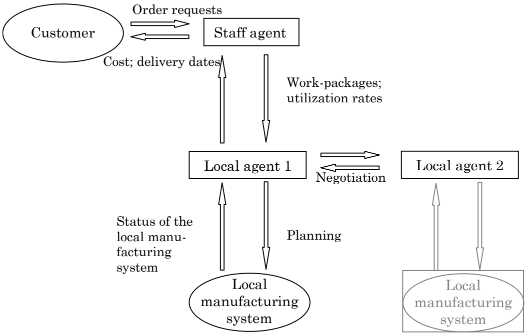


Figure 9-5: Basic model of the MAS.

However, to account for local disturbances the local agent may independently decide to adjust total operator capacity by adding extra overtime. Local agents, however, act in a highly distributed manner. If, for instance, a disturbance occurs in a particular stage, the specific local agent receives input from the real manufacturing system (we assume that local agents have full online knowledge of the actual status of the manufacturing system they represent) and subsequently evaluates the impact of the disturbance on the existing loading plan, and reloads (the jobs of) work-packages if necessary. Occasionally, a disturbance may lead to a new loading plan with higher costs of using overtime capacity then initially foreseen to complete the work in time. However, it may be a better overall solution to partly solve the results of the disturbance in a subsequent stage. That is, accept the internal lateness and catch up in a succeeding stage that implies a lower penalty cost than capacity adjustment costs for the stage where the disturbance occurred. Local agents have freedom to negotiate these types of issues mutually. However, to prevent myopic local solutions and other problems like blocking, the staff agent may intervene local negotiations. Hence, the MPCS is dynamically modified-hierarchical; see Figure 9-5.

9.2.6 Achievable authorization time fences

As mentioned before, the staff agent determines for each customer order a delivery date and price in case these are negotiable, or accepts/rejects new orders with imposed delivery dates. Both cases have similar approaches: at the arrival of a new customer request, a virtual order is determined with a global (aggregated) process plan over the various stages. Hence, virtual work-packages originate. In each stage these work-packages are further divided into virtual jobs by the local decentralized process planning module. The objective of the staff agent is to determine achievable workload dependent authorization time fences for each work-package in each stage. For this purpose, the staff agent is facilitated with a GKCS-based aggregated group loading system, which will be discussed in the next section. After the determination of appropriate initial authorization time fences for each virtual work-package in each stage, the staff agents consult each local agent for which there is a virtual work-package, and inquires if the initial authorization time fence is achievable. In other words, the staff agent requests each local agent to 'load' the virtual work-packages in their initial authorization time fences against available regular capacity in each stage, thereby taking into account that the total utilization of regular capacity (in the loading period under consideration) does not exceed the GKCS determined utilization norms (i.e., the *WIPcap*). Initially, for the loading of virtual work-packages only regular capacity up to the *WIPcap* is to be used.

If the loading of a virtual work-package with an initial authorization time fence is 'achievable', i.e., it does not lead to extra costs of using capacity beyond the *WIPcap* , or even of using overtime capacity, the local agent replies the staff agent with a positive message. Otherwise, the local agent replies a message with a negative advice accompanied with alternatives (i.e., an alternative internal delivery date, or the extra costs to meet the initial dead-line by using overtime capacity). Subsequently, the staff agent may adjust some authorization time fences and/or parameters based on this new information. He, then, re-consults all relevant local agents again, until a satisfactory external delivery date and corresponding internal milestones are achieved. In this negotiation process the staff agent may, however, adjust the total operator capacity in each stage by shifting operators from one stage to another, or by hiring extra personnel. The staff agent will act on the advice of the local agents as much as possible, but he is not obliged to. The staff agent can accept orders and command local agents to accept work-packages with other specific authorization time fences and capacity budgets to complete the work-package in time.

Each local agent aims to load the portfolio of accepted work-packages as good as possible where, initially, the authorization time fences are characterized by deadlines (i.e., hard internal milestones). If a disturbance occurs locally that delays the progress of a work-package and that jeopardizes the completion of the work-packages at predetermined costs, the local agent may try to negotiate crossing internal 'deadlines' with its customer, i.e., with the local agent of a successive stage. Hence, local agents have 'bounded' freedom to trade off possible cost of using overtime capacity with (lower) penalty cost for late delivery. Only if successive local agents and the staff agent allow it, the initial deadline from the authorization time fence may become a due-date.

An important addition to this highly distributed decision making process is that the staff agent may dynamically overrule decisions of local agents. All interactions between local agents take place via negotiation.

For detailed information on the design and implementation issues of the multi-agent system, for instance the adaptation and development of (i) the hybrid agent architecture *Interrap* of Müller [175], (ii) KQML as the protocol for communication in the multi-agent system implemented in XML as the message format, (iii) the implementation of the multi-agent MPCS system in Borland Delphi 6, (iv) the *Common Object Request Broker Architecture* (CORBA) as the platform and language independent object-oriented communication technique used for direct communication between two agents represented as a client and a server, and the message protocols fro communication between the simulation test bed (i.e., the simulator) and the agents, we refer to Van Assen and Meinders [20].

9.2.7 Negotiation based on a utility function

The primary objectives of the multi-agent MPCS addressed in this chapter are 1) to solve the problem of determining workload dependent delivery dates (in case of make-to-order environments) and corresponding achievable time fences for all stages, 2) the determination of capacity adjustments in busy periods, and 3) the reloading of work-packages that may be subject to complex precedence relations against finite resource capacity after occurrences of local disturbances.

Recall that, to account for local disturbances, a local agent may independently decide to adjust total operator capacity by adding extra overtime. Local agents, however, act in a highly distributed manner. If, for instance, a disturbance occurs in a particular stage, the specific local agent receives input from the real manufacturing system and subsequently evaluates the impact of the disturbance on the existing loading plan, and reloads (the jobs of) work-packages if necessary. Occasionally, a disturbance may lead to a new loading plan with significant more costs of using overtime capacity than initially foreseen to complete the work in time. However, it may be a better overall solution to partly solve the results of the disturbance in a subsequent stage. That is, accept the internal lateness and catch up in a succeeding stage that implies a lower penalty cost than capacity adjustment costs for the stage where the disturbance occurred. Local agents have freedom to mutually negotiate these types of issues.

However, agents have to evaluate the transaction costs associated with the reallocation of work-packages and their resources, and the external costs of changing the timing of jobs before actually making decisions. Note that these costs are work-package dependent. According to Kim et al. [131], a bilateral negotiation process cannot find an external cost easily, because agents need to consult other agents before making a counteroffer to the agent (since agents do not know the consequences of their decision until getting the responses). This also holds for our multi-agent MPCS. Thus, we adopt the compensatory negotiation methodology proposed by Kim et al. [131].

A utility of the timing of tasks is represented as a real valued number (i.e., money) which describes a difference between the benefits and costs of alternatives for the agent of the timing of the work-package. This utility function is the same for all agents and the utility is transferred between them for compensation [131][203]. In addition, the local agents are profit driven; hence, they strive for maximization of the utility. For a detailed discussion of (the working of) this utility function, we refer to Van Assen and Meinders [20].

9.2.8 Discussion, conclusion, and further research on MPCS

Discussion Increasingly more companies and researchers focus on the management and control of complete *supply chains*, comprising various suppliers that may operate in a network; see for instance Van Assen et al [15]. However, the Supply Chain Management / Advanced Planning and Scheduling systems that are available today can be characterized in a way similar to ERP systems: they link a wide variety of business functions (purchasing, logistics, marketing, for instance), but focus almost exclusively on centralized controlled environments, thereby concentrating on information management and hence without more intelligent, quantitatively based decision support functions [210][254]. The current state of the art shows the integration of hierarchical planning architectures with Linear Programming tools for aggregate production and capacity planning, and sometimes advanced shop floor scheduling systems at a low level in make-to-order production environments. Stochastic models that explicitly address demand or process uncertainties (e.g., stochastic multi-echelon models or models based on queuing networks) are absent in APS systems to date [254]. At the same time, the number of models and algorithms addressing a variety of problems in supply chain management is rapidly growing, for a recent overview we refer to Tayur et al. [222].

Zijm [254] also claims that models of multi-echelon systems would provide a useful starting point for the analysis of more complex supply chains, but that, until now, the far majority of models concentrate exclusively on stock-based production. This complementary research prototype, however, was an attempt to fill in some parts of such an advanced planning system.

Numerous authors claim that the generalized kanban control policies may become relevant for the development of models for capacitated supply networks, if it accounts for the periodic nature of the supply chain operations planning problem, as well as for possible material unavailability due to the basic assumption that the number of kanbans is equal or greater than the stock level in the performance evaluation algorithm used [138][254]. This implies that a queuing network analysis based on continuous review and FCFS at resources does not represent properly the planning characteristic and the periodic nature of the supply chain operations planning problem. However, De Kok and Fransoo [138] state that queuing network analysis may be a starting point for both the determination of planned lead-times and a heuristic analysis of the capacitated supply chain operations planning problem under stochastic demand. They state that the main idea behind this is that in most real-life situations capacity is hard to define; processes can be speeded up if necessary; resources can be reallocated to provide more capacity to specific capacity requirements. In addition, they state that this observation may be a reason to decompose the supply chain operations planning problem into a queuing network analysis of the resources to provide realistic planned lead-times for other planning modules. In this chapter, we proposed such a decomposition method that uses 1) a GKCS–based performance analysis system to analyze consecutive stages and 2) various detailed resource loading systems in each stage. In addition, these systems are integrated with the help of an agent architecture that accounts for the non-stationary nature of the supply chain operations planning problem (e.g., resource calendars in the detailed resource loading systems).

Conclusion and further research In this chapter, we presented the working, the design, and the implementation of a dynamically modified-hierarchical multi-agent Manufacturing Planning and Control System for multi-stage manufacturing environments, in which local push mechanisms are combined with an overall pull mechanism to control workload and order releases to manufacturing stages. In this MPCS, we distinguish a central staff agent that is responsible of the overall coordination of the supply system, i.e., coordination of work-packages among the various stages, as well as customer order processing and due date determination. This staff agent is facilitated with a performance evaluation system in which the manufacturing system is modeled as a multi-stage multi-class Generalized Kanban Controlled System to incorporate the pull mechanism into the MPCS (i.e., the *WIPcap*); and that can be used to find 'achievable' workload dependent authorization time fences and parameter combinations for each stage to satisfy customer demand. Subsequently, and especially under an *assemble and make-to-order* strategy, one may decide to 'temporarily' increase the nominal resource capacity by adding extra non-regular operator capacity through hiring temporal staff, to speed up processes. In the traditional view of operations research such questions are classified as *aggregate finite capacity loading*. On the other hand, there are local agents for each stage. These local agents semi-autonomously act in a highly distributed manner for a given portfolio of work-packages. Each local agent is facilitated with a *detailed resource loading* system to determine the effective and efficient use of regular and overtime capacity in the stage to complete released work-packages in their 'achievable' authorization time fences.

Currently, we are validating the modified-hierarchical multi-agent Manufacturing Planning and Control System in a simulation test bed. Preliminary results indicate the advantages of decomposing the manufacturing and control problem into several smaller problems that are solved with fast heuristics and integrated with coordination and cooperation mechanisms provided by the concept of multi-agent systems. However, there are still numerous open questions to challenge. For instance: the analysis and optimization of large scale dual resource constrained multi-class multi-stage GKCS systems, the development of job-based heuristics for detailed resource loading instead of the workpackage-based DP-heuristic discussed in this chapter. In addition, further research is required to incorporate methods to account for uncertainty in the detailed resource problem. Finally, we aim to develop several extensions for the cooperation and negotiation mechanisms among the agents to use the system in external supply chains.

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Samenvatting

Productiebedrijven in de maakindustrie, ofwel discrete productiebedrijven, zijn onvermijdelijk gebonden aan de condities van hun omgeving; ze moeten voldoen aan een scala van eisen en wensen van verschillende belanghebbenden (klanten, toeleveranciers, overheid, financiers, arbeidsmarkt en vakbonden) die hun de middelen verschaffen om de activiteiten te ontplooien. Daarbij is de effectiviteit van een willekeurig productiebedrijf gerelateerd aan de consistentie van het productiesysteem met de omgeving. Hierbij speelt het concept onzekerheid (met name de dimensies complexiteit, dynamiek en informatie onbeschikbaarheid) een belangrijke rol. Anders gezegd, er moet consistentie zijn tussen de verschillende productiebeslissingen, productiestrategie, proceskeuze, de mate van decentralisatie, productieplanning en besturingstrategieën, –concepten en –systemen, en de karakteristieken van de dominante Product/Markt/Technologie (PMT) combinaties van het productiebedrijf. Dit proefschrift richt zich specifiek op empirische studies binnen de Nederlandse maakindustrie met betrekking tot de invloed van omgevingsonzekerheid op enkele van bovengenoemde productiedimensies. De centrale onderzoeksvraag van dit proefschrift is ‘wat is de impact van PMT-onzekerheid, gegeven de karakteristieken van de PMT-combinaties, op belangrijke productiemanagementonderwerpen zoals de strategische focus op competitieve prioriteiten, de dominante vorm van de productie layout, de mate van centralisatie (i.e., hiërarchie) van de beslissingsstructuur voor productieplanning, de adoptie van verschillende soorten productieplanning- en besturingssystemen, en de aandacht van het lijnmanagement voor individuele competenties’.

In Hoofdstuk 2 bespreken we de case Urenco Aerospace, een tweedelijns toeleverancier in de vliegtuigbouwindustrie. Het doel van de case is meer inzicht te verkrijgen in het probleemgebied en de verschillende begrippen die een rol spelen voor het beantwoorden van de hoofdonderzoeksvraag. In dit hoofdstuk bestuderen we vooral of de door het management van Urenco Aerospace geprefereerde productiestructuur met productgeoriënteerde cellen een functioneel georiënteerde productiestructuur overtreft op verwachte logistieke prestaties, zoals gemiddelde doorlooptijd en voorraad onderhandenwerk; en zo niet, waarom een productiebedrijf dan toch kiest voor zo’n productgeoriënteerde productiestructuur. In elk geval willen we van de uiteindelijke productiestructuur onderzoeken welke productieplanning en besturingbehoefte er is en welk type productieplanning- en besturingssysteem dan gebruikt wordt.

