SATELLITES AND LICENSEES: IMPROVING THE CAPITOLE 40 OEM PRODUCT AND PROCESS DESIGN TO IMPLEMENT MATERIAL KITTING

The reciprocity: Improving business processes to implement material kitting or implementing material kitting to improve business processes

(22nd of August, 2011)

Powering Business Worldwide

Frank Wageman
Hengelo, 22 August 2011

TITLE OF THE RESEARCH

Satellites and licensees: Improving the Capitole 40 OEM product and process design to implement material kitting

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MANAGEMENT SUMMARY

Eaton Industries B.V., a supplier of electrical switch and distribution systems, sells their Capitole 40 system in both domestic and foreign markets. Foreign markets are served by OEM (Original Equipment Manufacturer) partners. These OEM partners are subdivided into: (1) satellite partners, which are Eaton property and (2) licensee partners, which are non Eaton property. Eaton Industries B.V. purchase, (if needed) produce, and supplies a range of components or all components needed for assembly. The job of the OEM partners is restricted to sell, assemble, and deliver Capitole 40 systems.

As stated in the strategic goals of both Eaton Industries B.V. and the Eaton Corporation, OEM related throughput have to increase. However, the management team of Eaton Industries B.V. doubts the performance of the current OEM process and supplies. A hype in the electrical empowering business is to supply flat packs or material kits. These flat packs or material kits contribute to more efficient material handling in the assembly process. This research shows that Eaton Industries B.V. can implement material kitting to supply their OEM partners.

A major problem in the current situation is that all OEM related processes are second-class derivatives of the in-house assembly process. In this research, we conclude that Eaton Industries B.V. should focus on minimizing the – process design – gap between in-house assembly process and OEM (assembly) process.

We recommend Eaton Industries B.V. to implement stationary material kits (one material kit contains the components needed for one panel or drawer type and one workstation) and an OEM process design that uses the same management and design policies used in the in-house assembly process. In this process design, routing information is used to allocate components to material kits. The implementation of material kitting will affect the OEM material handling workload and the total inventory levels. We estimate the annual inventory costs to rise with € 21,000 and the annual material handling costs to decline with € 10,000. Result, it will cost Eaton Industries B.V. approximately € 11,000 on an annual basis to supply material kits to their OEM partners. This € 11,000 is less than 1% of the current Capitole 40 OEM related turnover.

In this research, we conclude that Eaton Industries B.V. is capable to implement material kitting. However, just as important, we identify some barriers Eaton Industries B.V. have to overcome, in order to make the implementation of material kitting a success. The most important barriers are: (1) employees of Eaton Industries B.V. should start realizing that the in-house assembly process and the OEM process are highly interrelated (material kitting requirements should be included in the new LVS process design), (2) the supply chain value of material kitting is unknown, this makes it impossible to state whether the implementation of material kitting will contribute to the intended goal (increase OEM related turnover), and (3) the currently ongoing project, focussing on implementation of Bid Manager and Design Automation, should strive to standardize the flow of – input – information for the processes of Eaton Industries B.V.

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PREFACE

This thesis is the final requirement in order to achieve my Master of Science degree for my study Industrial Engineering and Management at the University of Twente. In the period between November 2011 and August 2011, I focused on how Eaton Industries B.V. should design and implement material kitting to supply their OEM partners. The management team of Eaton Industries B.V. expects that the implementation of material kitting, to supply their OEM partners, improves the competitive position of Eaton Industries B.V. and ultimately improves supply chain performance. Therefore, the implementation of material kitting contributes to secure the long-term competitive position of Eaton Industries B.V.

I really enjoyed the time studying Industrial Engineering and Management at the University of Twente. The time I spent at Eaton Industries B.V. was an amusing, challenging, and instructive closure of my student years.

First, I thank my Eaton Industries B.V. supervisor Judith Rouhof for her advice, feedback, and stimulus. I also thank my supervisors of the University of Twente, Marco Schutten and Waling Bandsma for their tart, innovating, and stimulating feedback.

For the seven months I participated in the Material Management team (as a pupil), I experienced how a complex manufacturing firm operates. I observed and learned how my colleagues worked on a day-to-day basis to apply – scientific – knowledge to practical and workable situations. In the time I spent at Eaton Industries B.V., I learned to see that the true value of each theory is achieved by the way one applies these in practice. I thank my direct colleagues of the Material Management department for sharing this valuable insight with me.

Finally, I thank everybody (I prefer thanking everybody in person, but I do not want to make the mistake forgetting someone) for all their support, devotion, and encouragements.

Frank Wageman, August 2011.

1 PROBLEM BACKGROUND AND RESEARCH APPROACH

Eaton Industries B.V. is located in Hengelo (the Netherlands) and is part of the publicly listed American Eaton Corporation. The Eaton Corporation offers products and services for industrial applications in the car and plane industry. The Eaton Corporation employs more than 75,000 people around the world and offers products and services to their customers in more than 150 countries. Eaton Industries B.V. produces components and systems to switch and distribute electricity. Their product portfolio includes a wide variety in Low Voltage (until 1 kilovolt) Components (LVC), Low Voltage Systems (LVS), and Medium Voltage (more than 1 and less than 36 kilovolt) Systems (MVS). Eaton Industries B.V. employs more than 850 people and established a turnover of 138 million euros in the year 2010.

The problem as discussed in this research applies to more products supplied by Eaton Industries B.V., in the scope of this research we will focus on the Capitole 40. The Capitole 40 is a Low Voltage System.

Section 1.1 introduces the problem, which is further discussed and defined in Section 1.2. Section 1.3 provides the research questions subdividing the problem as defined in Section 1.2. Section 1.4 provides the research approach. The last section, Section 1.5, clarifies the scope boundaries of this research and provides an overview of the assumptions used during this research.

1.1 INTRODUCTION TO THE PROBLEM

Within the Eaton Corporation, product designs are owned by one single plant. In most cases, this is the plant that developed the product. The goal of ownership is to prevent two of the same products, supplied by different plants, differ on performance, quality, or appearance. Therefore, performance, quality, and appearance defining components will be produced by the plant owning the product. Eaton Industries B.V. owns the Capitole 40.

Eaton Industries B.V. is part of the EMEA (Europe, Middle East, and Africa) group and serves EMEA markets. This implies that customers are scattered over multiple countries and regions. This geographical distribution influences: (1) details in customer specifications, due to differing requirements and regulations and (2) the distribution channel, because assembly plants are intended to serve national markets only.

In the year 2000, Eaton Industries B.V. started an intensive collaboration with a foreign assembler (referred to as an OEM partner). The main drivers, at that time, were market characteristics and strategic goals. Eaton Industries B.V. distinguishes two types of OEM partners: satellites partners and licensee partners. Both differentiate on many aspects (see Chapter 3). However, both share the important characteristic that assembly takes place at a remote location in a foreign country, while production takes place at Eaton Industries B.V. OEM partners is the collective noun, within Eaton Industries B.V., referring to both satellite partners and licensee partners.

The abbreviation OEM stands for Original Equipment Manufacturer and is used to describe a specific type of suppliers. According to Lambert & Cooper (2000), a supplier is an Original Equipment Manufacturer if: (1) the supplier supplies critical and complex components or subassemblies and (2) the supplier works very closely with the customer during the development phases of – new – products.

The strategies of both Eaton Industries B.V. and the Eaton Corporation state turnover have to increase. Given the relatively stable sales volume in the Dutch market over the last years (Eaton

Industries B.V, 2011) and the prospect this will not change in the near future, Eaton Industries B.V. is forced to realize this turnover increase in foreign markets (Stampfel, 2010).

To increase turnover in foreign markets, a change in the way of thinking of Eaton Industries B.V., as an organization, have to take place (see Figure 1). In the current situation, the plant in Hengelo is supplemented by – less important – OEM assembly plants. To achieve its strategic goals, the management team of Eaton Industries B.V. envisions the plant Hengelo to become a knowledge centre, serving different assembly plants, including the assembly plant Hengelo. Figure 1 visualizes this change. The term knowledge centre in Figure 1 stands for a variety of overhead functions such as R&D, product maintenance and support, but it also includes production functions to supply the above described performance, quality, and appearance defining components.

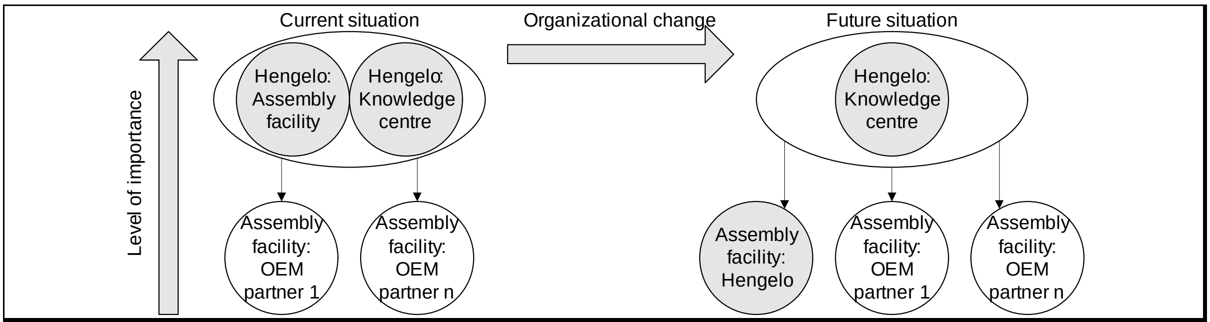


FIGURE 1: ENVISIONED ORGANIZATION CHANGE

Although Eaton Industries B.V. produces and assembles products and systems for more than 100 years, the OEM process is relatively new to Eaton Industries B.V. The sections below provide insight into the differences between (1) in-house production and in-house assembly and (2) in-house production and OEM assembly.

Description of in-house production and in-house assembly

In-house production and in-house assembly refers to the production and assembly process without any intervention of an OEM partner. Hereinafter referred to as the in-house assembly process.

Figure 2 visualizes the goods flow for in-house produced and in-house assembled systems. In this figure, suppliers deliver components to Eaton Industries B.V., where these components are received and stored until production or assembly. In the production phase, components that need preceding treatment are processed to semi-manufactured goods and stored until assembly. In the assembly phase, components and semi-manufactured goods are consolidated to one functional switch and distribution system. A functional system is stored until shipment.

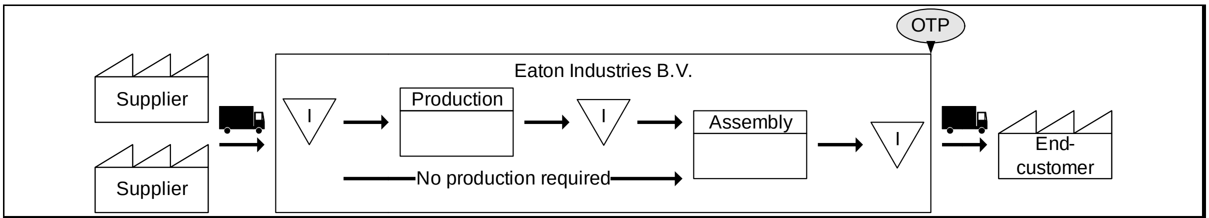


FIGURE 2: GOODS FLOW FOR IN-HOUSE PRODUCTION AND IN-HOUSE ASSEMBLY

In Figure 2, the most important performance measure to measure customer satisfaction is On-Time Performance (OTP). OTP is the percentage of early or on-time supplied systems to the customer. Goal is to supply 90% of the systems on-time. The annual report of 2010, however, states an OTP of 83% for in-house assembly.

Description of in-house production and OEM assembly

In-house production and OEM assembly refers to the in-house production and foreign OEM assembly process. In this process, OEM partners execute the assembly activities. Hereinafter referred to as the OEM process.

Figure 3 visualizes the goods flow for OEM assembled systems. In contrast to the in-house assembly process (see Figure 2), no assembly activities take place at Eaton Industries B.V. Instead, components and semi-manufactured goods are packed on pallets or in carton boxes and stored until shipment. After shipment, components and semi-manufactured goods are received by the OEM partner and stored until needed for assembly. In the assembly phase, components and semi-manufactured goods are consolidated to one functional switch and distribution system.

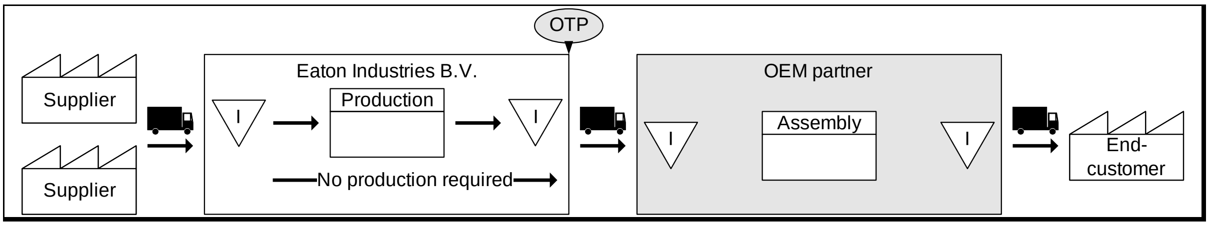


FIGURE 3: GOODS FLOW FOR IN-HOUSE PRODUCTION AND OEM ASSEMBLY

Customer satisfaction of the OEM process is also measured by OTP. In this process, OTP is the percentage of early or on-time supplied order lines to the OEM partner. Goal is to supply 95% of the order lines on-time. Consulting Cognos (reporting software in use at Eaton Industries B.V.) reports, we conclude an OTP of 88% for OEM assembly over the year 2010.

1.2 PROBLEM DEFINITION

In order to realize the organizational change as visualized in Figure 1, the management team of Eaton Industries B.V. have identified two developmental spearheads. The first spearhead concerns the introduction of a new software packages, Bid Manager and Design Automation. The introduction of Bid Manager and Design Automation affects the information exchange in the order intake process and should enable OEM partners to design, configure, and tender Capitole 40 systems. The second spearhead concerns an investigation to determine whether and how Eaton Industries B.V. can apply material kitting to improve the perceived quality of supplies from an OEM partner's perspective. In essence, material kitting should enforce accurate supplies and should contribute to make the OEM assembly process more efficient (from a supply chain perspective). To summarize, the two key activities defined by the management team of Eaton Industries B.V. are:

1. redesign the order intake process, by implementing Bid Manager and Design Automation;
2. explore the applicability and possibilities to apply material kitting.

Although both activities are interrelated, this research will focus merely on activity 2. It is important to note that currently the OEM process is secondary compared to the in-house assembly process. As a result, the OEM process is a derivative of the in-house assembly process and the OEM process is not fully embedded into the core business and employees' mindsets. Furthermore, material kitting is a completely new material supply concept for Eaton Industries B.V.

We define the problem of Eaton Industries B.V. as:

> *"To achieve its strategic goals, Eaton Industries B.V. should increase the OEM related sales volume. Material kitting – a not previously pioneered practise – is expected to be valuable. Eaton Industries B.V., however, is lacking the knowledge and resources to determine what the impact of material kitting will be and how material kits should be designed, managed, and implemented."*

Section 1.3 provides the research questions answered in this research. The answers to each of the research questions will enable us to advise the management team of Eaton Industries B.V. on the above described matter.

1.3 RESEARCH QUESTIONS

This section provides the research questions to be answered in this research. Later chapters discus each of the research questions. To gain understanding of what material kits are, how material kits influence supply chain performance, and how material kits can be designed we define research question 1:

1. *What is the influence of material kitting on supply chain performance and how can material kits be designed?*
    - *How can supply chain activities be categorized and how do (material kit) products influence supply chain activities and supply chain performance?*
    - *What fields of expertise require attention during the design of a new product – in general – and how to adapt this to this special case, material kitting?*

As discussed Chapter 2, designing new material kit products requires design decisions in three interrelated design domains: (1) the product design, (2) the process design, and (3) the supply chain design. Before discussing new material kit designs, Chapter 3 provides insight into the currently applied product, process, and supply chain designs. Therefore, we define research question 2:

2. *What are the current Capitole 40 product, process, and supply chain designs and what are the differences between in-house assembly and OEM assembly?*
    - *What are consequences of the differences in the product, process, and supply chain designs?*
    - *How do we define the value of a (new) material kitting product and process design for Eaton Industries B.V.?*

As discussed in Chapter 3, in-house assembly, satellite assembly, and licensee assembly differ on: the supply chain framework design, product design, process design, and supply chain design. A Root Cause Analysis (RCA) is used to conclude that a new material kit design should reduce the level of differences between the in-house assembly process and the OEM process. Given this point of reference, Chapter 4 discusses new material kit designs. We define research question 3:

3. *What are feasible material kit product and process designs for Eaton Industries B.V.?*
    - *What material kit product and process design do we define to be best for Eaton Industries B.V.?*

As discussed in Chapter 4, both the Capitole 40 product characteristics and the currently applied management policies influence the determination of the best material kit product design. The best material kit process design is determined by estimating the impact on the root causes indentified in Chapter 3 and general financial figures. Given the material kit product and process design, Chapter 5 provides insight into how to manage and control material kitting in the current ERP system (BaaN). Therefore, we define research question 4:

4. *How can the chosen material kit design be managed and controlled in the current ERP system, BaaN?*

As discussed in Chapter 5, BaaN can support material kitting without developing new or additional applications. To advise Eaton Industries B.V. on how to implement material kitting we define research question 5:

5. *How can the chosen material kit design be implemented at Eaton Industries B.V.?*

As discussed in Chapter 6, the change related to the implementation of material kitting is currently passing through the preparation phase. Therefore, the discussion in Chapter 6 focuses on previewing activities in the acceptance and commitment phase.

1.4 RESEARCH APPROACH

The research questions, listed in the previous section, are used to structure the contents of this research.

The first phase of this research is devoted to supply chain performance and product design literature. Goal is to clarify how new – material kit – product designs influence supply chain performance. Chapter 2 discusses this literature.

Chapter 3 describes the current variety in product, process, and supply chain designs within Eaton Industries B.V. To describe these product, process, and supply chain designs information is retrieved from various information sources within Eaton Industries B.V. These sources include Eaton Industries B.V. reports, intranet, business presentations, the Enterprise Resource System (ERP), Cognos, and employee interviews. This part of the research of explorative and descriptive. At the end of this chapter a Root Cause Analysis is constructed, to find the non-evident cause(s) of the problems in the current situation.

Objective is to conclude this chapter with a Root Cause Analysis (RCA). A RCA are used to find the non-evident cause of the major system failure (Staugaitis, 2002).

In Chapter 4 and Chapter 5 various material kit product, process, and process control designs are proposed and discussed. Theories (see Chapter 2), observations (see Chapter 3), and employees' suggestions serve as the main sources of "creative input". Employees of Eaton Industries B.V. serve as the most important source to evaluate the quality and feasibility of various material kit designs. According to Durlauf & Blume (2010), we cannot assume that evaluations these employees are objective (since they lack perfect information). The root causes, identified in Chapter 3, serve as criterion to evaluate various material kit designs.

In Chapter 6 the implementation of material kitting is described from an – organization – change perspective. This chapter provides a roadmap regarding the implementation of material kitting. In this chapter stages and phases of change are classified using the framework of Conner (1992). The enumeration of activities and corresponding goals are the result of observations gained during management and employees interviews and studying Eaton Industries B.V. project procedures.

1.5 RESEARCH SCOPE

Goal of this research is to advise Eaton Industries B.V. on how to design, control, manage, and implement material kitting to supply their OEM partners. In the scope of this research, we will focus our attention to the Capitole 40 switch and distribution system.

In Chapter 2, we define material kits to be a specific collection of components or subassemblies that together support one or more assembly operations for a given product. Therefore, the material kit design and implementation would suggest involvement – at least some – OEM partners of Eaton Industries B.V. to investigate their OEM assembly operations. In this research, we will assume that OEM assembly operations are similar to in-house assembly operations. Furthermore, supplies and agreements with supplies, as well as customers and agreements with customers, are out of scope. Figure 3 provides a visualization of the research boundaries.