Gebaseerd op een analyse van de verwachte logistieke prestatie-indicatoren vonden we dat voor deze case een productiestructuur met volledig autonome product cellen niet noodzakelijkerwijs beter zou presteren dan een functionele productie-structuur met teams. De prestatie van een productiestructuur met product cellen kan in dit geval sterk worden verbeterd door grensoverschrijdende productrouteringen toe te staan—dit resulteert echter in een aanzienlijke stijging van de productieplanning en besturingsbehoefte. Het werk voor de uiteindelijke productiecellen met grensover-schrijdende productrouteringen werd bij Urenco Aerspace in eerste instantie zelfs gecoördineerd en bestuurd met behulp van een 'low-end' Advanced Planning en Scheduling (APS) systeem, en later met behulp van een meer eenvoudig visueel besturingssysteem op de productievloer. Deze verschillende productieplanning- en besturingssystemen werden ondersteund door een centraal ERP systeem (SAP R/3) waarin data van de verschillende bedrijfsprocessen centraal zijn opgeslagen, maar dat juist geïmplementeerd was met de bedoeling om een decentrale productiestructuur te ondersteunen

In Hoofdstuk 3 staat de vraag centraal hoe onzekerheid, gegeven het productie-systeem en haar omgeving gekarakteriseerd door de (verzameling van) dominante PMT combinatie(s), gerelateerd is aan de beslissingsstructuur van productieplanning en de frequentie van overleg met betrekking tot productieplanning en besturings-aspecten. Om deze vraag te beantwoorden hebben we een survey (i.e., vragenlijst-onderzoek) uitgevoerd onder bedrijven in de Nederlandse maakindustrie met meer dan 20 werknemers. Gebaseerd op een aselecte steekproef van 206 respondenten, concluderen we dat de invloed van de verschillende dimensies van onzekerheid op de mate van centralisatie van de productieplanningsbeslissingen verschillend zijn. Omgevingscomplexiteit, en in het bijzonder klantenordercomplexiteit, leidt tot een meer gedecentraliseerde beslissingsstructuur voor productieplanning, maar ook tot een meer gecentraliseerde beslissingsstructuur van klantenorderacceptatie en levertijdafgifte.

Zo hebben productiebedrijven met hoge klantenordercomplexiteit minder vaak productieplanning en besturingsoverleg en een meer gecentraliseerde beslissingsstructuur van klantenorderacceptatie en levertijdafgifte. Maar productiebedrijven met een hoge mate van eindproductcomplexiteit hebben juist een hogere frequentie van productie-planning en besturingsoverleg en juist een meer gedecentraliseerde beslissingsstructuur van klantenorderacceptatie en levertijdafgifte. Een andere conclusie is dat de invloed van omgevingsdynamiek op de beslissingsstructuur van productieplanning klein is. Tenslotte is een interessante uitkomst dat productiebedrijven die een hoge (financiële) bedrijfsprestatie realiseren een lage mate van klantenordercomplexiteit en een gedecentraliseerde beslissingsstructuur van klantenorderacceptatie en levertijdafgifte hebben, vergeleken met productiebedrijven die een lage (financiële) bedrijfsprestatie realiseren. Daarom stellen we dat productiebedrijven die hun productieplanning en besturingsstructuur willen decentraliseren er verstandig aan doen om eerst de klantenordercomplexiteit te reduceren. Verder vonden we dat het gebruik van een Enterprise Resource Planning systeem correleert met een meer centrale beslissingsstructuur voor productieplanning.

Op basis van de data uit deze eerste enquête hebben we in Hoofdstuk 4 de vraag beantwoord wat de invloed van omgevingsdynamiek, omgevingscomplexiteit en het gebrek aan informatie is op het gebruik van verschillende productieplanning- en besturingssystemen (i.e., kanban besturing, conventioneel planbord, spreadsheet software, ERP, en APS). We concluderen dat binnen de Nederlandse maakindustrie de invloed van omgevingsonzekerheid op het gebruik de verschillende productieplanning- en besturingssystemen gering is; complexiteit van interne routering, bijvoorbeeld, is geen voorspeller voor een bepaald type productieplanning- en besturingssysteem. Verder vonden we dat van alle gebruikte dynamiek-gerelateerde variabelen alleen productdynamiek negatief correleert met het gebruik van een APS systeem, en dat gebrek aan informatie juist leidt tot het gebruik van spreadsheetsoftware. Tenslotte is bedrijfsgrootte van belang als voorspeller voor het gebruik van een conventioneel planbord en een kanbanbesturingssysteem.

In Hoofdstuk 5 richten we ons volledig op de invloed van verschillende organisatie specifieke en innovatie gerelateerde factoren op de adoptie van een Advanced Planning & Scheduling (APS) systeem in de Nederlandse maakindustrie. Gebaseerd op een tweede survey onder Nederlandse discrete productiebedrijven, met uiteindelijk een representatieve steekproef van 136 respondenten, vonden we dat management ondersteuning, de aanschafkosten van APS systemen en de hoeveelheid verschillende eindproducten dat een productiebedrijf voert, direct van invloed is op de adoptie van een APS systeem. Verder zijn de begrippen observeerbaarheid (van de voordelen van het APS systeem), de mening van andere gebruikers en het innovatief vermogen van productiebedrijven van invloed op de adoptie van een APS systeem: productiebedrijven die hoog scoren op innovatief vermogen hechten minder waarde aan zowel de mening van andere gebruikers als de observeerbaarheid van APS systemen dan productiebedrijven die laag scoren op innovatief vermogen (en die meer onzekerheid ondervinden rondom een nieuwe technologie zoals APS). Daarnaast speelt professionaliteit op het gebied van operationeel management / logistiek een indirecte rol in de adoptie van een APS systeem.

In Hoofdstuk 6 beantwoorden we de vraag of de dominante vorm van de productiestructuur (i.e., layout), en met name de cellsgewijze en de functionele structuur, van invloed is op de adoptie van geavanceerde planning en scheduling systemen (APS): worden APS systemen vooral gebruikt door traditioneel georganiseerde discrete productiebedrijven of ook wel door productiebedrijven die georganiseerd zijn in groepen? Bovendien onderzoeken we of er een verschil is in de mate van professionaliteit (i.e., pragmatisme) op het gebied van OM/logistiek tussen productiebedrijven met een cellsgewijze layout versus productiebedrijven zonder een cellsgewijze layout. Richten productiebedrijven met een cellsgewijze layout zich met name op complexiteitsreductie en corresponderende socio-techische onderwerpen of hebben ze ook gedegen kennis en expertise ontwikkeld over recente commerciële en theoretische ontwikkelingen op het gebied van OM/logistiek en APS applicaties? Gebaseerd op de data verkregen met de tweede survey, zoals besproken in Hoofdstuk 5, vonden we dat APS systemen juist ook werden geadopteerd door productiebedrijven met een cellsgewijze layout. Dit was ook het geval voor het gebruik van ERP systemen. Verder vonden we dat productiebedrijven met een cellsgewijze layout juist een hogere mate van OM/logistiek gerelateerde professionaliteit hebben en een grotere diversiteit aan externe communicatiekanalen dan productiebedrijven die traditioneel georganiseerd zijn. Productiebedrijven die zowel APS hadden geadopteerd en in een cellsgewijze layout produceren gaven aan de beste concurrentiepositie te bezitten. Daarom stellen we dat productiebedrijven met cellsgewijze layout meer ontwikkeld zijn op het gebied van recente OM/logistieke onderwerpen dan de traditioneel georganiseerde discrete productiebedrijven.

Hoofdstuk 7 behandelt de verschillen in omgevingsonzekerheid, klantspecifieke vijandigheid en de aandacht voor specifieke strategische prioriteiten voor productiebedrijven met een cellsgewijze layout versus productiebedrijven met een functionele layout. Op basis van de data verkregen uit de eerste survey (zoals besproken in Hoofdstuk 3) concluderen we dat er geen verschillen zijn in de onzekerheidsvariabelen voor productiebedrijven met een cellsgewijze layout versus productiebedrijven met een functionele layout. Productiebedrijven met een functionele layout ondervinden wel een hogere mate van klantspecifieke vijandigheid in de zin dat klanten meer invloed uitoefenen op de product-assortiment en dat klanten meer uitwijkmogelijkheden hebben om voor andere toeleveranciers te kiezen dan bij productiebedrijven met een cellsgewijze layout. Deze bevinding komt overeen met de algemeen aanvaarde stelling dat productiebedrijven met een functionele layout met name capaciteit verkopen—ze produceren een grote mix aan producten in zeer verschillende seriegroottes. Daarentegen richten productiebedrijven met een cells-gewijze layout zich meer op kwaliteit en leverprestatie voor een beperkt assortiment.

In Hoofdstuk 8 bestuderen we of discrete productiebedrijven waarin het lijnmanagement (de ontwikkeling van) individuele competenties ondersteunt een betere (financiële) bedrijfsprestatie realiseren dan productiebedrijven waarin het lijn-management geen aandacht heeft voor individuele competenties. Bovendien onder-zoeken we of de aandacht van het lijnmanagement voor individuele competenties gerelateerd is aan de strategische focus op het begrip ‘agility’. Gebaseerd op de data verkregen met behulp van de eerste survey (zoals besproken in Hoofdstuk 3) vonden we een relatie tussen de aandacht van het lijnmanagement voor individuele competenties en (financiële) bedrijfsprestatie. Bovendien vonden we dat productie-bedrijven waarin het lijnmanagement aandacht heeft voor individuele competenties ook een hogere mate van strategische focus hebben op flexibiliteit. Dit komt overeen met de gedachte dat productieflexibiliteit een competitief voordeel kan bieden als er consistentie is tussen de omgeving, de bedrijfsstrategie, organisatiestructuur, de technologie en het ‘menselijk kapitaal’.

Hoofdstuk 9 besluit dit proefschrift met een korte overzicht van alle bevindingen. Daarnaast behandelen we (de status van) een complementair onderzoeksproject waarin een prototype productieplanning- en besturingssysteem is ontwikkeld dat specifiek geschikt is voor decentrale productieomgevingen. In dat prototype productieplanning- en besturingssysteem staat multi-agent coördinatie, resource loading en het concept van het gegeneraliseerde kanban besturingssysteem centraal, waarbij de voordelen van zowel push en pull productie worden geïntegreerd.

10 Appendix: Survey research

This appendix adopts the normative perspective on 'good survey research practices' of Malhotra and Grover [161], who identified a set of ideal survey research attributes. Malhotra and Grover [161] state that employing multi-item constructs, assessing them for content validity, purifying them through field-based pretesting, and subsequently testing theory with reliable and valid scales that are relatively free of measurement related errors may lead to more sophisticated POM studies. Flynn et al. [261] also provide an overview of the methodology that should be followed for conducting empirical research in the POM field, which include guidelines for the theoretical foundation of anyone's research, selecting a correct research design and data collection method, properly implementing the study, and finally using correct data analysis techniques for interpreting the results.

10.1 The 'what' and 'when' of survey research

In general, a survey involves the collection of information about a large group of people or a population. In this Appendix, we focus on *survey research*, which is conducted to advance scientific knowledge or develop theory. Survey research has three distinct characteristics: 1) it involves the collection of information by *asking people* for information in some structured format. Depending on the quality and cost tradeoffs involved, collection of information or data could take place using mail questionnaire, telephone interview, or face-to-face interview. Depending on the unit of analysis, the individuals surveyed could be representatives of themselves, their project, their expertise, or their organization, 2) Survey research is usually a *quantitative method* that requires standardized information to define or describe variables, or to study relationships between variables, and 3) Information is gathered *via a sample*, which is a fraction of the population, with the need to be able to generalize findings from the sample to the population. Given these three characteristics, it is easier to distinguish survey research from other field-based methods like case studies. Case studies are not usually quantitatively oriented, the variables are often not predefined, and such studies involve examination of a phenomenon in depth within their natural setting, thereby precluding any attempt at generalization.

There are two major types of survey research. The first type can be classified as '*exploratory*' and the objective is to become more familiar with a topic. The second type of survey research is 'explanatory research' that is devoted to finding causal relationships among variables. It does so from theory-based expectations on how and why variables should be related by the positive or negative direction of the relationships. Both types have generally a *cross-sectional* design in which information is collected at one point in time from a sample chosen to represent the population. In contrast, *longitudinal designs* are appropriate for studying phenomena that change over time by collecting data in the same organization at two or more points over time. In designs, *triangulation* or the use of multiple methods both qualitative and quantitative to crosscheck each other, is desirable and can enhance confidence in the findings.

Kerlinger [267] defines theory as: "a set of interrelated constructs, i.e., systems and definitions and propositions that present a systematic view of phenomena by specifying relationships among variables, with the purpose of explaining and predicting the phenomena". This definition spans two domains. One can be labeled the *theoretical domain* and the other the *operational domain*. Constructs or systems are abstractions in the theoretical domain that express similar characteristics. These constructs are 'latent' or are not directly observable or measurable [256]. Therefore, theory attempts to explain observed phenomena by systematically setting out interrelationships between constructs. However, since these constructs are latent, researchers must provide an operational definition of it that is observable. This operational definition represents a symbol or a variable to which numeric values can be assigned. The theoretical domain expresses a relationship of interest between constructs X and Y. These relationships are the propositions. The operational domain examines a corresponding relationship between the variables x and y in the operational domain. We denote these operational relationships as the hypotheses. Propositions are tested via the hypothesis in the operational domain. The results of these tests can confirm or modify the propositions, i.e., the theory. Robust theory, i.e., one that can withstand scrutiny in multiple contexts is a noble goal, but is elusive when dealing with the socio-technical systems found in most real world manufacturing and service environments.

In translating latent constructs to measurable variables, a number of sources of error can be introduced. Survey research must work toward reducing these errors through careful adherence to norms or standards. These errors can be divided into four components.

- *Measurement Error* is the error in measuring latent constructs (i.e., X to x and Y to y). Careful validation of the instrument can reduce measurement error.
- *Sampling error* is the error introduced in selecting the study population and the representativeness of the sample for the population.
- *Internal Validity Error* reflects the error introduced if other explanations rival hypothesis can explain observed relationships. In other words, does x lead to y or are there other variables that can explain the change in y?
- *Statistical Conclusion Error* reflects the probability that the null hypothesis has been correctly rejected and that mathematical relationships between hypothesized variables do exist.

10.2 Ideal survey attributes

Before we discuss the various sources of error in survey research, some general attributes discussed earlier need to be formally stated. The first deals with the *unit of analysis*. While the respondent is usually an individual, the unit that person represents must be clearly articulated at the outset and the instrumentation should consistently reflect that unit. If the individual is appropriate for the research question and is responding for himself or herself, then there is no problem. However, if the unit is the organization, and the individual chosen is low in the organizational hierarchy, bias might be introduced by having a 'functional worker' respond to organizational level variables e.g., degree of centralization of major decision making in the organization. In other words, the person(s) most knowledgeable about the construct of interest should be chosen [266]. Stated as attribute questions are as follows.

- Is the unit of analysis clearly defined for the study?
- Does the instrumentation consistently reflect that unit of analysis?
- Is the respondent chosen appropriate for the research question?

Another general attribute pertains to the notion of *triangulation* or multiple methods to better assess the variables of interest. For instance, written instrumentation (i.e., a multi-item measure), multiple respondents (more than one response per company), interviews (a series of structured open questions with organizational representatives), and objective measures (financial data), can be used to assess PMT-uncertainty faced by organizations. Clearly, such cross validation of base data enhances confidence in results and is desirable, but it could also come at a tremendous cost respecting both time and effort and may not be practical in many instances.