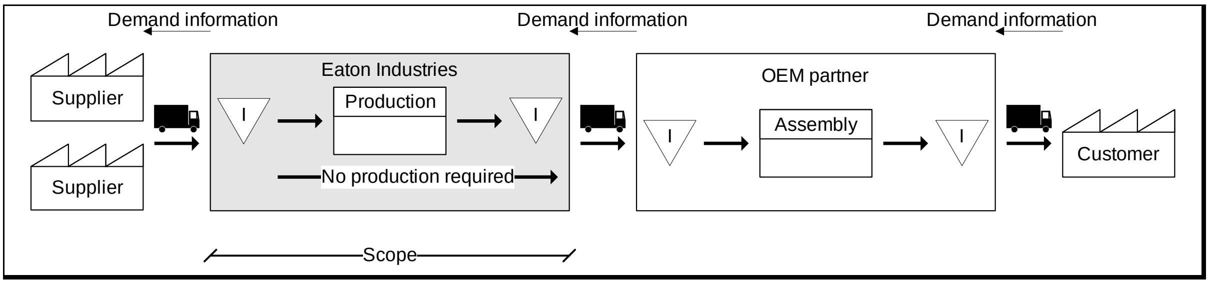


FIGURE 4: BOUNDARIES OF THE RESEARCH WITH REGARD TO THE SUPPLY CHAIN

Chapter 2 discusses the supply chain development program as proposed by Holmberg (2000). According to Holmberg (2000), businesses should adopt supply chain thinking, relate supply chain activities to supply chain performance, and gain understanding in behavioural patterns before deciding on improvement initiatives. At Eaton Industries B.V., these preceding activities have not been conducted before deciding on what to change (implementing material kitting). Therefore, the impact related to the implementation of material kitting on – supply chain – performance cannot be estimated. This research focuses on the design, management, control, and implementation of material kitting – regardless whether material kitting will positively influence business or supply chain performance.

Chapter 2 subdivides the material kit design into three interrelated design domains: (1) the material kit product design, (2) the material kit process design, and (3) the material kit supply chain design. We assume that OEM partners hold no inventories, this is in line with the strategic statements of Eaton Industries B.V. (Stampfel, 2010), and contributes to the ability to compose - customer specific – material kits (see Chapter 3 and Chapter 4).

In Chapter 2, we conclude that the design of material kitting includes job release and material allocation policies. Since job release and material allocation policies influence processes and activities business wide, we strive not to change these policies. Furthermore, a currently ongoing project, central planning, concentrates of these topics.

2 THEORECTICAL FRAMEWORK

This chapter provides a literature review to provide an answer to the question: "*What is the influence of material kitting on supply chain performance and how can material kits be designed?*" How can supply chain activities be categorized, how do (material kit) products influence supply chain activities and performance, what fields of expertise require attention during the design of a new product, and how to adapt this information to material kitting are additional sub questions discussed in this chapter.

Section 2.1 provides insight into supply chain activities and the management of theses supply chain activities. Section 2.2 introduces three interrelated decision domains (product, process, supply chain) to be addressed during the introduction of new products. In Section 2.3, the three decision domains are adapted to the material kitting case. Since Eaton Industries B.V. strives for Lean-production, Section 2.4 provides insight into the Lean-principles and Lean-theories applied the Eaton Lean System (ELS). To support the implementation discussion in Chapter 6, Section 2.5 provides a theoretical framework with respect to - businesses – changes and change management.

2.1 ACTIVITIES IN AND MANAGEMENT OF SUPPLY CHAINS

According to various authors, including Lummus & Vokurka (1999) and Lambert & Cooper (2000), the traditional autonomous business management perspective is changing towards a supply chain management perspective. According to Lambert & Cooper (2000), the competitive success of a single business is highly influenced by the management ability to integrate businesses into supply chains and the management ability to build business relationship networks. This network relationship management is referred to as Supply Chain Management (SCM). Mentzer et al. (2001) describe a difference in SCM between upstream, supplier oriented activities and downstream, customer or consumer oriented activities.

Within a supply chain, two types of SCM activities are identified: (1) the flow and management of demand information and (2) the flow and management of supplies (Frohlich & Westbrook, 2001). Frohlich & Westbrook (2001) define the management of demand information to be a backward oriented SCM activity, in contrast to the management of supplies to be a forward oriented SCM activity. According to them, Just-In-Time (JIT) delivery is a typical example of a forward oriented SCM activity, while integration of information systems to share demand information (e.g. using Electronic Data Interchange, EDI) is a typical example of a backward oriented SCM activity.

Managing activities in a supply chain is a challenging task. According to Holmberg (2000), the fact that supply chains consists of a large number of related and interdependent activities is one of the causes of this challenge. The fact that, at least some, interrelated activities are separated by time or place and are managed by different functional divisions adds even more difficulty. Lambert & Cooper (2000) argue that effective management of supply chains requires a change from managing the individual supply chain functions towards managing integrated activities in a supply chain perspective.

To continuously improve behaviours in supply chains, in order to continuously improve supply chain performance, Holmberg (2000) introduces a stepwise developmental program:

1. adopt system thinking to performance measures;
2. fragment supply chain performance measures into activities;

3. gain understanding in behavioural patterns;
4. influence, structure, or redesign behavioural patterns;
5. update performance measures and go to step 1.

2.2 INTERRELATING PRODUCT, PROCESS, AND SUPPLY CHAIN DESIGNS

Introducing a new, or renewed, product effectively requires multiple organizational resources and competences to collaborate. Stelzer & Ulrich (2010) describe this important collaboration in terms of interrelation between product and process designs.

According to Stelzer & Ulrich (2010), a product design is incomplete without a process (and a process control) design. Fixson (2005) concludes there are three decision domains requiring attention during the introduction of a new product: (1) the product domain, (2) the process domain, and (3) the supply chain domain. Decisions in the product domain have long-term effects and range from product engineering to the development of strategic alliances. Decisions in the process domain typically influence – large scale – production investments and range from production capacity determination to the determination of the manufacturing process type. Decisions in the supply chain domain are typical strategic decisions and range from the determination of production and distribution locations to sourcing agreements.

As above described, design domains interrelate, e.g. product modularity relates to product, process and supply chain domain (Fixson, 2005). According to both Klocke et al. (2000) and Kusiak (2002), product modularity is an important design issue. Product modularity can be considered from three interrelated perspectives: (1) product modularity, (2) process modularity, and (3) resource modularity (Kusiak, 2002). Kusiak (2002) concludes, a modular designed product will positively influences throughput time, manufacturing costs, reliability, quality, and manufacturability.

Considering the process domain, business process redesigns can be divided into three methods: (1) the starting point method, (2) the clean sheet method, and (3) the reference method (Reijers, et al., 2003). In the starting point method, a current process is subject for improvement. The process will be gradually redefined, using the current process as a starting position. The most important drawback of the starting point method is that current impossibilities obstruct the creative freedom. The clean sheet method, also known as the Business Process Reengineering (BPR) described by amongst others O'Neill & Sohal (1999) and Gunasekaran & Nath (1997), copes with this problem by designing a new process from scratch. The most important drawback of the clean sheet method is that details are easily overlooked, causing new designs become invalid. Reijers et al. (2003) describe the so called reference method. In this method a reference process layout is taken to gradually redesign the process under consideration towards this reference process layout. According to Reijers et al. (2003), this method copes with the creative freedom problem, while process details are not easily overlooked.

2.3 MATERIAL KIT DESIGN

The first scientific publications on material kitting originate from the mid 1980s, e.g. Wilhelm & Wang (1986). It was however in the beginning of the 1990s, the amount of publications related to material kitting and the design of material kits steadily increased, e.g. Bozer & McGinnis (1992), Chen & Wilhelm (1993), and Som et al. (1994).

In this research, we use material kit definitions defined and described by Bozer & McGinnis (1992);

- a *component* is a fabricated or purchased part that cannot be subdivided into distinct parts;
- a *subassembly* is the aggregation of two or more components or other subassemblies through an assembly process;
- an *end-product* is the result of one or more assembly operations that requires no further processing in the current facility;
- a *material kit* is defined as a specific collection of components or subassemblies that together supports one or more assembly operations for a given product.

Different authors elaborate on different material kitting topics most often in isolation. Using the domain partitioning as described by Fixson (2005), we subdivided literature related to material kitting into three categories: (1) the material kit product design, (2) the material kit process design, and (3) the material kit supply chain design. Each category is discussed individually.

2.3.1 MATERIAL KIT PRODUCT DESIGN

According to Medbo (2003), the main goal of a material kit product design is to enable and support efficient material handling in the assembly process. Medbo (2003) states, a material kit product design should be in alignment with the standardized work instructions, the operators' handling, and the operators' cognition.

Bozer & McGinnis (1992) distinct two types of material kit product designs: (1) stationary material kits and (2) travelling material kits. Figure 5 illustrates the principle to supply components using travelling material kits. A travelling material kit is supplied at one workstation and consumed over more than one workstation, travelling along with the product.

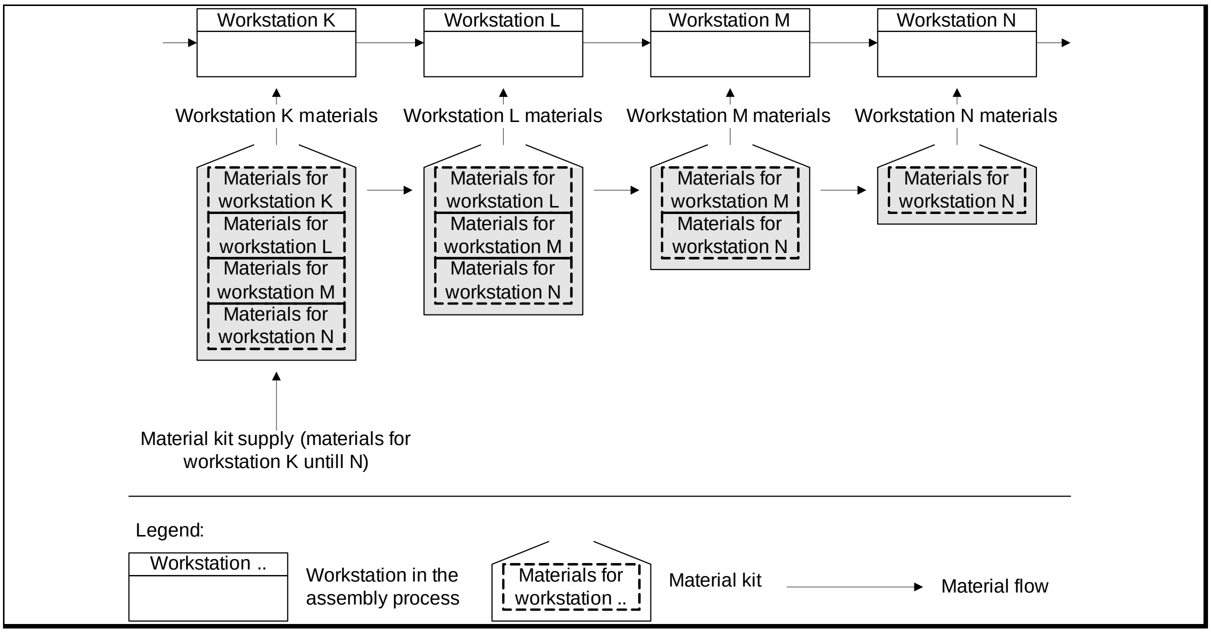


FIGURE 5: TRAVELLING MATERIAL KIT PRODUCT DESIGN (SOURCE: BOZER & MCGINNIS, 1992)

Figure 6 visualizes the alternative stationary material kits. A stationary material kit is supplied and totally consumed at one workstation (Bozer & McGinnis, 1992).

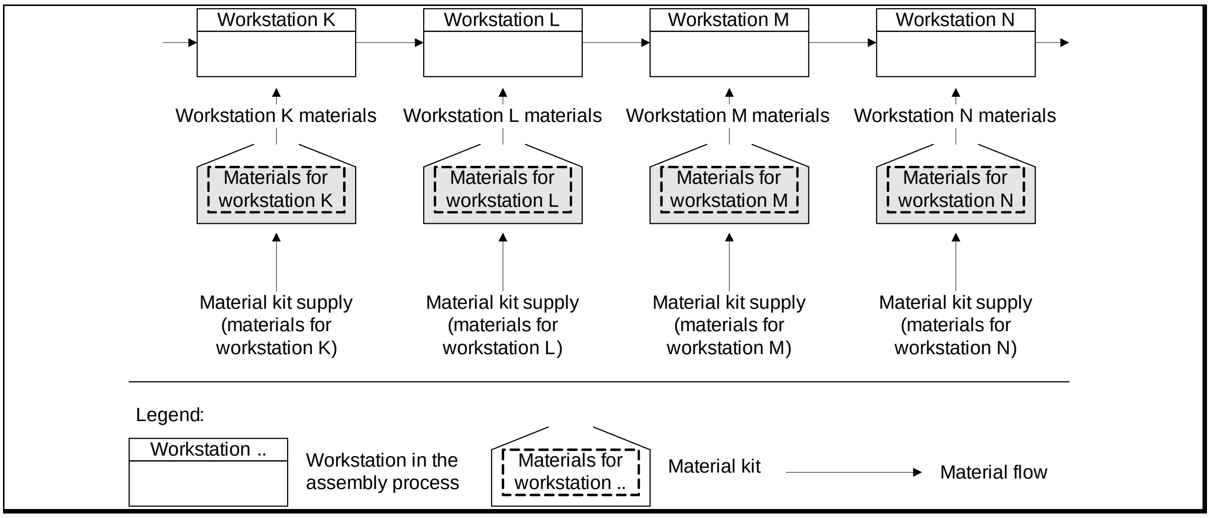


FIGURE 6: STATIONARY MATERIAL KIT PRODUCT DESIGN (SOURCE: BOZER & MCGINNIS, 1992)

According to Bozer & McGinnis (1992), it is not common that a material kit contains all components or subassemblies needed to support on or more assembly operations. Due to weight, physical dimensions, complexity, value, or expendability components (and subassemblies) can be excluded from the material kits.

2.3.2 MATERIAL KIT PROCESS DESIGN

With respect to the material kit process, various authors apply different perspectives when describing the material kit process. Som et al. (1994) and Ramachandran & Delen (2005) focus on the flow of materials in the material kitting process. Wilhelm & Wang (1986) and Chen & Wilhelm (1993), concentrate on job release and allocation policies in the material kitting process. Brynzér & Johansson (1995) describe and compare various order picking methods (e.g. batching, zone picking, etc.) from a material kitting perspective.

Flow of materials

According to both Som et al. (1994) and Ramachandran & Delen (2005), the material kitting process is a compilation of (1) an incoming stream of components and subassemblies, (2) an accumulations process, and (3) an outgoing stream of material kits.

The flow of components and subassemblies through the material kit accumulation process can be described as a stochastic process, including arrival streams, queues, and processing times. The flow of materials, through the accumulation process, in the material kitting process plays a crucial role and influences the performance of the material kitting process (Ramachandran & Delen, 2005). Ramachandran & Delen (2005) present an optimization model minimizing the total set of associated costs in the kitting process, including holding and shortage costs.

Som et al. (1994) conclude, if all incoming streams of components and subassemblies have similar Poisson parameters, the outgoing stream of material kits can be described using a similar Poisson stream. In their model, Som et al. (1994) use the double-ended queue described by Dobbie (1961) and Kashyap (1965). According to Som et al. (1994), this approximation offers the ability to decouple material kitting processes from assembly processes.

Job release and allocation policies

According to Chen & Wilhelm (1993), the job release and allocation problem in case of the material kitting can be interpreted as a resource-constrained, multi-project scheduling problem.

Chen & Wilhelm (1993) distinguish two types of allocation heuristics: (1) on-hand stocks are allocated to a specific material kit and (2) on a daily basis material kit requirements are released (and components are allocated to specific material kits) only if all requirements are available. Chen & Wilhelm (1993) state that the resource allocation problem, that can be used to solve this problem, is NP-hard. Therefore, heuristics used to find – near optimal – solutions should incorporate four goals simultaneously: (1) a good material kitting job sequence, (2) low material kit tardiness, (3) low material kit earliness, and (4) low subassembly holding costs.

Chen & Wilhelm (1993) argue that the material kit allocation policy should clarify whether it is possible for components and subassemblies to 'catch up' with material kits. Catching up of components implies that uncompleted kits are released and the 'catch up components' are treated with special attention in the system to catch up with the corresponding kit. According to both Chen & Wilhelm (1993) and Wilhelm & Wang (1986), catching up of components should be discouraged.

According to Wilhelm & Wang (1986), the job release and allocation problem in case of the material kitting can be solved using MRP (Material Requirements Planning) techniques. Most important drawback when using MRP is that the use safety lead-times imply a dual risk for both early and late deliveries.

Order picking policies

The order picking process highly influences both performance and accuracy of the material kitting process (Brynzér & Johansson, 1995). Brynér & Johansson (1995) define four decisions that influence the material kitting – order picking – process:

1. to use automatic storage and retrieval system, described by amongst other de Koster et al. (2007);
2. to use batch picking;
3. to use picking zones;
4. to use additional tools (e.g. pick to light, barcode scanning, or weight checking).

According to Brynér & Johansson (1995), the usage of automatic storage and retrieval systems and the used of additional tools have a positive effect on the material kitting accuracy. In contrast to batch picking and zone picking, this negatively influences the material kitting accuracy. According to Brynér & Johansson (1995), batch picking in particular should be discouraged in material kitting processes.

2.3.3 MATERIAL KIT SUPPLY CHAIN DESIGN

As described in Chapter 1, both agreements with suppliers and agreements with customers are out of scope. Therefore, this section focuses on the Customer Order Decoupling Point (CODP) and the policies to manage forecast driven inventories.

According to Hoekstra & Romme (1992), the CODP specifies the distinction between forecast driven processes and demand driven processes. In the COPD discussion, Hoekstra & Romme (1992) assume that the downstream buyer is the – ultimate – end customer. Others, including Mason-Jones et al. (2000), argue that each individual business within a supply chain has its own COPD.

Figure 7 visualises the four CODPs described by Mason-Jones et al. (2000). It is important to note that each party in the supply chain has its own reference point and can have its own stock policy. Therefore, one product can have more CODP classifications in one supply chain.

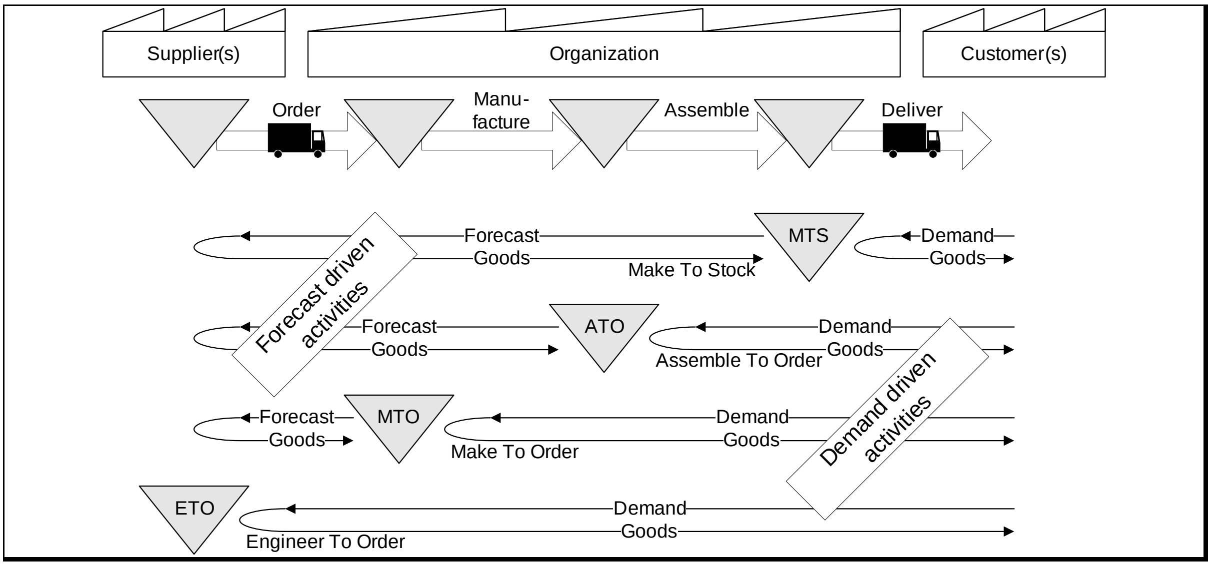


FIGURE 7: CUSTOMER ORDER DECOUPLING POINT (SOURCE: HOEKSTRA & ROMME, 1992)

Hoekstra & Romme (1992) define the of the four different CODP in Figure 7 as;

- Make To Stock (MTS): products are manufactured, assembled, and stored in a central stock point at the end of the assembly process based on forecasts. Customers are supplied from this stock point;
- Assemble To Order (ATO): only components and subassemblies are produced based on forecasts, end-products are assembled based on customer specifications;
- Make To Order (MTO): components are purchased based on forecasts, each system is produced and assembled based on customer specifications;
- Engineer To Order (ETO): no stocks are kept. For each system components are purchased, produced, and assembled based on customer specifications.