- Is any form of triangulation used to cross validate results?

Measurement error Measurement error represents a significant sources of error in survey research. Inappropriate measurement can be due to a number of factors including poorly worded questions, length of instrument, bias induced by method, etc. While measurement error is almost inevitable, the primary question for POM researchers is the extent to which these errors affect the findings. Fortunately, validation techniques are available to reduce measurement error. One such technique is the use of multi-item measures that can better specify the construct domain than single-items, and have higher reliability. In developing these measures, however, it is very important that the domain of the construct be well specified and that the items be generated based on this domain. This assessment of the appropriateness of the items to the domain of the construct is named *content validation*. It can be done through the theoretical basis for the items in the literature or a panel of experts who are well versed with the domain.

Content validity assessment—after items have been generated, they should be subjected to an assessment of content validity. This process will serve as a pretest, permitting the deletion of items that are deemed to be conceptually inconsistent.

Existing and preferably validated scales should be adopted wherever possible, and pretesting with practitioners in the field is highly desirable. This should involve field-based validation of the research, content validity of items, and clarity and wording problems. At this stage, actual pilot data should also be collected to purify the measure. Internal consistency or *reliability* of the items through assessment of Cronbach's Alpha [181] should be done to test whether items 'hang together'. Items that do not, can be dropped based on their item/total correlation. Low inter-item correlations can also indicate that the items are not drawn from the same domain.

Other validity testing can also be done. The most common is *construct validation*, which lies at the heart of the scientific process and addresses the question of what the instrument is actually measuring. An internally homogeneous measure might not be measuring what it is supposed to. Two components of construct validity, *convergent* and *discriminant* validity can be assessed. These collectively refer to whether the measure is similar within itself and yet sufficiently different from other measures. Confirmatory factor analysis using items from multiple measures in the research model have been used to establish construct validity. If the items for each variable load together in factor analysis but do not cross load onto other variables, there is evidence of construct validity. Based on these recommendations, the following 'ideal attributes' are proposed:

- Are multi-item variables used?
- Is content validity assessed?
- Is field-based pretesting of measures performed?
- Is reliability assessed?
- Is construct validity assessed?
- Is pilot data used for purifying measures or are existing validated measures adapted?
- Are confirmatory methods used?

Sampling error A critical element of the sampling procedure is the sample frame that is used to represent the population of interest. This frame may be inaccurate if it excludes elements that should be a part of the population or includes elements that should not. *Sample frame error* is introduced based on the representativeness of the frame to the population of interest. At the minimum, any POM survey research should describe and justify the sample frame [261]. Estimation of possible frame error bias (or lack thereof) by a comparison estimation of the probability of the target population being included in or excluded from the sample frame is desirable.

The next type of error involves *error of selection,* which involves the error introduced if the sample used for analysis is not representative of the sample frame. Ideally, random selection from the sample frame will reduce selection error. Further, response rate should be reported to indicate the extent of the sample frame polled. If the entire sample frame responds to an instrument, there is no selection error and we have a census. However, that is usually impossible in a research context. Therefore, *high response rates* and an estimation of non-response bias should be conducted. While the higher the response rate the better; response rates of under 20% are extremely undesirable [273]. All efforts should be made (i.e., incentives for respondents and multiple mailings) to maximize response rate. *Non-response bias* can then be estimated by sampling a group of non-respondents or obtaining data on them through secondary sources and comparing them with respondents on key characteristics [255]. In sum, the key questions that need to be addressed are as follows:

- Is the sample frame defined and justified?
- Is random sampling used from the sample frame?
- Is the response rate over 20%?

- Is non-response bias estimated?

Internal validity error Internal validity error addresses the question of whether differences in the dependent variable are indeed caused by the independent variable or could other variables be confounding the relationship. In experimental designs using survey research, it is possible to control extraneous effects on the dependent variable by using experimental controls or by homogenizing the sample groups. Failure or inability to do that could lead to confounding effects and erroneous conclusions. Therefore, the question can be simply stated as:

- Are attempts made to establish internal validity of the findings?

Statistical conclusion error Statistical conclusion error relates to the statistical power of tests being used [271]. A greater power implies that there is a greater probability of finding statistical relationships among variables. Low power leads to erroneous conclusions. While type I error (i.e., the probability of finding a relationship when none exists) is indicated by the significance level in statistical tests, the lack of power leads to type 2 errors (i.e., the probability of incorrectly sustaining the null hypothesis; see for instance Baroudi and Orlikowski [257] and Verma and Goodale [272]). The power of a test is directly proportional to sample size and effect size, and inversely related to p-value [270]. However, the single most important factor in establishing adequate power for a test is sample size. Sample sizes of at least 100 are desirable, although a general heuristic for multivariate analysis is at least five times the number of variables in the model. For instance, a factor analysis of 40 items should have a sample size of at least 200 [265]. In other words:

- Is there sufficient statistical power to reduce statistical conclusion error?

10.3 Statistical procedures

The analytic procedures in this thesis include the calculation of descriptive statistics, reliability analysis, factor analysis (exploratory and confirmatory), multi-item path analysis [134], and cluster analysis [262].

10.3.1 Statistical procedures for reliability analysis

Classical reliability analysis – Although most of the items in this study are Likert-type ordinal scaled variables, for which we assume that they fully represent their underlying continuous variables–i.e., we treat them as interval variables, which is quite common in the literature [134], we apply parametric univariate and multivariate procedures, if the kurtosis and the skewness of each variable is smaller than 7 respectively 2 [238]. A classical parametric procedure to study the properties of measurement scales and the items that make them up is Cronbach's alpha. Hence, reliability is operationalized as internal consistency, which is the degree of inter-correlation among the items that comprise a scale [181]. After this step, three possibilities exist. First, as most of the scales are relatively new—which indicates the exploratory nature of this chapter—a scale is accepted straightaway if it has a reasonably strong alpha value (at least .60). Second, scales with alpha values near .60 (i.e., .45 − .60) are further analyzed to determine whether alpha can be improved by the removal of some items. We proceed our analysis with care if alpha values are between .55 and .60, and we investigate the measurement of the scale in a full measurement model of all primary constructs with confirmatory factor analysis as we would like instruments that are both reliable and valid—there is, however, no reason to expect that results from validity and reliability assessments will always coincide. Nevertheless, we claim that validity is more important than reliability, unless the only goal is prediction. Third, if the scale still failed to provide alpha values >.55, the scale of the construct is discarded and the items are to be analyzed separately.

Factor analysis Construct validity measures the extent to which the items in a scale all measure the same construct. Although classical reliability theory relies on univariate statistical procedures, such as Cronbach's alpha reliability analysis, we also use factor analysis on the items if the alpha value of the scale is sufficiently large and the scale comprises four or more items. The general objective of factor analysis is to determine the underlying dimensions of data, and in so doing that, it summarizes a large number of original variables into a small number of factors (i.e., constructs). However, we may also use factor analysis to test whether items in a scale really measure the same construct.

To investigate the appropriateness of a factor analysis, we investigate the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) index, to test whether the partial correlations among variables are small. Besides, we ask for Bartlett's Test of Sphericity, a test for correlation of the items that tests the null hypothesis that the correlation matrix is an identity matrix for which factor analysis is inappropriate. If KMO > .60 and the significance level $p < .05$, then we consider factor analysis appropriate [41], and we use Maximum Likelihood with varimax rotation as our basic (exploratory) factor analysis method (i.e., a factor analysis with a rotation that provides a simple structure with uncorrelated constructs). However, we should be aware of multicollinearity and singularity—factor analysis runs into problems when variables either perfectly correlate with each other (i.e., singularity) or correlate very highly (i.e., multicollinearity). As a result, we examine the correlations and remove any item for which item correlation coefficient is larger than .9 (i.e., $r_i > .9$).

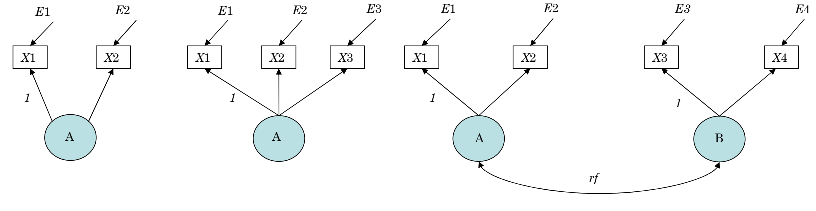
Confirmatory factor analysis (CFA) For the full measurement models of all higher-order constructs we use confirmatory factor analysis. Brynat and Yarnold [41] state that there is one major difference between exploratory and confirmatory factor analysis. Exploratory factor analysis (EFA) finds the one underlying factor model that best fits the data, while confirmatory factor analysis allows the researcher to impose a particular factor model on the data and then see how well that model explains responses to the set of measures. In other words, with EFA, the researcher lets the observed data determine the underlying factor model a posteriori (i.e., reasoning data inductively to infer a model from observed data; while in contrast, with CFA the researcher derives a factor model a priori. Hence, EFA primary represents a tool for theory building, while CFA represents a tool for theory testing.

While both procedures assume multivariate normality, there are examples in the literature of CFAs in which some or all items are items [46][135] in which it is assumed that they are items of continuous underlying factors. However, according to Kline [135] there are at least two problems when non-continuous variables are analyzed with CFA (or with hybrid SEM). First, correlations between ordinal observed variables tend to be truncated relative to correlations between the underlying continuous constructs. Second, scores on categorical or ordinal items are not normally distributed which influences the appropriateness of techniques like Maximum Likelihood, as it tends to reject correct models with fewer factors in favor of those with more factors. Note that, this is the reason to only allow variables in the analysis for which the kurtosis and the skewness is less than 7 and 2, respectively.

The two options proposed in the literature [135] are 1) to retain the ordinal items but use special statistical procedures to correct the observed covariances before they are analyzed in CFA (i.e., use polychoric, tetrachoric, or polyserial correlations, which are correlations between the continuous variables that underlie two items that are both ordinal (polychoric), both dichotomous (tetrachoric), or one continuous and the other ordinal (polyserial)). However, this procedure requires sample sizes of more than 2000 respondents to obtain reliable results [274]; there are, however, only few statistical packages available with the required functionality (e.g., EQS, PRELIS) and these software packages can handle only 20-25 variables at maximum [238]. West el al. [238] state that perhaps the only option would probably be to treat the ordinal data as continuous, estimate our model(s) by Maximum Likelihood, and use bootstrapping, if possible, to study the effects of non-normality.

Identification of CFA (adopted from Kline,* [135]*) Any CFA measurement model must meet two necessary (but insufficient) conditions to be identified: 1) the number of free parameters must be less than or equal to the number of observations (i.e., $v(v+1)/2$, where v is the number of observed variables) and every factor must have a scale. In other words, in CFA (or more general: SEM), a metric must be explicitly assigned to each unobserved construct. This is generally done by constraining a path from the construct to one of its item variables, by assigning the value of 1.0 to this path. Given this constraint, the remaining paths can then be estimated. The item selected to be constrained to 1.0 is the *reference* item. Typically, the researcher selects as the reference item the one that in factor analysis loads most heavily on the dimension represented by the construct, thereby allowing it to anchor the meaning of that dimension. Hence, the 1.0s in Figure 10-1 designate fixed loadings to set scales for constructs. Model (a) is unidentified: with two observed variables, there are three observations (i.e., 2(3)/2 = 3) but four parameters to be estimated. Model (b) is just-identified, as with three observed variables, there are three observations (i.e., 3(4)/2 = 6) and six parameters to be estimated.

CFA models that are theoretically identified are still susceptible to empirical underidentification, which occurs when data-related problems lead to non-identification rather than features of the model. If, for example, the factor loading of item X_2 on factor A of model (b) displayed in Figure 10-1 is close to zero, model (b) would, practically speaking, resemble model (a) in that both have two items, which is too few for a single-factor model. Model (c) displayed in Figure 10-1 may be empirically underidentified if the estimate of the correlation r_f between the factors A and B is close to zero. As a result, we prefer at least three items for each scale.



a) One factor, two indicators

b) One factor, three indicators

c) Two factors, each with two indicators

Figure 10-1: Identification of CFA models [135].

10.3.2 Statistical procedures for hypothesis testing

Structural Equations Modeling (SEM) The main limitations of classical multiple regression models is that one or more single-measure independent variables predict the value of only one single-measure dependent variable (i.e., $X_1,Y_1 \rightarrow Z_1$). Path analysis, which is the original SEM technique, concerns structural equations models with observed variables that can be viewed as an extension of multiple regression in which there is an ordering among measured variables (i.e., $X_1 \rightarrow Y_1 \rightarrow Z_1$). More precisely, path analysis is a special case of covariance structure analysis [134]. An advantage over classical regression analysis is that two types of non-causal relationships can be represented in path models; 1) unanalyzed associations (i.e., $X_1,\leftrightarrow X_2$) and 2) spurious associations (i.e., by specifying common causes). Furthermore, the procedure allows the researcher to assess which variables in the model have the strongest effect on the dependent variable.

Nevertheless, path analysis still has the drawback that it uses only a single measure of each construct that is inevitably susceptible to measurement error; see also Kline [135], page 189]. However, structural equations models extent classical path analysis with the integration of CFA (i.e., measurement models). Hence, it allows to analyze complex relationships between multi-item constructs as well, e.g., $X_1,X_2 \rightarrow Y_1,Y_2 \rightarrow Z$. For an introduction into SEM, we refer to Klem [134];

for more specialized work on SEM we refer to Kline [135], Bollen [259] or Jöreskog and Sörbom [267].

Two-step modeling: measurement model and path models The measurement model is that part of an SEM model that deals with the constructs and their items. A pure measurement model is a confirmatory factor analysis (CFA) model in which there is unmeasured covariance (two-headed arrows) between each possible pair of constructs, there are straight arrows from the constructs to their respective items, there are straight arrows from the error and disturbance terms to their respective variables, but there are no direct effects (straight arrows) connecting the constructs. Hence, the difference between a CFA as a measurement model and a structural equations model (i.e., a path analytic model) is that CFA estimates only unanalyzed associations (i.e., correlations) among factors, not direct causal effects. Presumed causal effects can be specified and tested with extended path analysis. However, the measurement model is evaluated like any other SEM model, using goodness of fit measures. There is no point in proceeding to the structural equations model until *the researcher* is satisfied the measurement model is valid. As a result, Kline [135] urges SEM researchers always to test the pure measurement model underlying a full structural equation model first, and if the fit of the measurement model is found acceptable, then to proceed to the second step of testing the structural equations model by comparing its fit with that of different structural equations models (i.e., with models generated by trimming or building, or with mathematically equivalent models). In this thesis, we follow Kline's [135] recommendation.

Cluster analysis Cluster analysis is a group of multivariate techniques whose primary purpose is to assemble objects (i.e., respondents), so that each respondent is similar to others in the cluster for a predetermined selection criterion, but exhibit high external (between-cluster) heterogeneity.

Analysis of differences between subpopulations The One-Way ANOVA procedure produces a one-way analysis of variance for a quantitative dependent variable by a single factor (independent) variable. Analysis of variance is used to test the null hypothesis that several means are equal. If $p < \epsilon$, with ϵ indicating the significance level, we reject the null-hypothesis and conclude that the means of the groups are significantly different. Subsequently, we analyse the relevance of the differences by means of Effect Size (ES). ES is measured in this thesis as Cohen's d [261], the difference between the means, M_1 - M_2, divided by standard deviation, σ, of either group. Cohen [261] argued that the standard deviation of either group could be used when the variances of the two groups are homogeneous. By convention the subtraction, M_1 - M_2, is done so that the difference is positive if it is in the direction of *improvement* or in the predicted direction and negative if in the direction of *deterioration* or opposite to the predicted direction.

10.3.3 Used statistical packages

In this project, we use the statistical software packages SPSS 11 and AMOS 4.0. The latter is an "…easy-to-use structural equation modeling (SEM) software, to create more realistic models than if you used standard multivariate methods or regression alone…". For an introduction to AMOS, we refer to Byrne [46].

AMOS has a specific approach to handle incomplete data as it uses the full information Maximum Likelihood estimation approach that offers several advantages over both the more common listwise and pairwise deletion approaches. However, in AMOS it is impossible to use bootstrap functionality and/or modification indices to support model respecification in case of missing values, which is a major drawback if one has ordinal data.

Used fit indexes for SEM (path analysis and CFA) Each CFA yields an overall Maximum Likelihood chi-square and an associated p value, which indicates the probability that the matrix of fitted residuals generated by the model is different from zero. In contrast to other inferential statistical tests for which significant p values represent greater accuracy of prediction, with CFA, a statistically significant chi-square indicates a model that fails to reproduce the observed data accurately (i.e., the residuals it generates are significantly different from zero). In other words, the researcher seeks a model that produces a nonsignificant *p* value, thereby striving to confirm the null hypothesis. However, as the method assumes multivariate normality, it becomes difficult to obtain non-significant *p* values if most items are ordinally scaled. In other words, because of non-normality in the underlying distribution of the input variable, and because the chi-square test of absolute model fit is sensitive to sample size, investigators often turn to various descriptive fit statistics to assess the overall fit of a model to the data. In this framework, a model may be rejected on an absolute basis, but a researcher may still claim that a given model outperforms some other baseline model, typically the independent model, by a substantial amount, as a model that is parsimonious and yet performs well in comparison to other models may be of substantial interest [135] and Byrne [46]. Many researchers who use SEM believe that with a reasonable sample size (i.e., > 200) and good approximate fit as indicated by other fit tests (e.g., NFI, TLI, RMSEA, and others discussed below), a significant chi-square is not a reason by itself to reject and modify the model; see for instance [46][135][238].

1) Chi-square fit index (χ^2): This is the most common fit test. AMOS refers to this simply as chi-square. The chi-square fit index tests the hypothesis that an unconstrained model fits the covariance/correlation matrix as well as the given model. The chi-square value should not be significant if there is a good model fit. However, a problem with this test is that the larger the sample size is, the more likely the rejection of the model will be. The chi-square fit index is also very sensitive to violations of the assumption of multivariate normality.

2) Ratio of chi-square (χ^2) to degrees of freedom (*df*) The ratio χ^2/df allows the researcher to compare the fit of alternative models, controlling for differences in complexity [41]. The more parameters a model contains, the greater the model's complexity, and, generally, the lower the chi-square (but also the lower the degrees of freedom). As this ratio decreases and approaches to zero, the fit of the given model improves. Some researchers allow values as large as 5 as an adequate fit, but conservative use calls for rejecting models with relative chi-square greater than 2 or 3 (i.e., we require $\chi^2/df < 3$).

3) Goodness of fit tests comparing the given model with an alternative model
Comparative Fit Index (CFI) also known as the Bentler Comparative Fit Index [258]. CFI compares the existing model fit with a null model which assumes the constructs in the model are uncorrelated (the "independence model"). That is, it compares the covariance matrix predicted by the model to the observed covariance matrix, and compares the null model (covariance matrix of 0's) with the observed covariance matrix, to gauge the percentage of lack of fit which is accounted for by going from the null model to the researcher's SEM model. CFI is similar in meaning to NFI (see below) but penalizes sample size. CFI varies from 0 to 1. CFI close to 1 indicates a very good fit. However, by convention, CFI should be equal to or greater than .90 to accept the model, indicating that 90% of the covariation in the data can be explained by the given model.

Normed fit index (NFI), also known as the *Bentler-Bonett normed fit index* was developed as an alternative to CFI without the chi-square assumptions. It varies from 0 to 1, with 1 indicating perfect fit. NFI reflects the proportion by which the researcher's model improves fit compared to the null model (random variables). For instance, an NFI of .50 means the researcher's model improves fit by 50% compared to the null model. By convention, NFI values below .90 indicate a need to respecify the model. Some authors have used the more liberal cutoff of .80. However, we require NFI > .90.

Tucker-Lewis index (TLI) also known as Non-Normed Fit Index (NNFI) or Non-Normed Bentler-Bonnet Index is similar to NFI, but penalizes model complexity. TLI (or NNFI) close to 1 indicates a good fit. By convention, TLI (NNFI) values below .90 indicate a need to respecify the model.

Some authors have used the more liberal cutoff of .80 but more recently, Hu and Bentler [113] have suggested TLI (NNFI) > = .95 as the cutoff for a good model fit. Hence, we require TLI > .95.

<u>4) Root Mean Square Error of Approximation (*RMSEA*)</u> Root Mean Square Error of Approximation (*RMSEA*) and its lower and upper confidence interval boundaries are known as the discrepancy per degree of freedom. It is the goodness of fit test based on predicted versus observed covariances <u>but</u> penalizing for lack of parsimony. By convention, there is good model fit if RMSEA less than or equal to .05. There is adequate fit if RMSEA is less than or equal to .08. More recently, Hu and Bentler [113] have suggested RMSEA ≤ .06 as the cutoff for a good model fit. RMSEA is a popular measure of fit, partly because it does not require comparison with a null model and thus does not require the author posit as plausible a model in which there is complete independence of the constructs as does, for instance, CFI. We require RMSEA < .065 for good fit and .1 > RMSEA > .065 for adequate fit.

10.4 EFA Factors

Construct	Items
F1: customer order complexity	number of orders per month (INV)
α = .7051	type of orders
	size of customer orders
F2: information deficiency	information about the products
α = .7917	information about the processing times
	information about material availability
	information about available operator capacity
	information about available machine capacity
F3: size	turnover
α = .7507	number of employees
	number of production related managers
	number of employees with at least a bachelor degree in logistics
F5: end-product change	rate of change of the number of end products
α = .7164	rate of change of the number of different modules
	rate of change of the number of products in family
F9: end-product complexity	number of product families
α = .6003	number of variants per product family
	number of modules to build end products with
	number of different end-products
F10: supplier complexity	number of suppliers
α = .5434	number of supplied parts and components
	number of production steps subcontracted
F11: component and part change	rate of change of the number of supplied parts on stock
α = .5256	rate of change of the number of procured and subcontracted parts
	rate of change of the number of customer-specific parts in end-products
F12: delivery time complexity	frequency of rush orders
α = .6187	delivery time (INV)
F13: customer order change	rate of change of the number of orders per month
α = .5866	rate of change of the size of customer orders
F14: route complexity	entanglement of departments
α = .5684	number of different types of machines in a department
	number of production steps in the route
	average utilization levels
	entanglement of machines
APS familiarity	We are familiar with advanced planning techniques
α = .6706	We are familiar with the working, advantages and disadvantages of APS
	Within our company there is an APS specialist

Table 10-1: EFA factors.

10.5 First survey - questionnaire

No.	Question	Scale	Answering options
	General information		
1	The sector our firm operates in:	Nominal	Basic metals and fabricated metal products / machinery / textile- and leather products / electronic equipment and apparatus / transport devices / products of wood and furniture/ construction materials and glass / paper and paper products / other.
2	The (financial) turnover of our firm in 2001 was:	Ordinal	1,000,000 – €3,000,000 / €3,000,001 – €10,000,000 / €10,000,001 – €25,000,000 / more than €25,000,000
3	The market share of our firm for major products in 2001 was:	Ordinal	1–10% / 11–25% / 26–50% / 51–80% / 81–100% / unknown
4	The return-on-investments at our firm in 2001 was:	Ordinal	0–5% / 6–10% / 11– 20% / 21–35% / more than 35%
5	The return-on-sales at our firm in 2001 was:	Ordinal	Less than 0% / 0–5% / 6–15% / 16– 30% / more than 30%
6	The growth of turnover at our firm over the past five years was:	Ordinal	Less than 0% / 0–5% / 6–10% / 11– 25% / more than 25% / unknown
7	The total number of employees in our firm is:	Ordinal	Less than 20 / 20 – 49 / 50 – 99 / 100 – 249 / 250 or more
8	The maximum number of different production locations controlled by the same Master Planning is		1 / 2 / 3/ 4/ more than 4
9	The number of different production departments in our firm is:	Ordinal	1 / 2 or 3 / 4 – 6 / 7 – 10 / more than 10
10	The number of production related managers in our firm is:	Ordinal	1 or 2 / 3 or 4 / 5 – 8 / 9 – 12 / more than 12
11	The number of employees with at least a bachelor's degree in logistics in our firm is:	Ordinal	0 / 1 – 3 / 4 – 8 / 9 – 15 / more than 15
12	In our firm there is a planning/logistics department	Dichotomous	Yes / no
13	In our firm there is an IT department	Dichotomous	Yes / no
	Market/ customers		
14	The average size of customer orders at our firm is:	Ordinal	1 piece / 2 – 10 pieces / 11 – 25 pieces / 26 – 50 pieces / more than 50 pieces
15	The average number of orders our firm processes in a month is:	Ordinal	Less than 1 per month / 1 – 10 / 11 – 50 / 51 – 100 / more than 100
16	Orders placed at our firm can be characterized as	Ordinal	Only one-off unique orders / mostly one-off unique orders / as much one-off unique orders as repetitive orders / mostly repetitive orders / only repetitive orders / unknown
17	The percentage of seasonal products in our product mix is:	Ordinal	0 / 1 – 25 / 26 – 50 / 50 – 90 / more than 90% / unknown
18	The average delivery lead time of our products that make up about 80% of the turnover is	Ordinal	1 day / 1 week / 2 – 3 weeks / 1 – 2 months / more than 2 months
19	The frequency of rush orders at our firm is	Ordinal	Every day / once per week / once in two weeks / once a month / less than once a month
20	The influence of customers on our product mix is:	Ordinal	Very small / small / neither small nor large / large / very large
21	The extent to which our customers have vendor switching possibilities is:	Ordinal	Very small / small / neither small nor large / large / very large
22	The predictability of demand of specific products at our firm is:	Ordinal	Very small / small / neither small nor large / large / very large
23	The markets in which our firm operates can be characterized as :	Nominal	A shrinking market / a stable market / an expanding market / a fluctuating market / unknown
	Products		
24	The average number of product families our firms offers is:	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 20 / more than 20
25	The average number of end-product / variants in these product families is:	Ordinal	1 – 10 / 11 – 20 / 21 – 50 / 51 – 100 / more than 100

26	The average number of standard modules to manufacture end-products with is:	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 15 / more than 15
27	The average number of end-products our firm offers is	Ordinal	1 – 10 / 11 – 50 / 51 – 100 / 101 – 500 / more than 500
	Operations Technology		
28	The production strategy (i.e. customer-order decoupling point) of our firm is:	Nominal	Engineer-to-order / make-to-order / assemble-to-order / make-to-stock / other
29	The dominant type of manufacturing layout in our firm is:	Nominal	Process layout (i.e., a job shop), product layout (i.e., a flow shop), fixed position layout (i.e., project layout – the product stays in place) / group or cellular layout
30	If the dominant type of layout is a job shop: how many different production routings are there on average	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 15 / more than 15
31	If the dominant type of layout is a flow shop: how many different production lines are there on average	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 15 / more than 15
32	If the dominant type of layout is a cellular/group layout: how many different cells / groups are there on average	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 15 / more than 15
33	If your firm has a cellular layout or you have multiple production departments: to what extent are these cells or departments entangled	Ordinal	Very much entanglement between cells or departments / much entanglement / some entanglement / almost no entanglement / no entanglement at all
34	What is the average number of levels in the Bill-of-Materials in your main end-products	Ordinal	1 / 2 – 5 / 6 – 10 / 11 – 15 / more than 15
35	How many different components and parts are in your main end-products	Ordinal	1 – 10 / 11 – 50 / 51 – 100 / 101 – 500 / more than 500
36	On average, how many different types of machines does your firm has in the dominant production department?	Ordinal	1 / 2 or 3 / 4 – 6 / 7 – 10 / more than 10
37	On average, how many process steps does main product routings have?	Ordinal	1 – 5 / 6 – 10 / 11 – 25 / 16 – 50 / more than 50
38	To what extent are different process steps entangled with each other	Ordinal	Very much entanglement between cells or departments / much entanglement / some entanglement / almost no entanglement / no entanglement at all
39	What is the average utilization rate of important manchines in your dominant production department	Ordinal	Less than 50% / 50 – 70% / 71 – 85% / 86 – 95% / more than 95%
40	To what extent are different machines in your dominant department entangled	Ordinal	Very much entanglement between cells or departments / much entanglement / some entanglement / almost no entanglement / no entanglement at all
41	To what extent are different departments in your plant entangled	Ordinal	Very much entanglement between cells or departments / much entanglement / some entanglement / almost no entanglement / no entanglement at all
42	To what extent is your workforce multi-skilled	Ordinal	Very much multi-skilled./ much multi-skilled / ?? / ?? / no multi-skilled workforce
	Information deficiency		
43a	Information availability just before the start of production of the demanded product structure	Ordinal	No information available / some of the required information available / much of the required information available / almost all of the required information available / all required information available
43b	Information availability just before the start of production of the processing times	Ordinal	No information available / some of the required information available / much of the required information available / almost all of the required information available / all required information available
43c	Information availability just before the start of production of the material availability	Ordinal	No information available / some of the required information available / much of the required information available / almost all of the required information available / all required information available
43d	Information availability just before the start of production of the available operator capacity	Ordinal	No information available / some of the required information available / much of the required information available / almost all of the required information available / all required information available
43e	Information availability just before the start of production of the available machine capacity	Ordinal	No information available / some of the required information available / much of the required information available / almost all of the required information available / all required information available
	The use of Advanced Manufacturing Technology		
44a	In our firm we use CNC control	Dichotomous	Yes / no