Managing forecast driven inventories and reducing costs associated to forecast driven inventories is widely discussed in literature. Two methods to reduce – forecast driven inventory – costs are: (1) aggregating – safety – stocks described by Zinn, et al. (1989) and (2) reducing the variety of forecast driven components, described by Collier (1982) and Baker et al. (1986).

According to Zinn et al. (1989), safety stocks serve to buffer against uncertainties for one or more downstream processes or customers. Aggregating stock points – including safety stocks – will positively influence the total stock level for a given service level. Zinn et al. (1989) refer to this effect as the Portfolio Effect (PE). The Portfolio Effect is influenced by the magnitude in demand variation and the correlation of demand patterns.

Reducing the variety of forecast driven components is often referred to as risk pooling and described by various authors, e.g. Collier (1982) and Baker et al. (1986). Risk pooling describes the relationship between component commonality, stock levels, and service levels. Collier (1982) introduces an equation to express component commonality, influenced by: (1) the number of end-products served by a component and (2) the lateness of dedication to a certain end-product. According to Gerchak et al. (1988), component commonality has a performance maximizing impact, although the exact impact strongly depends on the type of performance measurements used.

2.4 THE EATON LEAN SYSTEM AND THE UNDERLYING LEAN-PHILOSOPHIES

Eaton Industries B.V. strives for Lean-production. Figure 8 visualizes the Eaton Lean System (ELS) chart (Eaton Holec, 2004). This chart highlights the eight major Lean-tools in use at Eaton Industries B.V. To provide more insight into the ELS further clarification on each of these Lean tools is provided.

FIGURE 8: THE EATON LEAN SYSTEM CHART (SOURCE: EATON HOLEC, 2004)

Value Stream Mapping (VSM)

VSM is a tool used to gain insight into the companywide picture. VSM requires information of the total value stream, from end-to-end over the entire plant. This includes supplier logistics, processes, and customers. (Narusawa & Shook, 2009). Value Stream Mapping is often referred to as material and information flow mapping and can be used define opportunities and possibilities for discontinuous, companywide improvements.

5S

5S refers to the collection of terms forming the basis of each Kaizen activity. According to Narusawa & Shook (2009), the five Ss and their meanings are:

- sort out, separate needed from not needed things;
- set in order, arrange things so they are easy to use (possibly in the sequence of usage);
- shine, keeping the work area and machines clear and inspect for abnormalities;
- standardize, work stations and work instructions should be identical for identical jobs. The first three Ss contribute to standardization;
- sustain, once the first four Ss have become the new standard action should be take in order to prevent from declining back to the old situation. Therefore, the first 4 Ss should continuously be reviewed and improved.

Standardized work

Standardized work forms the basis to perform operations and make correct products in the safest, easiest, and most effective way (Narusawa & Shook, 2009). Business developed techniques and tools serve as a handle when defining standardized work instructions.

Total Productive Maintenance (TPM)

TPM involves production workers and maintenance activities to reduce various losses in machinery (e.g. breakdowns, changeovers and adjustments, minor stoppages, speed losses, scrap, and rework). Proper TPM positively influences availability rates, performance rates, and quality rates of equipment (Narusawa & Shook, 2009).

Error proofing

Error proofing, or poka-yoke, implies using simple – and inexpensive – devices to help operators avoiding mistakes. Error proofing should prevent using wrong parts or leaving out parts.

Set up reduction

Set up reductions contribute preventing batch production and contributes to the ability to reduce inventories and inventory holding costs. According to Narusawa & Shook (2009), set up reductions are relatively easy achievable in downstream assembly processes, while upstream processes are, in general, more batch oriented.

Continuous flow

Continuous flow stands for producing and moving one item at a time, matching the takt time of the downstream process without stagnation or any waste in between (Narusawa & Shook, 2009). Beside continuous flow, takt time and a pull system contribute to the ability to produce Just-In-Time (JIT).

Pull system

A pull system is used to improve the ability to produce JIT. Pull stands for providing the customer or downstream process with what is needed, when it is needed, and in the amount it is needed according to the signal from the downstream process.

2.5 CHANGES AND CHANGE MANAGEMENT

Chapter 6 of this research discusses the implementation of material kitting at Eaton Industries B.V. This section provides insight to business changes.

According to McCann (1991), the competitive position of businesses is determined by the configuration of four key competitive elements embedded in each business. Both McCann (1991) and Daft (2004) state that organizational or business changes require changes in one or more of these four interrelated competitive elements.

First, the four competitive elements of McCann (1991) are introduced. Second, methods on how to manage the change in each of these competitive elements are provided. Last, the phases and stages of change, introduced by Conner (1992), are discussed.

Four competitive elements of a business

According to McCann (1991), the competitive position of a business is the result of the applied configuration of the four key competitive elements within a business: (1) the products and services offered by a business, (2) structures and systems within a business, (3) people in the business organization, and (4) technologies and skills mastered by a business. Daft (2004) argues that changes will affect a combination of these interrelated elements.

Element 1: Products and services

The products and services element, described by McCann (1991), concerns all the products, including all the associated services, offered by a business to their customers. Changes in the products and services element include both small and large adoptions of existing products or services and the introduction of new products and services. According to Daft (2004), changes in products and services element are generally intended to increase or further develop markets share.

Element 2: Structures and systems

The structures and systems element concerns all administrative domains, the supervision, and the management functions of a business (Daft, 2004). The goal of structures and systems is two-fold: (1) structures and systems should provide structure and guidance to support daily business operations and (2) structures and systems should be uncluttered and adaptable to provide flexibility (McCann, 1991).

Element 3: People

Both Daft (2004) and de Wit & Meyer(2004) state that people in an organization can be described by means of values, attitudes, expectations, beliefs, abilities, and behaviours. According to McCann (1991), the influence of this element has such a significant influence on the business competitive composition, that selecting and developing people within an organization could be the most important business activity influencing the competitive position of a business.

Element 4: Technologies

Business technologies refer to more than the tangible process technologies of a business. Technologies include both tangible process technologies and the entire knowledge and skill base (McCann, 1991). The element technologies includes all techniques related to the production of products and services. Therefore, changes in technologies can serve two distinct goals: (1) support the introduction of new products and services and (2) improve the processes for existing products and services.

Changes and their relation to the business

Changing products and services

According to Daft (2004), adapted or new products and services are a special case of change (or innovation), because the adapted or new product and service will be used by customers outside the organization. Since products and services should meet the requirements of the environment, uncertainty about the success of an adapted or new product or service is very high. Cooper (1979) argues that the likelihood of successful product or service introduction is improved if:

- the new product or service is superior in meeting market requirements in comparison to competing products and services;
- the new product or service takes advantage of competitive resources of the business;
- during the development phase, considerable resources have been devoted to gain technical and market information;
- the resources required for the product or service reveal a high degree of compatibility with current available business resources.

Changing structures and systems

Since the goal of structures and systems is to structure business processes, changing structures and systems could be a direct cause of a change in products and services element or technologies element (Daft, 2004).

De Wit & Meyer (2004) distinguishes two approaches to implement these structures and systems changes: (1) top-down and (2) bottom-up. According to Daft (2004), the top-down approach suites bureaucratic organizations (e.g. government, financial, or legal sectors), while the bottom-up approach best suites organizations in which lower-level employees have (more) freedom and autonomy.

Changing people

Businesses and organizations are made up out of people and relationships of people with one another. Changes in strategy, products and services, structures and systems, or technologies do not happen on their own; people will be involved in each of these changes.

Hayes (2007) considers organizations to be a collection of internal – and external – stakeholders, each pursuing their own objectives. In the perspective of Hayes (2007), individuals and groups attempt to influence each other in the pursuit of self-interest. Therefore, the power and influence of individuals and groups influences the outcome of change processes. De Wit & Meyer (2004) describe individuals by means of an attitude and behaviour towards the change (see Figure 9). According to them, initiatives to influence attitude and behaviour can be a combination of one or more management policies: (1) issue management, showing people they can do it; (2) management of perceptions and beliefs, clarifying people they should do it; and (3) power and politics management, clarifying people they have to do it.

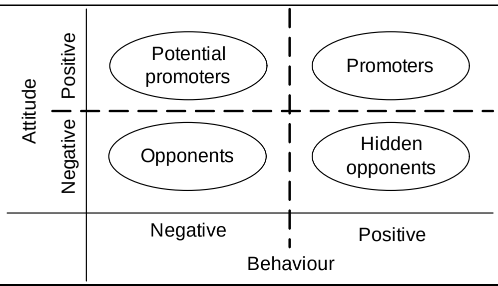


FIGURE 9: ATTITUDES AND BEHAVIOURS OF INDIVIDUALS AFFECTED BY CHANGES (SOURCE: DE WIT & MEYER, 2004)

Changing technologies

As described above, changes in business technologies include the tangible business process technologies supplemented by business' knowledge and skill base. According to Merrifield (1993), bottom-up incentives to change and improve business technologies are the most important source for technologies changes to improve the competitive advantage of a business. According to him, top management commitment and non bureaucratic business systems should enable business to benefit from this latent entrepreneurial spirit.

Phases and stages of change

Conner (2011) introduces an eight stage model to efficiently support attitude, behaviour, and acceptance of changes. Figure 10 illustrates this model, consisting out of three phases: (1) the preparation phase, (2) the acceptance phase, and (3) the commitment phase. Each stage is discussed separately below.