44b	In our firm we use a FMS system	Dichotomous	Yes / no
44c	In our firm we use CAD/E/M (Computer Aided Design/Engineering of Manufacturing)	Dichotomous	Yes / no
44d	In our firm we use Robots (welding robot, pick-& place robot, etc.)	Dichotomous	Yes / no
44e	In our firm we use JIT/ Lean (Just in Time & Lean manufacturing	Dichotomous	Yes / no
44f	In our firm we use 6σ (Six Sigma)	Dichotomous	Yes / no
44g	In our firm we use Kanban (kanban pull control)	Dichotomous	Yes / no
44h	In our firm we use TQM/SPC (Total Quality Management & Statistical Process Control)	Dichotomous	Yes / no
44i	In our firm we use 5S (Five S) method of workplace organization	Dichotomous	Yes / no
	Suppliers		
45	The average number of suppliers of our firm is (excluded suppliers of disposables):	Ordinal	1 – 5 / 6 – 10 / 11 – 25 / 26 – 100 / more than 100
46	The average number of supplied parts and components as percentage of the total number of parts in dominant end-products is:	Ordinal	1 – 5% / 6 – 10% / 11 – 20% / 21 – 50% / more than 50%
47	The delivery reliability of suppliers of critical parts is		0 – 40% / 41 – 65% / 66 – 85% / 86 – 90% / more than 90%
48	To what extent are production steps in the route subcontracted	Ordinal	
	Rate of change		
49	To what extent does the size of customer orders in hand change:	Ordinal	Never/ not often / sometimes / regularly / many times
50	To what extent does the number of end-products change:	Ordinal	Never/ not often / sometimes / regularly / many times
51	To what extent does the number of variants in a product family	Ordinal	Never/ not often / sometimes / regularly / many times
52	To what extent does the number of different standard modules to build end-products with change:	Ordinal	Never/ not often / sometimes / regularly / many times
53	To what extent do production routings change during production:	Ordinal	Never/ not often / sometimes / regularly / many times
54	To what extent does the required number of process steps to make end-products change (not necessarily during actual production):	Ordinal	Never/ not often / sometimes / regularly / many times
55	To what extent does the number of customer-specific parts of end-products change:	Ordinal	Never/ not often / sometimes / regularly / many times
56	To what extent does the number of outsourced parts and components change:	Ordinal	Never/ not often / sometimes / regularly / many times
57	To what extent does the number of parts and components kept in stocks change:	Ordinal	Never/ not often / sometimes / regularly / many times
58	To what extent does the average size of customer orders change:	Ordinal	Never/ not often / sometimes / regularly / many times
59	To what extent does the average number of orders processed per month change:	Ordinal	Never/ not often / sometimes / regularly / many times
	Strategic priorities		
60	At our firm, we consider the strategic importance of high product quality as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
61	At our firm, we consider the strategic importance of high product reliability as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
62	At our firm, we consider the strategic importance of quick product renewal and innovations as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
63	At our firm, we consider the strategic importance of quick supply as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
64	At our firm, we consider the strategic importance of low prices as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
65	At our firm, we consider the strategic importance of high delivery reliability as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
66	At our firm, we consider the strategic importance of high volume flexibility as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
67	At our firm, we consider the strategic importance of high product-mix flexibility as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
68	At our firm, we consider the strategic importance of short lead-times as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
69	At our firm, we consider the strategic importance of high utilization rates as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
70	At our firm, we consider the strategic importance of advanced technology as	Ordinal	Unimportant (no strategic content) / order qualifier (strategic prerequisite) / order winner (strategic priority)
	Agreement with statements		

71	For our firm, quality is a strategic priority	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
72	For our firm, short lead-times is a strategic priority	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
73	For our firm, high delivery reliability is a strategic priority	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
74	For our firm, high efficiency is a strategic priority	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
75	For our firm, manufacturing in small batch sized is a strategic priority	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
76	At our firm, we closely monitor technological developments	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
77	It is important that operators keep their work place neat	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
78	It is important that operators quickly signal problems	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
79	It is important that operators solve problems independently	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
80	It is important that operators show initiative	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
81	It is important that operators are willing to change	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
82	It is important that operators independently collect information and seek for knowledge		Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
83	It is important that operators independently transfer information and knowledge		Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
84	It is important that operators independently gain process related knowledge	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
85	It is important that operators independently gain process related knowledge	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
86	I think our operators organize their workplace neat	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
87	I think our operators show initiative	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
88	I think our operators are sensitive for stress	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
89	I think that at our firm lead-times are too long	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
90	I think that at our firm utilization rates are too low	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
91	I think that at our firm delivery reliability is too low	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
92	Our firm uses production cells, groups or teams	Dichotomous	Yes / no
93	Our firm invests a lot in quality improvement programs	Dichotomous	Yes / no
94	Our firm values participation of operators on tactical and strategic issues	Dichotomous	Yes / no
95	Our firm has standard work processes	Dichotomous	Yes / no
96	Our firm gains competitive advantage with firm-specific work processes	Dichotomous	Yes / no
97	Our firm gains competitive advantage with specific skills of staff	Dichotomous	Yes / no
98	Our firm gains competitive advantage with specific skills of operators	Dichotomous	Yes / no
99	Our firm distinguishes one or more core competencies	Dichotomous	Yes / no
100	Our firm is able to supply products fast by the use of core competencies	Dichotomous	Yes / no
101	Our firm stimulates continuous improvement	Dichotomous	Yes / no
102	Our firms makes use of Business Process Reengineering	Dichotomous	Yes / no
103	Our firm has a lot of customer complaints for late deliveries	Dichotomous	Yes / no
104	Our firm conducted quality improvement programs in the past	Dichotomous	Yes / no
105	Our firm conducted Total Preventive Maintenance programs and training for operators	Dichotomous	Yes / no
	Locus of control		.
106a	Indicate the decision level of order acceptance	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by an operator.
106b	Indicate the decision level of due date quoting	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral 118on the shop floor by an operator.
106c	Indicate the decision level of capacity planning of departments	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by an operator.
106d	Indicate the decision level of sequencing	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by

			an operator.
106e	Indicate the decision level of resource loading	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by an operator.
106f	Indicate the decision level of dispatching	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by an operator.
106g	Indicate the decision level of material availability check	Ordinal	central by management / central by a staff department / decentral by a production leader or teamleader / decentral on the shop floor by an operator.
	Frequency of planning meetings		.
107a	Indicate the frequency of planning meetings between managers on production management level	Ordinal	once a month / once per two weeks / once a week / twice a week / every day
107b	Indicate the frequency of planning meetings between production management and team leader/sector manager	Ordinal	once a month / once per two weeks / once a week / twice a week / every day
107c	Indicate the frequency of planning meetings between planner(s) and representatives of groups or functional departments	Ordinal	once a month / once per two weeks / once a week / twice a week / every day
107d	Indicate the frequency of planning meetings between production manager and planner(s)	Ordinal	once a month / once per two weeks / once a week / twice a week / every day
	Use of production planning and control tools		
108a	Our firm uses a conventional plan board	Dichotomous	Yes / no
108b	Our firm uses spreadsheets	Dichotomous	Yes / no
108c	Our firm uses Enterprise Resources Planning (& please indicate the vendor's name)	Dichotomous	Yes / no
108d	Our firm uses Advanced Planning and Scheduling (& please indicate the vendor's name)	Dichotomous	Yes / no
	Performance		
109	At our firm the number of on-time orders as a percentage of the total number or orders last year was	Ordinal	Less than 25% / 25 – 50% / 51 – 75% / 76 – 95% / 96 – 100%
110	The quality our firms offers is:	Ordinal	Excellent / good / reasonable / moderate / bad
111	The average processing time as percentage of the average total lead-time is:	Ordinal	0 – 10% / 11 – 20% / 21 – 40% / 41 – 60% / higher than 60%

10.6 Second survey - questionnaire

No.	Question	Scale	Answering options
	General information		
1	The sector our firm operates in:	Nominal	Metals / machine / chemical / textile- and leather products / electronic apparatus / transport devices / wood / construction materials and glass / furniture / paper and paper products / other.
2	The (financial) turnover of our firm is:	Ordinal	Less than €500,000 / €500,000 – €1,000,000 / €1,000,001 – €5,000,000 / €5,000,001 – €15,000,000 / more than €15,000,000
3	The number of different departments in our firm is:	Ordinal	1 / 2 or 3 / 4 – 6 / 7 – 10 / more than 10
4	The total number of employees in our firm is:	Ordinal	Less than 20 / 20 – 49 / 50 – 99 / 100 – 199 / 200 – 499 / 500 or more
5	The number of employees with a bachelor degree in logistics in our firm is:	Ordinal	0 / 1 / 2 or 3 / 4 – 8 / more than 8
6	The number of employees with a master's degree in logistics in our firm is:	Ordinal	0 / 1 / 2 or 3 / 4 – 8 / more than 8
7	The number of managers in our firm is:	Ordinal	1 or 2 / 3 or 4 / 5 – 8 / 9 – 12 / more than 12
8	In our firm there is a planning/logistics department	Dichotomous	Yes / no
9	In our firm there is an IT department	Dichotomous	Yes / no
10	In our firm there is an R&D department	Dichotomous	Yes / no
	Market		
11	The average number of customers of our firm is:	Ordinal	1 – 10 / 11 – 20 / 21 – 50 / 51 – 100 / more than 100
12	The average number of orders our firm processes in a month is:	Ordinal	1 – 5 / 6 – 10 / 11 – 50 / 51 – 100 / more than 100
13	The distribution of the orders is:	Ordinal	Only one-off unique orders / mostly one-off unique orders / as much one-off unique orders as repetitive orders / mostly repetitive orders / only repetitive orders / unknown
14	The average number of production related suppliers to our firm is:	Ordinal	1 – 5 / 6 – 10 / 11 – 25 / 26 – 50 / more than 50
15	The average number of (direct) competitors of our firm in our market is:	Ordinal	0 / 1 – 5 / 6 – 10 / 11 – 20 / more than 20
16	The competitive position of our form in our main markets is:	Ordinal	Market leader / top 5 / top 10 / top 20 / lower than top 20 / unknown
17	The markets in which our firm operates can be characterized as :	Nominal	A srinking market / a stable market / an expanding market / a fluctuating market / unknown
	Production process		
18	The number of distinct production locations of our firm is:	Ordinal	1 / 2 / 3 / 4 / more than 4
19	The dominant type of manufacturing layout in our firm is:	Nominal	Process layout (i.e., a job shop), product layout (i.e., a flow shop), fixed position layout (i.e., project layout – the product stays in place) / group or cellular layout
20	The average number of different end-products our firm offers is:	Ordinal	1 – 10 / 11 – 20 / 21 – 50 / 51 – 100 / more than 100
21	The extent to which our firm manufactures standard or customer-specific products is:	Ordinal	Completely customer specific / there are customer specific variations / standard products with standard variations / completely standard products
22	The production strategy (i.e. customer-order decoupling point) of our firm is:	Ordinal	Engineer-to-order / make-to-order / assemble-to-order / make-to-stock / other
	Planning		
23	The number of weeks for which the production planning is made is (i.e., planning horizon):	Ordinal	0 – 1 week / 2 – 4 weeks / 5 – 8 weeks / 9 – 16 weeks / more than 16 weeks / unkown
24	The frequency of making a production plan is:	Ordinal	Daily / weekly / once in two weeks / once a month / less than once a month
25	At our firm we use an Enterprise Resources Planning (ERP) system	Dichotomous	Yes / no
26	The vendor of our Enterprise Resources Planning (ERP) system is:	Open question	
27	At our firm we use an Advanced Planning & Scheduling (APS) system, or we are currently	Dichotomous	Yes / no

	implementing one:		
28	The vendor of our Advanced Planning & Scheduling (APS) system is:	Open question	
29	The number of departments using an APS system is:	Ordinal	1 / 2 / 3 / 4 / more than 4
30	The average number of people in our firm that uses an APS system is:	Ordinal	1/ 2 or 3 / 4 − 6 / 7 − 10 / more than 100
31	At our firm we use all functionalities of an APS system	Ordinal	Strongly agree / agree / neither agree nor disagree / disagree / strongly disagree
32	Which modules of an APS system are used within your firm? (multiple answers allowed)	Nominal	Strategic network planning / Master planning / Demand planning / Demand fulfillment & Available-to-Promise / Distribution planning / Transportation planning / production planning & scheduling
33	Which modules of an APS system have been most advantageous for your firm? (multiple answers allowed)	Nominal	Strategic network planning / Master planning / Demand planning / Demand fulfillment & Available-to-Promise / Distribution planning / Transportation planning / production planning & scheduling
34	At our firm we have the intention to adopt an APS system in the near future	Dichotomous	Yes / no
35	The available budget to buy and implement an APS system is:	Ordinal	€ 0 / €1 − €25,000 / €25,001 − €50,000 / €50,001 − €100,000 / more than €100,000
36	Which modules of an APS system will your firm use in the future? (multiple answers allowed)	Nominal	Strategic network planning / Master planning / Demand planning / Demand fulfillment & Available-to-Promise / Distribution planning / Transportation planning / production planning & scheduling
	Arguments for APS adoption		
37	Purchase cost of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
38	Implementation cost of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
39	The possibility to experiment with an APS system before purchasing	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
40	The possibility of step-wise implementation of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
41	The ease to understand an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
42	The ease to use an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
43	The degree of compatibility of an APS system with the existing firm's culture	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
44	The degree of compatibility of an APS system with the current way of planning	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
45	The degree to which an APS system can be integrated with present ERP or other business administration software	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
46	The ease and agility of generating a plan with an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
47	Reduction in throughput time by implementation and use of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
48	Increase in delivery reliability by the use of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
49	Reduction in inventory by the use of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
50	Increase in the utilization rates by the use of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
51	Reduction in production costs by the use of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
52	The feasibility of production plans created with an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
53	The ease to demonstrate advantages of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
54	The ease to demonstrate results of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
55	The ease to adapt an APS system to changing circumstances	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
56	The possibility to run what-if analysis with the help of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
57	The possibility to (manually) adapt the results generated by an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
58	Other user's opinions about an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
59	Vendor support during the implementation of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
60	The offering of training programs by the vendor of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
61	Familiarity with the vendor of an APS system	Ordinal	Very unimportant / unimportant / neither unimportant, nor important / important / very important
	Agreement with statements		
62	The management of our firm has a positive attitude towards innovations	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
63	Employees of our firm frequently visit seminars on production and logistics	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree

64	Employees of our firm frequently read production and logistics literature	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
65	Employees of our firm frequently attend logistics training	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
66	At our firm everyone can bring-up ideas for innovations	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
67	In our firm the communication between departments is good	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
68	In our firm we are familiar with advanced planning techniques	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
69	In our firm we are familiar with the working, advantages and disadvantages of APS	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
70	In our firm there is an APS specialist	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
71	In our firm we frequently implemented new applications/ innovations	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
72	In our firm the implementation of an innovation is generally successful	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
73	The setup and operation times in production are precisely known	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
74	Before the use of an APS system we had to adapt and change plans frequently	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
75	For our firm, customer demand is well predictable	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
76	The rate of change in customer demand is high	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree
77	Our firm frequently hires external logistics consultants	Ordinal	Totally disagree / disagree / neither disagree, nor agree / agree / totally agree

Figure 10-2: Distribution of sectors compared for early and late respondents.

Figure 10-3: Distribution of number of employees compared for early and late respondents.

Figure 10-4: Distribution of turnover compared for early and late respondents.

Constructs		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
customer order complexity (F1)	L	2.45***	2.93***	3.31**			3.41***		3.66***	3.25**	3.00***	3.06***	3.56***			
	H	3.90***	3.46***	3.04**			3.02***		2.89***	2.97**	3.42***	3.44***	2.81***			
	T	3.19***	3.18***	3.18**			3.20***		3.18***	3.10**	3.19***	3.23***	3.17***			
information deficiency (F2)	L	1.69***	1.41***									1.82**	1.99**			
	H	2.11***	2.42***									2.01**	1.79**			
	T	1.90***	1.90***									1.91**	1.88**			
size (F3)	L		3.39*	2.55***							3.15**					3.07***
	H		3.15*	4.05***							3.40**					3.44***
	T		3.27*	3.26***							3.26**					3.27***
planning decisions (F4)	L				2.31***			2.98**	2.71**							
	H				3.33***			2.76**	2.93**							
	T				2.86***			2.86**	2.85**							
end-product change (F5)	L					2.57***				2.97*		2.87***		2.93***	3.04*	
	H					3.94***				3.22*		3.50***		3.32***	3.26*	
	T					3.14***				3.10*		3.15***		3.15***	3.15*	
financial performance (F6)	L						1.69***		2.26*							
	H						3.03***		2.51*							
	T						2.42***		2.42*							
freq. of prod. planning and control consult. (F7)	L	3.78**						2.93***		3.48**			3.56*			
	H	3.54**						4.32***		3.76**			3.77*			
	T	3.66**						3.67***		3.63**			3.66*			
COP decisions decentrality (F8)	L	2.29***			1.89***		1.94*		1.31***	1.92***		2.18***	1.79***		2.17*	
	H	1.79***			2.21***		2.15*		2.49***	2.25***		1.89***	2.14***		2.01*	
	T	2.04***			2.06***		2.05*		2.07***	2.08***		2.05***	2.01***		2.09*	
end-product complexity (F9)	L	3.34**				2.97**		2.99**	2.78***	2.16***			2.83***	2.88***		
	H	2.95**				3.43**		3.36**	3.35***	4.11***			3.56***	3.40***		
	T	3.16**				3.16**		3.18**	3.16***	3.18***			3.22***	3.17***		
supplier complexity (F10)	L	2.76***		2.86**				3.23*			2.19***					
	H	3.22***		3.17**				2.94*			4.02***					
	T	2.99***		3.01**				3.01*			3.01***					
component and part change (F11)	L	2.99**	3.02*			2.85***			3.36***		3.01**	2.47***		2.87***	2.95**	
	H	3.28**	3.24*			3.55***			2.99***		3.28**	3.95***		3.30***	3.29**	
	T	3.14**	3.13*			3.14***			3.13***		3.13**	3.13***		3.10***	3.13**	
delivery time complexity (F12)	L	3.64***	3.29**					2.95*	2.69***	2.88***	3.25*		2.23***			
	H	2.62***	2.97**					3.22*	3.35***	3.42***	2.98*		3.96***			
	T	3.13***	3.14**					3.09*	3.13***	3.17***	3.13*		3.13***			
customer order change (F13)	L				3.60**	3.59***				3.58***		3.59***	3.67*	3.04***		3.90**
	H				3.90**	4.04***				3.93***		3.99***	3.88*	4.37***		3.65**
	T				3.76**	3.78***				3.76***		3.76***	3.78*	3.77***		3.77**
route change (F14)	L									2.34*		2.27***	2.49*	2.26**	1.81***	2.30*
	H									2.54*		2.55***	2.29*	2.48**	2.93***	2.50*
	T									2.45*		2.39***	2.38*	2.38**	2.40***	2.41*
route complexity (F15)	L		3.83***	2.88**									3.09**			2.30***
	H		4.21***	3.13**									2.85**			3.58***
	T		4.02***	3.00**									2.97**			2.99***

Table 10-2: **Differences in means on factors obtained from EFA for respondents with high/low scores on the factors.**

* significant at $p < .1$, ** significant at $p < .05$, *** significant at $p < .01$ (2-tailed).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
Order Complexity (F1)	–														
Information Availability (F2)	0,335 ***	–													
Company Size (F3)	− 0,105	− 0,167**	–												
Detailed Planning Decisions (F4)	− 0,078	0,141**	0,051	–											
End-Product Change (F5)	0,16**	− 0,013	0,115	− 0,023	–										
Financial Performance (F6)	− 0,178**	0,082	0,098	0,039	− 0,084	–									
Management Meeting Frequency (F7)	− 0,158**	− 0,08	0,078	− 0,147*	0,05	− 0,028	–								
COP Decisions Centrality (F8)	− 0,451***	− 0,081	0	0,323***	− 0,12	0,066	− 0,042	–							
End-Product Complexity (F9)	− 0,217***	− 0,114	0,133*	− 0,001	0,188**	0,02	0,153	0,291***	–						
Supplier Complexity (F10)	0,277***	0,006	0,23***	0,116	0,154**	0,026	− 0,141*	− 0,069	0,039	–					
Component & Part Change (F11)	0,184**	0,137*	− 0,052	0,006	0,457***	− 0,058	− 0,048	− 0,223 (181)***	0,125	0,121	–				
Delivery Time Complexity (F12)	− 0,57***	− 0,166**	− 0,04	0,01	0,053	0,048	0,175**	0,312***	0,362***	− 0,139*	0,01	–			
Order Change (F13)	0,057)	− 0,064	0,094	0,147**	0,267***	− 0,053	− 0,072	− 0,022	0,231***	0,033	0,289***	0,092	–		
Route Change (F14)	0,099	0,138*	0,045	− 0,001	0,095	0,001	0,022	− 0,101	0,141*	− 0,011	0,26***	− 0,134*	0,109	–	
Route Complexity (F15)	0,037	− 0,047	0,303	− 0,019	− 0,027	0,138*	0,117	− 0,085	0,052	0,043	− 0,084	− 0,178**	− 0,2***	0,077	–
Aggregate Route Complexity (F18)	0,22***	0,185**	− 0,107	− 0,007	0,074	− 0,034	0,09	− 0,161*	− 0,106	− 0,007	0,038	− 0,235***	− 0,051	− 0,063	0,229***

Table 10-3: Factor correlation matrix.

10.7 References (continued)

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11 Appendix: MPX base-case data

Products	Comment	End Demans	Lot Size
Impeller	5053-131-001-1LC350	114	5
Wheelturbine	3504752-2BR700	276	10
Wheel	361655-2ATS	92	10
Carrier Assy	361677-1ATS	93	10
Fan	203707-1ATS	412	25
Shaft ATS	361686-921ATS	72	20
Impeller Rotor.CentrDriven	3822558-2LC400	31	5
Body Assy	3173329-3ATS	101	10
Housing Exhaust ATS	3501664-1ATS	73	10
Housing Assy	362494-1ATS	95	10
Housing Bearing Inlet	3827459-1LC400	27	10
Shielding Flange	33207890LC350Schil3	83	10
Shaft Drive	361686-4ATS	110	10
Diffuser	2331202120	90	15
Diffuser Compressor	3827470-1LC400	21	10
Back Shroud Assy	331208000LC350	129	10
Nozzle	203703-2ECS	37	10
Diffuser Assy	5053-183-001-501LC350	112	10
Housing IGV LC400	3827481-1	24	10
Casing IGV LC350	331208260	102	10
Backshroud Dr Compr Housing	3827471-1	28	5
Body Assy Actuator	858462-5	15	20
Body Assy Valve	3173653-1	72	15
Body Valve	3178172-1	18	20
Body Valve2	118543-4	78	15
Centr. Impeller (rep)	5053-131-001-1/RO	38	10
Exducer	203485-5	144	25
Flange	2331200460	99	20
Housing Compressor Scroll	3827467-2	28	10
Housing Inlet LC350	5053-176-001-501LC350	104	10
Impeller Shroud	331207840LC350	131	10
Plate	3827470-1/FN3	37	10
Plate Vane	3827470-1/FN2	35	10
Scroll LC350	5053-181-001-501	83	10
Wheel Turbine2	203342-2	128	25
ACM Wheel 1	204829-13	46	10
ACM Wheel 2	204829-9	155	10
ACM Wheel 3	204837-1	39	10
ACM Impeller 1	2205358-1	37	10
ACM Impeller 2	2205466-1	41	10
ACM Impeller 3	2205467-1	45	10
ACM Ring Nozzle	681567-1	124	10
ACM Nozzle	681568-1	81	10
Shaft3	33201830LC350	81	10
Shaft Tie LC400	3822562-1	10	10
Body Valve BR700	3181016-2BR700	260	10
Body Valve2 BR700	3179460	33	10
Housing Exhaust BR700	3504749-1BR700	302	15

Table 11-1: Parts and corresponding demand in 2001 (base-case).

Equipment Name	MTTF	MTTR	Setup	Run	Varbility	Labor	Overtime
Dixi 120.48	1	0	1	1	1	DixiPloeg	0
Boley 120.21	1	0	1	1	1	EmagPloeg	-50
Spinner 120.60	1	0	1	1	1	EmagPloeg	-50
Emag6 120.45	1	0	1	1	1	EmagPloeg	0
Hermle 120.62	1	0	1	1	1	DixiPloeg	0
Mori Seiki 120.07	1	0	1	1	1	DixiPloeg	0
Ov_test 300.70	1	0	1	1	1	Balanceren	-50
Bal 298.00	1	0	1	1	1	Balanceren	-50
Jung 120.50	1	0	1	1	1	SlijpPloeg	-50
Tech 120.44	1	0	1	1	1	SlijpPloeg	-50
Kellenb 120.19	1	0	1	1	1	SlijpPloeg	0
Wahli 1_2	1	0	1	1	1	WahliPloeg	0
Wahli_3 120.38	1	0	1	1	1	WahliPloeg	-50
Fehlm 120.32	1	0	1	1	1	EmagPloeg	-50
Reinigen	1	0	1	1	1	None	0
Uitbesteden	1	0	1	1	1	None	0
Broachmach	1	0	1	1	1	None	-50
Emag8OntbrPlaats	1	0	1	1	1	Emag8Ploeg	-50
Emag8	1	0	1	1	1	Emag8Ploeg	0
Weiler	1	0	1	1	1	WeilerPloeg	-50
Deckel	1	0	1	1	1	EmagPloeg	-50

Table 11-2: Equipments in 2001 (base-case).

LaborDesc	Size	Setup	Run	Varbility	LabComment	% absence	Overtime
None	-1	1	1	1		0	0
DixiPloeg	1	1	1	1	2 men in 2 shifts	20	0
EmagPloeg	1	1	1	1	1 men in dayshift + Karel 1 day a week	20	-40
SlijpPloeg	1	1	1	1	2 men in 2 shifts	20	0
WahliPloeg	2	1	1	1	4 men in 2 shifts	20	0
Emag8Ploeg	1	1	1	1	2 men in 2 shifts	20	0
Balanceren	1	1	1	1	1 men in dayshift	20	-50
WeilerPloeg	1	1	1	1	1 men in dayshift	20	-50

Table 11-3: Labor groups in 2001 (base-case).

Table 11-4: (Preferred) Main routings of parts in 2001 (base-case).

OpID	ProdFore	OpNam	OpNum	% assigned	Eq Setup Time	Eq Run Time	Lab Setup Time	Lab Run Time	Parts	Equip.	eqRunLot
1	1	Dock	0	100	0	0	0	0	Impeller	None	0
2	1	Stock	9999	100	0	0	0	0	Impeller	None	0
3	1	Scrap	10000	100	0	0	0	0	Impeller	None	0
4	1	Frezen	10	100	120	1320	120	660	Impeller	Dixi 120.48	0
5	1	Draaien	20	100	175	44	175	44	Impeller	Emag6 120.45	0
6	1	Slijpen	30	100	441	63	441	63	Impeller	Kellenb 120.19	0
7	1	Slijpen2	40	100	173	32	173	32	Impeller	Kellenb 120.19	0
8	1	Frezen2	50	100	240	60	240	60	Impeller	Wahli_3 120.38	0
9	1	Balanceren	60	100	69	63	69	63	Impeller	Bal 298.00	0
10	1	Overspeed	70	100	63	44	63	44	Impeller	Ov_test 300.70	0
11	1	Reinigen1	80	100	0	0	0	0	Impeller	Reinigen	1920
12	1	Shotpeenen	90	100	0	0	0	0	Impeller	Uitbesteden	2880
13	1	Reinigen2	100	100	0	0	0	0	Impeller	Reinigen	1920
14	1	Slijpen3	110	100	189	63	189	63	Impeller	Kellenb 120.19	0
15	1	Reinigen3	120	100	0	0	0	0	Impeller	Reinigen	1920
16	2	Dock	0	100	0	0	0	0	Wheelturbine	None	0
17	2	Stock	9999	100	0	0	0	0	Wheelturbine	None	0
18	2	Scrap	10000	100	0	0	0	0	Wheelturbine	None	0
22	2	Voordr. Achtervlak	10	100	90	27	90	27	Wheelturbine	Emag6 120.45	0
23	2	Voordraaien Voorvlak	20	100	75	24	75	24	Wheelturbine	Emag6 120.45	0
24	2	Nadraaien Achtervlak	30	100	240	51	240	51	Wheelturbine	Emag6 120.45	0
25	2	Nadraaien Voorvlak	40	100	180	36	180	36	Wheelturbine	Emag6 120.45	0
26	2	Opzuiveren	50	100	15	6	15	6	Wheelturbine	Tech 120.44	0
27	2	Voorslijpen	60	100	75	20	75	20	Wheelturbine	Kellenb 120.19	0
28	2	Merken	70	100	0	0	0	0	Wheelturbine	Uitbesteden	960
29	2	Schoepen Frezen	80	100	45	480	45	96	Wheelturbine	Hermle 120.62	0
30	2	Spline aanbrengen	90	100	15	30	15	30	Wheelturbine	Mori Seiki 120.07	0
31	2	Uitbesteden1	100	100	0	0	0	0	Wheelturbine	Uitbesteden	6720
32	2	Afbramen	110	100	0	0	0	0	Wheelturbine	Uitbesteden	240
33	2	Balanceren	120	100	30	20	30	20	Wheelturbine	Bal 298.00	0
34	2	Overspeed testen	130	100	75	21	75	21	Wheelturbine	Ov_test 300.70	0
35	2	Beitsen & Penetrant	140	100	0	0	0	0	Wheelturbine	None	1920
36	2	Uitbesteden2	150	100	0	0	0	0	Wheelturbine	Uitbesteden	6720
37	2	Slijpen	105	100	130	50	130	50	Wheelturbine	Kellenb 120.19	0
39	1	Balanceren2	130	100	69	19	69	19	Impeller	Bal 298.00	0
40	3	Dock	0	100	0	0	0	0	Wheel	None	0