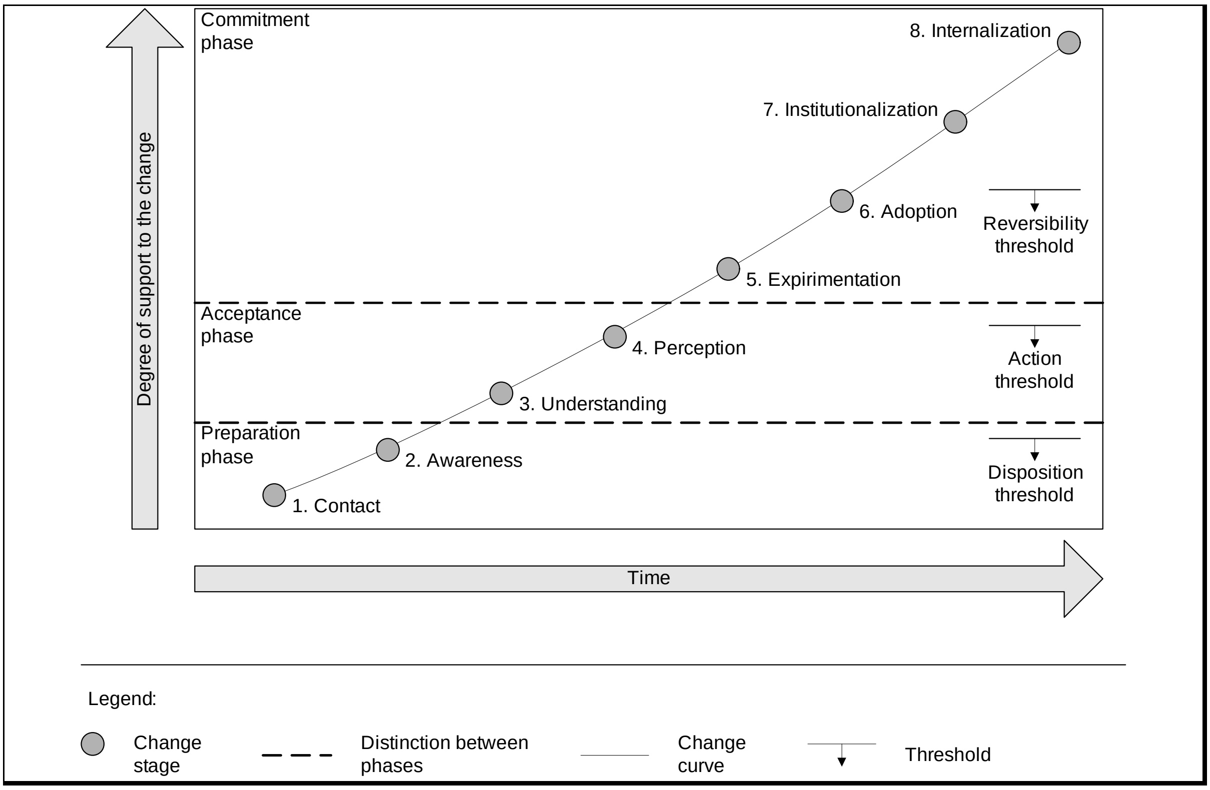


FIGURE 10: STAGES OF COMMITMENT TO CHANGE (SOURCE: CONNER, 2011)

Stage 1: Contact

The contact stage focuses on making people aware of the change. Various kinds of communication tools can be used to communicate the change with the intention to make people aware of the change (Daft, 2004). Activities in this phase should positively influence the attitudes of people (Conner, 2011).

Stage 2: Awareness

Awareness, stage 2 in the preparation phase (see Figure 10), implies that everyone affected by a change realizes that the change will affect their work (Conner, 2011). In this stage, people do not have to understand the full implications of the change. Making people aware of the change should positively influence their behaviour and acceptance.

Stage 3: Understanding

Understanding, the first stage in the acceptance phase, focuses on making people fully understand the impact of the change on their work (Daft, 2004). According to Conner (2011), activities in this stage are obstructed by the fact that individuals are influenced by their own cognitive and emotional filters and their personal perceptions. Making people understand the change increases their perception in the next stage.

Stage 4: Perception

Conner (2011) argues that people decided to support or not to support the change in the perception stage. The decision to support the change can be influenced by all three management policies introduced by de Wit & Meyer (2004). If an organization fails to achieve change perception, the change process is expected to become inactive.

Stage 5: Experimentation

The experimentation stage, the first stage in the implementation phase, focuses on gaining people's involvement and support to increase the acceptance and commitment to the change (Conner, 2011). According to Daft (2004), this stage provides to opportunity to find, discuss, and solve problems. Goal of the experimentation phase is to stimulate people to continue further exploration of the change (Conner, 2011).

Stage 6: Adoption

In the experimentation phase, benefits of the change are demonstrated and individuals involved in the experimentation phase should agree on details describing the change before the adoption phase can take-off (Conner, 2011).

In the adoption phase, in contrast to the experimental phase, attention has to be devoted to how things should work and who should be responsible for what (instead of testing and proving things can work). According to Conner (2011), this stage is the latest possible stage in which changes can be rejected.

Stage 7: Institutionalization

The institutionalization stage follows directly after the decision – definitely – to not reject the change (Conner, 2011). From this moment on, power and politics management, described de Wit & Meyer (2004), can be used to influence undesirable behaviours.

Stage 8: Internalization

Internalization refers to the individuals in the organization adapting the roots for their attitudes and behaviours (Conner, 2011). In this stage the change is no longer seen as a change, but as the new standard.

2.6 CONCLUSIONS FOR THIS CHAPTER

This chapter provides an answer to the research question: "*What is the influence of material kitting on supply chain performance and how can material kits be designed?*".

To answer the first part of the above described research question, what is the influence of material kitting on supply chain performance, we first distinct two types of supply chain activities: (1) the flow and management of demand information and (2) the flow and management of supplies (Frohlich & Westbrook, 2001). We classify material kitting to be a forward oriented activity, focussing on the flow and management of supplies.

According to both Holmberg (2000) and Daft (2004), a market (or supply chain) research is necessary to approximate the influence of new products on supply chain performance. Holmberg (2000), elaborating on supply chains structures and supply chain improvements, suggests a five stage program. In the first stage of Holmberg's program, organization should evaluate performance using supply chain performance measurements, after which supply chain performance measure can be linked to one or more supply chain activities. Linking supply chain activities to supply chain performance offers the opportunity to gain understanding in behaviour patterns within the supply chain before deciding on what and how to influence, restructure, or redesign these behaviour patterns. Since no market research – related to the supply chain activities, performance, and behaviour patterns – is conduced, we are unable to approximate the impact of material kitting on supply chain (or business) performance.

To answer the second part of the above described research question, how can material kit be designed; we conclude that material kitting can be considered a special case of the new product design and implementation. Fixon (2005) proposes three interrelated design domains involved in the design phase of a product: (1) the product design, (2) the process design, and (3) the supply chain design. These decision domains are interrelated, because some product design issues relate to two or three of these design domains.

During this literature review, we conclude that those authors describing material kitting focus primarily on (parts of) the material kit product design or the material kit process design. Using the decisions domains of Fixon (2005), we define a material kitting product domain (describing the material kit product design), a material kitting process domain (describing the material kitting process design), and a material kitting supply chain domain (describing the material kitting supply chain design).

We conclude that the material kit product domain, defining the material kit product design, includes two material kit product design issues:

Material Kit Product Design Issue 1:	Define the preferred material kit type, travelling or stationary;
Material Kit Product Design Issue 2:	Define policies to exclude components from the preferred material kit type.

We conclude that the material kit process domain, defining the material kit process design, includes four material kit process design issues:

Material Kit Process Design Issue 1:	Define the flow of materials;
Material Kit Process Design Issue 2:	Define job release policies;
Material Kit Process Design Issue 3:	Define order picking methods;
Material Kit Process Design Issue 4:	Define methods and policies to guarantee material kitting accuracy.

We conclude that the material kit supply chain domain, defining the material kit supply chain design, includes one material kit supply chain design issue:

Material Kit Supply Chain Design Issue 1:	Define the position of the Customer Order Decoupling Point.

3 CURRENT PRODUCT, PROCESS, AND SUPPLY CHAIN DESING

This chapter discusses the current product, process, and supply chain designs of Eaton Industries B.V. to answer the research question: "*What are the current Capitole 40 product, process, and supply chain designs and what are the differences between in-house and OEM assembly?*". Additional sub question to be answer in this chapter are: what are the consequences of the differences in the product, process, and supply chain designs and how to define the value of a (new) material kit product and process design.

This chapter describes and compares the in-house assembly process and the OEM process. All comparisons start describing the in-house assembly process. We apply this procedure for two reasons: (1) the majority of processes are initially designed for in-house assembly and thereafter converted to OEM and (2) the mindset of the majority of employees at Eaton Industries B.V. is in-house oriented.

Section 3.1 provides some basic insights into the Capitole 40 and its characteristics. Section 3.2 describes the daily used policies to manage, control and coordinate materials and capacities. Section 3.3 elaborates on the applied SCM procedures to manage and coordinate supplies. Section 3.4 discusses both the in-house assembled and OEM assembled product designs. Section 3.5 discusses both in-house assembly process and the OEM processes designs and Section 3.6 discusses both supply chain designs. Section 3.7 provides an overview of causes and root causes why the OEM product and process design do not support the strategic goals of Eaton Industries B.V. The last section, Section 3.8, provides the conclusions for this chapter.

3.1 INTRODUCTION TO THE CAPITOLE 40

The Capitole 40 is a low voltage switch and distribution system. Capitole 40 designs are a compilation of multiple panels and drawers (see Figure 11). According Stampfel (2010), the Capitole 40 is currently passing through the maturity state of the product life cycle and is expected to attain the decline state in 2014. The product life cycle, used to describe evolutionarily stages products are expected to pass through, can be used to predict the course of product evolution, these stages and evolutionary transitions are described by, amongst others, Klepper (1996).

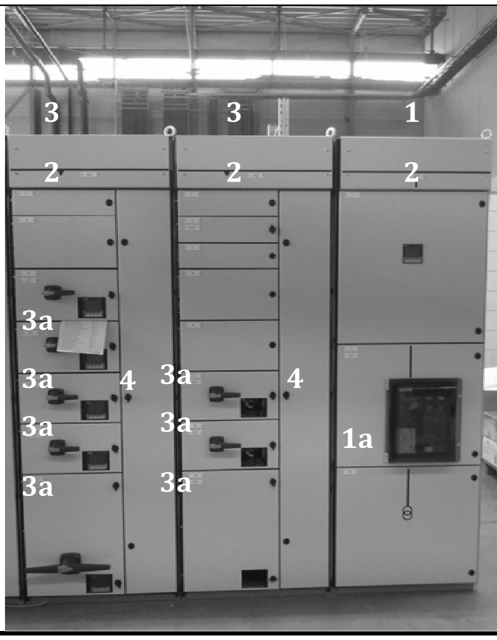


FIGURE 11: ILLUSTRATION OF A CAPITOL 40

Material requirements are specified using BOMs (Bills Of Material), within Eaton Industries B.V. often referred to as modules or typicals. A BOM contains one or more components and possibly lower level BOMs. Each of these components and BOMs can be made customer specific in order to comply with customer requirements. Within a Capitole 40 system, a variety of basic functions can be distinguished (see Figure 11);

- incoming feeders (1), including circuit breakers (1a);
- horizontal busbars (2);
- outgoing panels (3), including one or more drawers (3a) and fixed compartment (not visualized);
- cable-entry compartments (4).

The Capitole 40 marketing slogan states “full personal safety, optimum operational reliability and application flexibility, uniquely combined in standard design” (Eaton Electric B.V., 2007). In practice, this implies that the Capitole 40 is relatively expensive compared to competitors’ switch and distribution systems, but is esteemed for the fact that customers can request for adjustments on the basic design.

3.2 MANAGEMENT AND CONTROL OF THE PRODUCTION PROCESS

At Eaton Industries B.V., BaaN is used as Enterprise Resources Planning (ERP) system. BaaN provides daily production and purchase advises. Furthermore, production schedules within BaaN are used for internal material coordination and transportation.

Figure 12 visualizes the Manufacturing Recourse Planning (MRP II) hierarchy with BaaN at Eaton Industries B.V. Figure 12 is an adaption of the MRP II hierarchy described by Hopp & Spearman (2008). In Figure 12, three hierarchal levels are present: (1) the long-range strategic planning, (2) the intermediate-range tactical planning, and (3) the short-term operational control. Activities in this figure are part of a hierarchal level (strategic, tactical, or operational) and a functional area (technological planning, resource capacity planning, or material coordination), described by Hans et al. (2007).

In the long-range strategic planning (up to 12 months), Sales Inventory and Operations Planning (SIOP) meetings form the pivot between sales (forecasts) and the compilation of the Master Production Schedule (MPS). The primary goal of SIOP meetings is to balance demand and supply and aligning forecast expectations over all departments (including finance, supply chain, engineering, and materials planning).

In the intermediate-range tactical planning (up to 13 weeks), MPS information and order intake information is used for MRP (Material Requirements Planning) calculations. Fed by BOMs, inventory information, and planning MRP provides purchase and production advices. The production planning, schedules and releases production orders based on urgency, availability of capacity, availability of materials, and the production mix. The production (and capacity) schedule is the most important planning input controlling shop floor operations.

Different tools are used to manage and control activities in the intermediate-range planning for Low Voltage Components (LVC), Low Voltage Systems (LVS), and Medium Voltage Systems (MVS). Reason for this difference leads back to before 2003, when these three product families were autonomous business units. In the year 2003, these three business units merged to one business unit and one ERP system. All three product families are managed and controlled in the same BaaN system, although applications in the intermediate-range level differ.

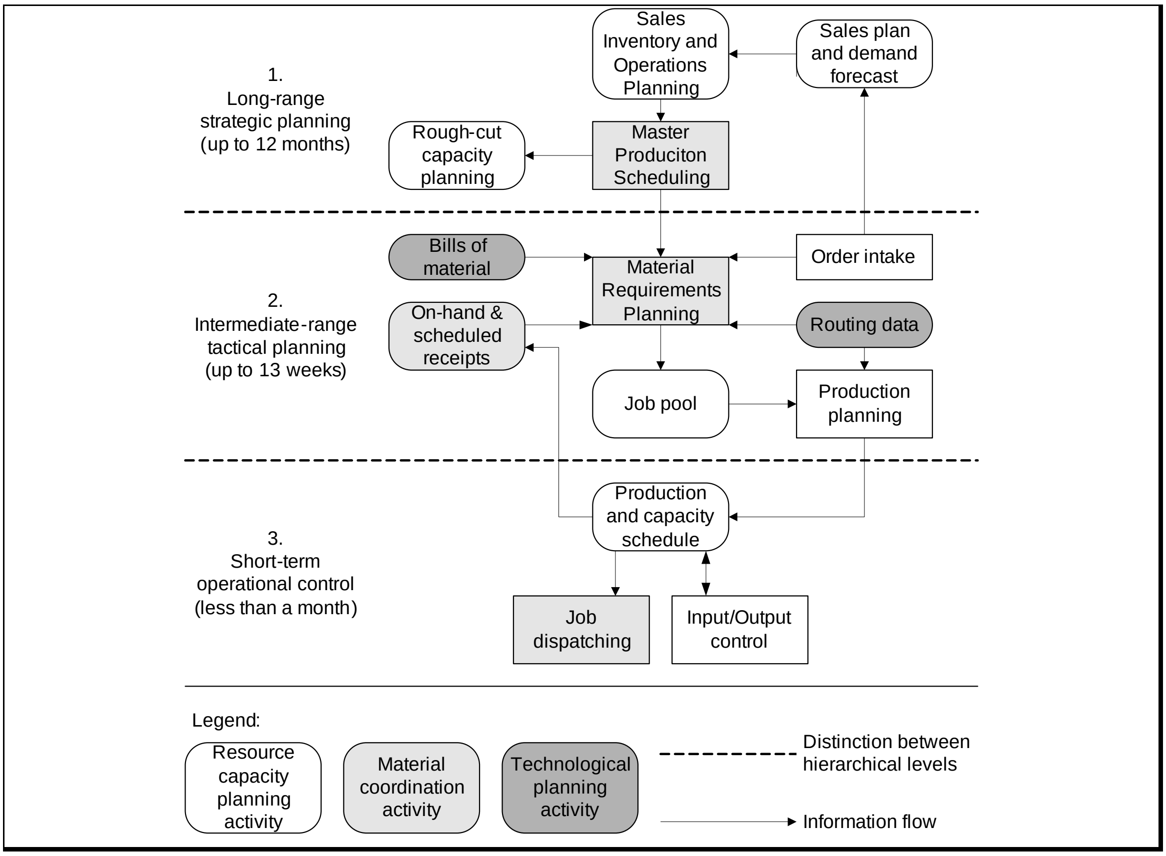


FIGURE 12: THE MRP II HIERARCHY IN BAAN AT EATON INDUSTRIES B.V.

3.3 MANAGING THE SUPPLY CHAIN: THREE DIFFERENT SUPPLY CHAIN FRAMEWORKS

As discussed in Chapter 2, two key SCM activities are: (1) managing the flow of demand and demand information and (2) managing the flow of supplies. At this stage, it is useful to introduce a distinction between in-house assembly, satellite assembly, and licensee assembly when describing different supply chain frameworks.

Figure 13 visualizes the supply chain framework for the in-house assembly process. The process organization is as follows: the end-customer requests a quotation at Eaton Industries B.V., Eaton Industries B.V. has the knowledge and experience to make and offer quotations. In case a quotation results in an order, the goal is to supply the end-customer on the agreed due date.

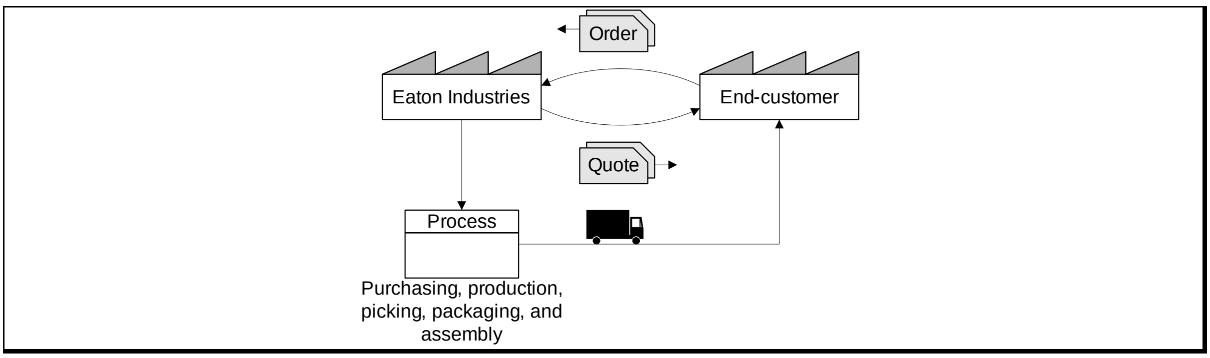


FIGURE 13: SUPPLY CHAIN FRAMEWORK FOR IN-HOUSE ASSEMBLY

Figure 14 visualizes the supply chain framework for the satellite assembly process. In contrast to the in-house assembly process, the end-customer requests a quotation at a satellite partner. Satellite partners have the knowledge and experience to make and offer quotations. Satellite partners purchase and produce customer specific components and assemble the Capitole 40 system. In general, satellite partners keep inventories, therefore supplies from Eaton Industries B.V. to their satellite partners are based on components usage (inventory levels).