41	3	Stock	9999	100	0	0	0	0	Wheel	None	0
42	3	Scrap	10000	100	0	0	0	0	Wheel	None	0
43	3	Draaien	10	100	180	60	180	60	Wheel	Emag6 120.45	0
44	3	Schoepen Frezen	20	100	45	135	45	65	Wheel	Wahli 1_2	0
45	3	Opzuiveren	30	100	73	8	73	8	Wheel	Tech 120.44	0
46	3	Slijpen	40	100	181	11	181	11	Wheel	Kellenb 120.19	0
47	3	Draaien2	50	100	283	15	283	15	Wheel	Emag6 120.45	0
48	3	Boren	60	100	60	6	60	6	Wheel	Fehlm 120.32	0
49	3	Frezen	70	100	15	20	15	15	Wheel	Mori Seiki 120.07	0
50	3	Slijpen2	80	100	170	13	170	13	Wheel	Kellenb 120.19	0
51	3	Beitsen e.d.	90	100	0	0	0	0	Wheel	Uitbesteden	4800
52	3	Balanceren	100	100	73	18	73	18	Wheel	Bal 298.00	0
53	4	Dock	0	100	0	0	0	0	Carrier Assy	None	0
54	4	Stock	9999	100	0	0	0	0	Carrier Assy	None	0
55	4	Scrap	10000	100	0	0	0	0	Carrier Assy	None	0
56	4	Draaien1	10	100	117	21	117	21	Carrier Assy	Emag6 120.45	0
57	4	Slijpen	20	100	165	38	165	38	Carrier Assy	Kellenb 120.19	0
58	4	Draaien2	30	100	280	13	280	13	Carrier Assy	Emag6 120.45	0
59	4	Slijpen2	40	100	264	37	264	37	Carrier Assy	Kellenb 120.19	0
60	4	Boren	50	100	210	56	210	56	Carrier Assy	Wahli_3 120.38	0
61	4	Frezen	60	100	124	12	124	12	Carrier Assy	Wahli 1_2	0
62	4	Boren2	70	100	63	9	63	9	Carrier Assy	Fehlm 120.32	0
63	4	Draaien1b	15	100	122	13	122	13	Carrier Assy	Emag6 120.45	0
64	5	Dock	0	100	0	0	0	0	Fan	None	0
65	5	Stock	9999	100	0	0	0	0	Fan	None	0
66	5	Scrap	10000	100	0	0	0	0	Fan	None	0
68	5	Draaien2	20	100	175	9	175	9	Fan	Boley 120.21	0
69	5	Hardheidstest	30	100	0	0	0	0	Fan	Uitbesteden	4800
70	5	Frezen	40	100	90	102	90	56	Fan	Hermle 120.62	0
71	5	Nadraaien2	50	100	179	7	179	7	Fan	Spinner 120.60	0
72	5	Balanceren	60	100	27	9	27	9	Fan	Bal 298.00	0
73	5	Overspeedtesten	70	100	90	19	90	19	Fan	Ov_test 300.70	0
74	5	Reinigen	80	100	0	0	0	0	Fan	Reinigen	1920
75	5	Nadraaien1	45	100	60	3	60	3	Fan	Boley 120.21	0
76	6	Dock	0	100	0	0	0	0	Shaft ATS	None	0
77	6	Stock	9999	100	0	0	0	0	Shaft ATS	None	0
78	6	Scrap	10000	100	0	0	0	0	Shaft ATS	None	0
79	6	Voordraaien	20	100	172	15	172	15	Shaft ATS	Emag6 120.45	0
80	6	Reinigen	30	100	0	0	0	0	Shaft ATS	Reinigen	4800
81	6	Draaien	40	100	120	20	120	20	Shaft ATS	Emag6 120.45	0
82	6	Spline Trekken	50	100	60	2	60	2	Shaft ATS	Broachmach	0
83	6	Boren	60	100	189	40	189	40	Shaft ATS	Wahli 1_2	0
84	6	Frezen	70	100	6	11	6	11	Shaft ATS	Wahli 1_2	0

86	6	Boren2	80	100	79	5	79	5	Shaft ATS	Fehlm 120.32	0
87	6	Nadraaien	55	100	157	6	157	6	Shaft ATS	Boley 120.21	0
101	10	Dock	0	100	0	0	0	0	Impeller Rotor	None	0
102	10	Stock	9999	100	0	0	0	0	Impeller Rotor	None	0
103	10	Scrap	10000	100	0	0	0	0	Impeller Rotor	None	0
104	10	Draaien	10	100	240	150	240	150	Impeller Rotor	Emag8	0
105	10	Boren	20	100	60	12	60	12	Impeller Rotor	Fehlm 120.32	0
106	10	Frezen	30	100	240	200	240	100	Impeller Rotor	Dixi 120.48	0
107	10	Draaien2	40	100	120	240	120	240	Impeller Rotor	Emag6 120.45	0
108	10	Slijpen	50	100	180	60	180	60	Impeller Rotor	Kellenb 120.19	0
109	10	Merken	60	100	0	0	0	0	Impeller Rotor	Uitbesteden	2880
110	10	Balanceren	70	100	180	60	180	60	Impeller Rotor	Bal 298.00	0
111	10	Overspeedtesten	80	100	60	48	60	48	Impeller Rotor	Ov_test 300.70	0
112	5	Draaien1	10	100	30	7	30	7	Fan	Boley 120.21	0
120	11	Draaien2	20	100	282	21	282	21	Body Assy	Boley 120.21	0
121	11	Frezen1	30	100	103	16	103	16	Body Assy	Wahli 1_2	0
122	11	Draaien3	40	100	129	7	129	7	Body Assy	Emag6 120.45	0
123	11	Frezen2	50	100	219	34	219	34	Body Assy	Wahli 1_2	0
124	11	Boren/Ruimen	60	100	102	11	102	11	Body Assy	Mori Seiki 120.07	0
125	12	Frezen1	10	100	150	6	150	6	Housing Exhaust	Mori Seiki 120.07	0
126	12	Draaien	20	100	319	28	319	28	Housing Exhaust	Emag6 120.45	0
127	12	Frezen2	30	100	178	15	178	15	Housing Exhaust	Mori Seiki 120.07	0
128	12	Boren&Frezen	40	100	191	16	191	16	Housing Exhaust	Wahli_3 120.38	0
129	12	Backspotten	50	100	49	19	49	19	Housing Exhaust	Fehlm 120.32	0
130	12	Afbr & uitbesteden	60	100	0	0	0	0	Housing Exhaust	Uitbesteden	9600
131	12	Slijpen	70	100	110	8	110	8	Housing Exhaust	Kellenb 120.19	0
135	14	Draaien	1	100	660	51	660	51	Housing Assy	Emag8	0
136	14	Frezen1	10	100	240	19	240	19	Housing Assy	Wahli 1_2	0
137	14	Frezen2	20	100	240	44	240	44	Housing Assy	Wahli_3 120.38	0
138	14	Boren	30	100	0	0	0	0	Housing Assy	Uitbesteden	4800
139	14	Afbramen	40	100	0	0	0	0	Housing Assy	Uitbesteden	2880
140	14	Reinigen e.d.	50	100	0	0	0	0	Housing Assy	Uitbesteden	1920
141	14	Slijpen	60	100	600	75	600	75	Housing Assy	Kellenb 120.19	0
143	14	Kotteren	70	100	61	12	61	12	Housing Assy	Fehlm 120.32	0
144	15	Dock	0	100	0	0	0	0	Housing Bear. Inlet	None	0
145	15	Stock	9999	100	0	0	0	0	Housing Bear. Inlet	None	0
146	15	Scrap	10000	100	0	0	0	0	Housing Bear. Inlet	None	0
147	15	Draaien1	10	100	60	33	60	33	Housing Bear. Inlet	Emag8	0
148	15	Frezen	20	100	120	42	120	42	Housing Bear. Inlet	Wahli 1_2	0
149	15	Draaien2	30	100	60	37	60	37	Housing Bear. Inlet	Emag8	0
150	15	Opspannok	40	100	0	0	0	0	Housing Bear. Inlet	Uitbesteden	1920
151	15	Draaien3	50	100	60	60	60	60	Housing Bear. Inlet	Emag6 120.45	0
161	18	Voorslijpen	10	100	297	20	297	20	Shaft Drive	Kellenb 120.19	0

162	18	Inserts plaatsen	20	100	0	0	0	0	Shaft Drive	Uitbesteden	1920
163	18	Boren	30	100	66	12	66	12	Shaft Drive	Fehlm 120.32	0
164	18	Slijpen	40	100	160	5	160	5	Shaft Drive	Kellenb 120.19	0
165	18	Groefsteken	50	100	66	8	66	8	Shaft Drive	Broachmach	0
166	17	Vlakken	10	100	180	18	180	18	Shaft2	None	0
167	17	Boren/Frezen	20	100	180	6	180	6	Shaft2	None	0
168	17	Slijpen	30	100	99	14	99	14	Shaft2	None	0
169	17	Frezen	40	100	114	18	114	18	Shaft2	None	0
170	16	Frezen	10	100	120	60	120	60	Shielding Flange	Wahli 1_2	0
171	16	Richten	20	100	0	0	0	0	Shielding Flange	Uitbesteden	1920
172	16	Draaien	30	100	120	30	120	30	Shielding Flange	Emag8	0
182	19	Draaien1	10	100	120	60	120	60	Diffuser	Emag8	0
183	19	Draaien2	20	100	120	120	120	120	Diffuser	Emag8	0
184	19	Boren	30	100	60	60	60	60	Diffuser	Fehlm 120.32	0
185	19	Frezen	40	100	240	330	240	250	Diffuser	Wahli 1_2	0
186	20	Draaien1	10	100	120	90	120	90	Diffuser Compressor	Weiler	0
187	20	Draaien2	20	100	120	120	120	120	Diffuser Compressor	Emag8	0
188	20	Afbramen	30	100	0	0	0	0	Diffuser Compressor	Uitbesteden	1920
189	20	Frezen	40	100	240	120	240	120	Diffuser Compressor	Wahli 1_2	0
190	21	Frezen1	10	100	216	2	216	2	Back Shroud Assy	Wahli 1_2	0
191	21	Frezen2	20	100	603	30	603	30	Back Shroud Assy	Wahli_3 120.38	0
192	21	Draaien	30	100	392	88	392	88	Back Shroud Assy	Emag8	0
193	21	Frezen3	40	100	289	49	289	49	Back Shroud Assy	Wahli 1_2	0
194	21	Frezen4	50	100	264	27	264	27	Back Shroud Assy	Wahli_3 120.38	0
201	24	Dock	0	100	0	0	0	0	Diffuser Assy	None	0
202	24	Stock	9999	100	0	0	0	0	Diffuser Assy	None	0
203	24	Scrap	10000	100	0	0	0	0	Diffuser Assy	None	0
204	24	Draaien1	10	100	120	30	120	30	Diffuser Assy	Weiler	0
205	24	Boren	20	100	180	60	180	60	Diffuser Assy	Fehlm 120.32	0
206	24	Ontvetten e.d.	30	100	0	0	0	0	Diffuser Assy	Uitbesteden	6720
207	24	Draaien2	40	100	131	120	131	120	Diffuser Assy	Weiler	0
208	24	Draaien3	50	100	132	93	132	93	Diffuser Assy	Emag8	0
210	24	Boren2	70	100	102	17	102	17	Diffuser Assy	Fehlm 120.32	0
212	24	Frezen2	80	100	204	151	204	151	Diffuser Assy	Wahli 1_2	0
213	22	Draaien1	10	100	167	39	167	39	Nozzle	Emag8	0
214	22	Boren	20	100	90	47	90	47	Nozzle	Mori Seiki 120.07	0
215	22	Boren2	30	100	90	126	90	126	Nozzle	Mori Seiki 120.07	0
216	22	Draaien2	40	100	78	12	78	12	Nozzle	Emag8	0
217	22	Slijpen	50	100	330	34	330	34	Nozzle	Kellenb 120.19	0
228	25	Draaien1	10	100	120	20	120	20	Housing IGV LC400	Emag8	0
229	25	Draaien2	20	100	120	30	120	30	Housing IGV LC400	Emag8	0
230	25	Draaien3	30	100	120	20	120	20	Housing IGV LC400	Emag8	0
231	25	Frezen	40	100	180	30	180	30	Housing IGV LC400	Wahli 1_2	0

232	26	Frezen1	10	100	184	40	184	40	Casing IGV LC350	Wahli 1_2	0
233	26	Draaien1	20	100	176	29	176	29	Casing IGV LC350	Emag8	0
234	26	Frezen2	30	100	360	84	360	84	Casing IGV LC350	Wahli 1_2	0
235	26	Draaien2	40	100	183	24	183	24	Casing IGV LC350	Emag8	0
236	26	Frezen3	50	100	432	91	432	91	Casing IGV LC350	Wahli 1_2	0
237	22	Uitbesteden	60	100	0	0	0	0	Nozzle	None	9600
238	22	Draaien3	70	100	210	43	210	43	Nozzle	None	0
239	25	Draaien4	50	100	120	20	120	20	Housing IGV LC400	Weiler	0
240	25	Uitbesteden	45	100	0	0	0	0	Housing IGV LC400	Uitbesteden	4800
244	27	Draaien	10	100	248	12	248	12	Body SCHIL3	Emag6 120.45	0
245	27	Frezen	20	100	199	31	199	31	Body	Wahli 1_2	0
322	29	Draaien	10	100	0	110	0	110	Adapter	Boley 120.21	0
323	29	Slijpen	20	100	27	150	27	150	Adapter	Kellenb 120.19	0
324	30	Frezen1	10	100	270	60	270	60	Backshroud	Wahli 1_2	0
325	30	Draaien	20	100	240	25	240	25	Backshroud	Emag8	0
326	30	Frezen2	30	100	240	85	240	85	Backshroud	Wahli 1_2	0
327	31	Frezen1	10	100	230	49	230	49	Body Assy Actuator	Wahli 1_2	0
328	31	Frezen2	20	100	256	58	256	58	Body Assy Actuator	Wahli 1_2	0
329	31	Boren1	30	100	67	5	67	5	Body Assy Actuator	Deckel	0
330	31	Boren2	40	100	92	12	92	12	Body Assy Actuator	Fehlm 120.32	0
331	32	Frezen1	10	100	232	71	232	71	Body Assy Valve	Wahli 1_2	0
332	32	Draaien1	20	100	350	41	350	41	Body Assy Valve	Emag8	0
333	32	Boren	30	100	125	25	125	25	Body Assy Valve	Mori Seiki 120.07	0
335	32	Ontvetten	50	100	0	0	0	0	Body Assy Valve	Uitbesteden	0
336	32	Backsp. aanbrengen	60	100	69	24	69	24	Body Assy Valve	Fehlm 120.32	0
337	33	Draaien	20	100	30	80	30	80	Body Diff. Lower	Boley 120.21	0
338	33	Frezen	30	100	30	90	30	90	Body Diff. Lower	Wahli 1_2	0
339	33	Boren	40	100	30	30	30	30	Body Diff. Lower	Fehlm 120.32	0
341	34	Draaien1	20	100	330	40	330	40	Body Valve	Boley 120.21	0
342	34	Frezen	30	100	173	57	173	57	Body Valve	Wahli 1_2	0
343	34	Boren	40	100	48	20	48	20	Body Valve	Fehlm 120.32	0
345	35	Frezen	10	100	137	40	137	40	Body Valve2	Wahli 1_2	0
346	35	Draaien	20	100	121	19	121	19	Body Valve2	Emag8	0
347	35	Draaien1	30	100	119	17	119	17	Body Valve2	Emag8	0
348	35	Frezen2	40	100	290	49	290	49	Body Valve2	Wahli 1_2	0
349	35	Backspot	50	100	88	15	88	15	Body Valve2	Deckel	0
351	36	Slijpen	10	100	180	60	180	60	Centr. Impeller (rep)	Kellenb 120.19	0
352	36	Balanceren	20	100	60	60	60	60	Centr. Impeller (rep)	Bal 298.00	0
353	37	Frezen1	10	100	30	4	30	4	Cover Differentiator	Fehlm 120.32	0
354	37	Boren	20	100	54	7	54	7	Cover Differentiator	Fehlm 120.32	0
355	38	Draaien1	10	100	60	18	60	18	Exducer	Boley 120.21	0
356	38	Draaien2	20	100	60	7	60	7	Exducer	Boley 120.21	0
357	39	Draaien1	10	100	120	90	120	90	Flange	Emag8	0

358	39	Draaien2	20	100	120	90	120	90	Flange	Emag8	0
359	40	Draaien1	10	100	390	360	390	360	Housing Compr. Scroll	Weiler	0
360	40	Frezen	20	100	720	300	720	300	Housing Compr.	Wahli 1_2	0
361	41	Frezen1	10	100	204	69	204	69	Housing Inlet LC350	Wahli 1_2	0
362	41	Boren	20	100	186	78	186	78	Housing Inlet LC350	Deckel	0
363	41	Draaien1	30	100	222	30	222	30	Housing Inlet LC350	Emag8	0
364	41	Frezen2	40	100	240	165	240	165	Housing Inlet LC350	Wahli_3 120.38	0
365	41	frezen3	50	100	300	112	300	112	Housing Inlet LC350	Wahli 1_2	0
366	41	Delay	60	100	0	0	0	0	Housing Inlet LC350	Uitbesteden	0
367	41	Draaien2	70	100	400	120	400	120	Housing Inlet LC350	Emag8	0
368	41	Frezen4	80	100	240	210	240	210	Housing Inlet LC350	Wahli 1_2	0
369	41	Frezen5	90	100	84	21	84	21	Housing Inlet LC350	None	0
370	41	Delay2	100	100	0	0	0	0	Housing Inlet LC350	Uitbesteden	0
371	41	Draaien3	110	100	180	18	180	18	Housing Inlet LC350	Emag8	0
372	41	Slijpen	120	100	81	78	81	78	Housing Inlet LC350	Jung 120.50	0
373	42	Draaien1	10	100	67	3	67	3	Housing Outer	Emag8	0
374	42	Draaien2	20	100	66	14	66	14	Housing Outer	Emag8	0
375	43	Draaien	10	100	439	136	439	136	Impeller Shroud	Emag8	0
376	43	Warmtebehandeling	20	100	0	0	0	0	Impeller Shroud	Uitbesteden	0
377	43	Draaien2	30	100	496	135	496	135	Impeller Shroud	Emag8	0
378	43	Frezen1	40	100	182	82	182	82	Impeller Shroud	Wahli 1_2	0
379	43	Uitbesteden	50	100	0	0	0	0	Impeller Shroud	Uitbesteden	0
380	43	Draaien3	60	100	525	122	525	122	Impeller Shroud	Emag8	0
381	43	Frezen2	70	100	194	52	194	52	Impeller Shroud	Wahli 1_2	0
382	44	Draaien	10	100	300	240	300	240	Plate	Weiler	0
383	45	Draaien1	10	100	120	120	120	120	Plate Vane	Weiler	0
384	45	Draaien2	20	100	240	45	240	45	Plate Vane	Emag8	0
385	45	Frezen	30	100	240	270	240	270	Plate Vane	Wahli 1_2	0
386	45	Draaien3	40	100	60	10	60	10	Plate Vane	Weiler	0
387	46	Draaien	10	100	137	7	137	7	Retainer	Boley 120.21	0
388	46	Slijpen	20	100	80	10	80	10	Retainer	Kellenb 120.19	0
389	47	Draaien1	10	100	227	9	227	9	Retainer Assy	Boley 120.21	0
390	47	Boren	20	100	196	7	196	7	Retainer Assy	Mori Seiki 120.07	0
391	47	Uitbesteden	30	100	0	0	0	0	Retainer Assy	Uitbesteden	0
392	47	Boren2	40	100	56	14	56	14	Retainer Assy	Fehlm 120.32	0
393	47	Insert inpersen	50	100	0	0	0	0	Retainer Assy	Uitbesteden	0
394	47	Uitdraaien	60	100	113	30	113	30	Retainer Assy	Mori Seiki 120.07	0
395	28	Draaien1	10	100	240	4	240	4	Retainer Diaphragm	Boley 120.21	0
396	28	Frezen	20	100	120	2	120	2	Retainer Diaphragm	Wahli 1_2	0
397	49	Frezen1	10	100	198	60	198	60	Scroll LC350	Wahli 1_2	0
398	49	Frezen2	20	100	218	129	218	129	Scroll LC350	Wahli_3 120.38	0
399	49	Draaien	30	100	120	120	120	120	Scroll LC350	Weiler	0
400	49	Frezen3	40	100	901	174	901	174	Scroll LC350	Wahli 1_2	0

402	52	Draaien1	20	100	240	22	240	22	Wheel Turbine2	Spinner 120.60	0
403	52	Frezen	30	100	126	7	126	7	Wheel Turbine2	Wahli 1_2	0
404	51	Draaien1	10	100	126	51	126	51	Turbine Wheel	Emag6 120.45	0
405	51	Draaien2	20	100	318	75	318	75	Turbine Wheel	Emag6 120.45	0
406	51	Opzuiveren	30	100	15	6	15	6	Turbine Wheel	Tech 120.44	0
407	51	Schoepen slijpen	40	100	60	15	60	15	Turbine Wheel	Kellenb 120.19	0
408	51	Merken	50	100	0	0	0	0	Turbine Wheel	Uitbesteden	0
409	51	Frezen	60	100	120	480	120	480	Turbine Wheel	Wahli 1_2	0
410	51	Spline aanbrengen	70	100	18	30	18	30	Turbine Wheel	Mori Seiki 120.07	0
411	51	Slijpen2	80	100	60	48	60	48	Turbine Wheel	Kellenb 120.19	0
412	50	Draaien1	10	100	112	3	112	3	Shaft Bearing Serrated	Boley 120.21	0
413	50	Draaien2	20	100	122	4	122	4	Shaft Bearing Serrated	Boley 120.21	0
414	50	Frezen1	30	100	114	20	114	20	Shaft Bearing Serrated	Mori Seiki 120.07	0
415	50	Slijpen	40	100	153	3	153	3	Shaft Bearing Serrated	Kellenb 120.19	0
416	50	Frezen2	50	100	114	13	114	13	Shaft Bearing Serrated	Mori Seiki 120.07	0
444	53	Draaien	10	100	0	75	0	75	ACM Wheel 1	Emag6 120.45	0
445	53	Frezen	20	100	0	15	0	15	ACM Wheel 1	Hermle 120.62	0
446	53	Slijpen	30	100	0	80	0	80	ACM Wheel 1	Kellenb 120.19	0
447	54	Draaien	10	100	0	75	0	75	ACM Wheel 2	Emag6 120.45	0
448	54	Frezen	20	100	0	15	0	15	ACM Wheel 2	Hermle 120.62	0
449	54	Slijpen	30	100	0	80	0	80	ACM Wheel 2	Kellenb 120.19	0
451	55	Draaien	10	100	0	240	0	240	ACM Wheel 3	Emag6 120.45	0
452	55	Frezen	20	100	0	618	0	618	ACM Wheel 3	Hermle 120.62	0
453	55	Slijpen	30	100	0	60	0	60	ACM Wheel 3	Kellenb 120.19	0
454	56	Draaien	10	100	0	120	0	120	ACM Impeller 1	Emag6 120.45	0
455	56	Frezen	20	100	0	420	0	420	ACM Impeller 1	Hermle 120.62	0
456	56	Slijpen	30	100	0	270	0	270	ACM Impeller 1	Kellenb 120.19	0
457	58	Draaien	10	100	0	138	0	138	ACM Impeller 2	Emag6 120.45	0
458	58	Frezen	20	100	0	300	0	300	ACM Impeller 2	Hermle 120.62	0
459	58	Slijpen	30	100	0	10	0	10	ACM Impeller 2	Kellenb 120.19	0
460	59	Draaien	10	100	0	210	0	210	ACM Impeller 3	Emag6 120.45	0
461	59	Frezen	20	100	0	420	0	420	ACM Impeller 3	Hermle 120.62	0
462	59	Slijpen	30	100	0	144	0	144	ACM Impeller 3	Kellenb 120.19	0
463	60	Draaien	10	100	0	60	0	60	ACM Ring Nozzle	Emag8	0
464	60	Frezen	20	100	0	81	0	81	ACM Ring Nozzle	Wahli 1_2	0
465	60	Slijpen	30	100	0	72	0	72	ACM Ring Nozzle	Kellenb 120.19	0
466	61	Draaien	10	100	0	150	0	150	ACM Nozzle	Emag8	0
467	61	Frezen	20	100	0	300	0	300	ACM Nozzle	Wahli 1_2	0
468	61	Slijpen	30	100	0	33	0	33	ACM Nozzle	Kellenb 120.19	0
511	72	Dock	0	100	0	0	0	0	Shaft3	None	0
512	72	Stock	9999	100	0	0	0	0	Shaft3	None	0
513	72	Scrap	10000	100	0	0	0	0	Shaft3	None	0
514	72	Draaien	10	100	300	180	300	180	Shaft3	Emag6 120.45	0

515	72	Broach	20	100	60	20	60	20	Shaft3	Broachmach	0
516	72	Carboneren	30	100	0	0	0	0	Shaft3	Uitbesteden	14400
517	72	Opzuiveren	40	100	33	3	33	3	Shaft3	Tech 120.44	0
518	72	Slijpen	50	100	72	54	72	54	Shaft3	Kellenb 120.19	0
519	72	Draaien2	60	100	240	120	240	120	Shaft3	Emag6 120.45	0
520	72	Frezen	70	100	120	45	120	45	Shaft3	Wahli 1_2	0
521	72	Slijpen2	80	100	90	120	90	120	Shaft3	Kellenb 120.19	0
523	73	Dock	0	100	0	0	0	0	Shaft Tie LC400	None	0
524	73	Stock	9999	100	0	0	0	0	Shaft Tie LC400	None	0
525	73	Scrap	10000	100	0	0	0	0	Shaft Tie LC400	None	0
526	73	Draaien	20	100	300	180	300	180	Shaft Tie LC400	Emag6 120.45	0
527	73	Broachen	30	100	60	20	60	20	Shaft Tie LC400	Broachmach	0
528	73	Uitbesteden	40	100	0	0	0	0	Shaft Tie LC400	Uitbesteden	14400
529	73	Opzuiveren	50	100	33	3	33	3	Shaft Tie LC400	Tech 120.44	0
530	73	Draaien2	60	100	240	120	240	120	Shaft Tie LC400	Emag6 120.45	0
531	73	Frezen	70	100	120	45	120	45	Shaft Tie LC400	Wahli 1_2	0
532	73	Slijpen	80	100	90	120	90	120	Shaft Tie LC400	Kellenb 120.19	0
533	73	Balanceren	90	100	18	36	18	36	Shaft Tie LC400	Bal 298.00	0
548	78	Dock	0	100	0	0	0	0	Body Assy2	None	0
549	78	Stock	9999	100	0	0	0	0	Body Assy2	None	0
550	78	Scrap	10000	100	0	0	0	0	Body Assy2	None	0
552	78	Draaien1	20	100	282	21	282	21	Body Assy2	Boley 120.21	0
553	78	Frezen	30	100	104	17	104	17	Body Assy2	Wahli 1_2	0
554	78	Draaien2	40	100	129	8	129	8	Body Assy2	Emag6 120.45	0
555	78	Frezen2	50	100	219	34	219	34	Body Assy2	Wahli 1_2	0
556	78	Frezen3	60	100	102	11	102	11	Body Assy2	Mori Seiki 120.07	0

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Empirical Studies in Discrete Parts Manufacturing Management

Manufacturing firms are bound by the conditions of their environment. They have to fulfil the demands of various stakeholders, such as customers, suppliers, government, financiers, and employees) that provide them the resources to perform their operations. The effectiveness of a manufacturing firm depends on the fit between the manufacturing system and the level of uncertainty in its environment. There must be consistency between numerous manufacturing dimensions, such as operations strategy, process choice, level of decentralization, production planning and control strategies, concepts, and tools, and the characteristics of the dominant Product / Market / Technology (PMT) combinations of the manufacturing firm. This book focuses on empirical studies that address the impact of PMT-uncertainty on various operations management issues in Dutch discrete parts manufacturing firms. It includes an in-depth exploratory longitudinal case study at Urenco Aerospace, a second-tier supplier in the aerospace industry, and two independent surveys (i.e., questionnaire-based research) among Dutch discrete parts manufacturers.

The central research question of this book is, 'what is the impact of PMT-uncertainty on important discrete parts manufacturing management issues, such as the strategic focus on competitive priorities, the dominant type of manufacturing layout, the decentrality of the locus of production planning and control, the use of various production planning and control tools, and line management's attention for social issues like individual competence management?'
In addition, we extensively focus on organizational and innovation-related characteristics that affect the adoption of an Advanced Planning and Scheduling system within the discrete parts manufacturing industry.

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