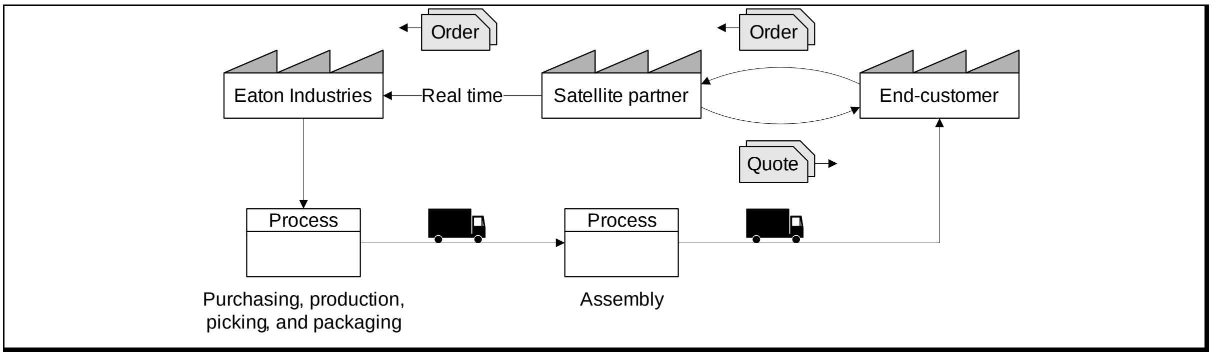


FIGURE 14: SUPPLY CHAIN FRAMEWORK FOR SATELLITE PARTNERS

Figure 15 visualizes the supply chain framework for the licensee assembly process. In contrast to the satellite and the in-house assembly process, the licensee partners have no or limited knowledge and experience to offer quotations to end-customers. Therefore, Eaton Industries B.V. supports their licensee partners during the quotation phase on engineering and pricing. In case a quotation results in an order, licensee partners order all needed components required for the project at Eaton Industries B.V. In contrast to satellite partners, licensee partners keep no inventories.

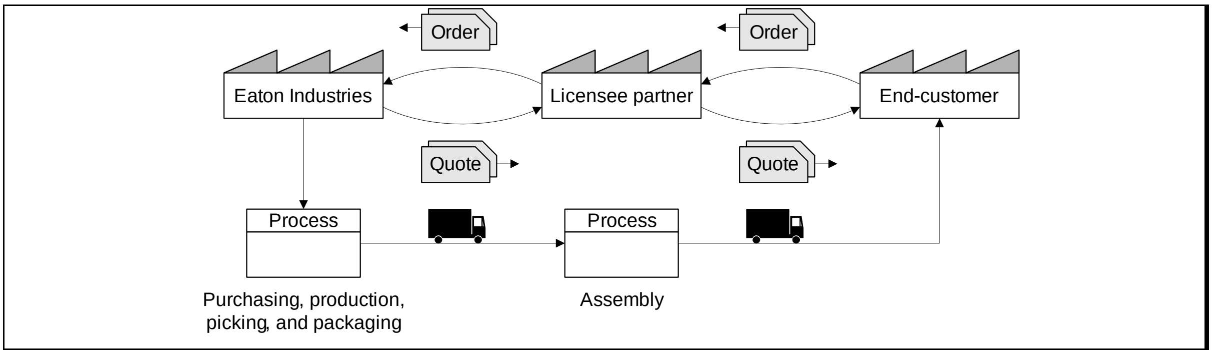


FIGURE 15: SUPPLY CHAIN FRAMEWORK FOR LICENSEE PARTNERS

Beside the differences in the supply chain framework design, Table 1 provides an overview of organizational differences between satellite and licensee partners. Since Eaton policies state that non Eaton companies have no access to Eaton information systems, ownership is the all-determining factor.

	Satellite partner	Licensee partner
Ownership	By the Eaton Corporation	Not by the Eaton Corporation
Order intake	Using integrated IT systems	Communicated through the customer support department of Eaton Industries B.V.
Supply on basis of	Predefined range of components (fixed or variable quantities)	Projects (the majority of components are supplied per project, based on material requirements)
Supply regularity	Predefined number of shipments per week, currently one or two	A predefined number of shipments per project, currently varying between one and seven

TABLE 1: ORGANIZATIONAL DIFFERENCES BETWEEN SATELLITE AND LICENSEE PARTNERS

3.3.1 CURRENT STATE PERFORMANCE

According to Beamon (1999), people in an organization are expected to concentrate on what is measured. Therefore, performance indicators, used to measure supply chain or business performance, should be in alignment with the strategic goals of a business or supply chain and consist of a multiple of unbiased performance measures (Beamon, 1999). Furthermore, using multiple unbiased performance measures should prevent from deterioration on the not measured business aspects.

Performance measures at Eaton Industries B.V. are subdivided into four key performance drivers: (1) growth and customer satisfaction, (2) achieve profit plan, (3) operational excellence, and (4) build organizational capabilities. Appendix B provides an overview of the plant wide performance over the years 2009, 2010, and 2011. Cognos (reporting software in use at Eaton Industries B.V.) reporting indicate that the OEM related turnover equals 4.5% of the total turnover in 2009, decreasing to 2.9% of the total turnover in 2010.

The performance measures in use at Eaton Industries B.V. (and provided in Appendix B) do not provide detailed information on the OEM process' performance. On-time Performance (OTP), one of the most important performance measurements, is registered manually for the two largest satellite partners (Brussel and Birmingham) of Eaton Industries B.V., see Figure 16. This measurement indicates 18 out of 24 below target measurements over the year 2010.

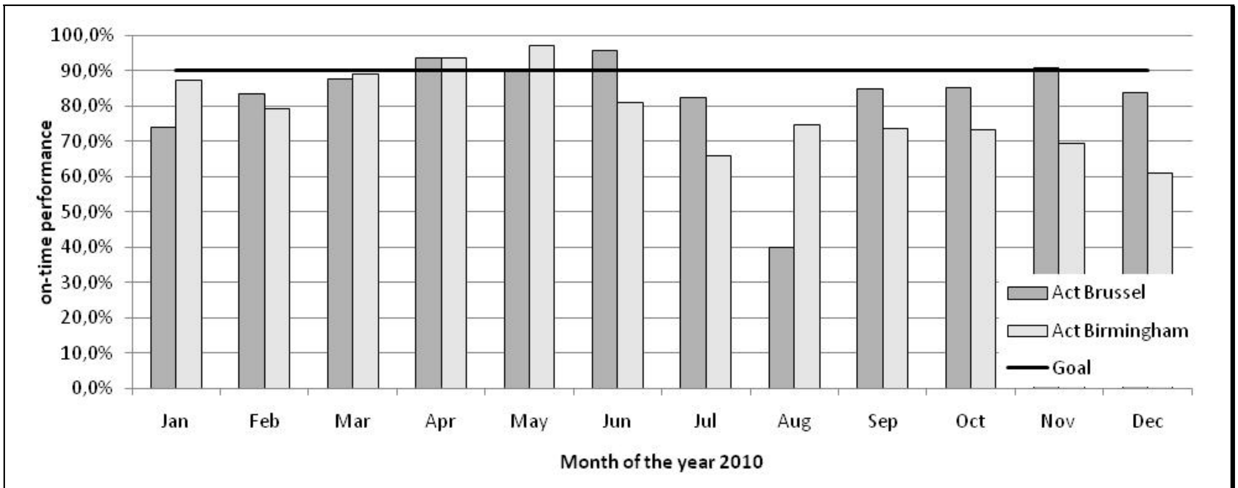


FIGURE 16: OTP MEASUREMENT FOR THE SATELLITES BRUSSEL AND BIRMINGHAM OVER 2010

Within Eaton Industries B.V., there is no univocal performance measurement reflecting on the licensee performance. However, regardless of the performance measurement outcome, it is valuable to provide insight into the method used to measure licensee OTP. Table 2 serves as an illustration.

After an order is confirmed, agreements are set defining how many shipments will take place and which components will be supplied in which shipment. This segmentation is based on: (1) expected capacity utilization at Eaton Industries B.V. and (2) preferences of the licensee partner. For the illustrative case in Table 2, all drawer components are scheduled for the 28th of February, all panels components are scheduled for the 7th of March, and all the main busbar components are scheduled for the 14th of March. If Eaton Industries B.V. fails to supply a component on the scheduled due date, but the component is supplied before or on the 28th of March, this component is measured as on-time. Therefore, components first needed in the assembly process of a drawer (e.g. a mounting plate) can be supplied a month later than agreed upon (and scheduled for), but still be measured as on-time.

Shipment no.	Content of the shipment	Date of shipment	Freight type	On-time
1	Drawers	28th of February 2011	Sea	Yes
2	Panels	7th of March 2011	Sea	Yes
3	Main busbars	14st of March 2011	Sea	Yes
4	Remaining components	28th of March 2011	Air	Yes
		On-Time Performance measurement		
≥ 5	Remaining components	Soon as possible	Air	No

TABLE 2: EXAMPLE TO ILLUSTRATE LICENSEE DELIVERY AGREEMENTS AND OTP MEASUREMENT

3.4 PRODUCT DESIGN

In Chapter 2, we concluded that product, process, and supply chain designs are highly interrelated design topics. This section first describes the in-house assembly product design, before describing the – derivative – OEM assembly product design.

Discussed in Chapter 2, modularly relates to both product and process design. According to Fixson (2005), product modularity and process modularity are mutually reinforcing and, according to Kusiak (2002), product modularity has a positive effect on throughput time, manufacturing costs, reliability, quality, and manufacturability.

Eaton Industries B.V. uses a modular Capitole 40 product design. However, we do not observe a modular process (design). We conclude, based on interviews and observations that the most important causes why the modular product design is not contributing to a modular process design are:

- Eaton Industries B.V. offers a wide range of Capitole 40 – design – modules (over 4,500 different BOMs). The production and assembly process supports all of these product modules. Therefore, when considering the process – design – attention is devote to be able to support the exceptional case, instead of concentrating on the general – possibly modular – case.
- the product design modules are sales oriented, not process oriented;
- the material specification of the final modular Capitole 40 product design is not 100% reliable (better known as the unreliable master data problem);
- all of the material requirements, specified in the BOMs, can be modified due to customer specific requirements. All of these – possible – modifications are supported in the production and assembly process.

3.4.1 PRODUCT DESIGN FOR OEM ASSEMBLY

In Chapter 2, an end-product is defined as the result of one or more assembly operations that requires no further processing in the current facility. Since OEM partners carry out the assembly operations for a Capitole 40, end-products for in-house assembly and OEM assembly differ.

In the OEM assembled product design, systems are supplied as a collection of components, instead of a functional system. All materials specified on the Bills of Material (BOMs) are listed on a sales order, picked, packed, and supplied. The end-product and product design for satellites and licensee partners differ. Cause for this difference is the methods to supply satellites partners (frequent supplies by truck) and licensee partners (a fixed number supplies per order by vessel or plane). These different methods used to supply satellite and licensee partners influences the product designs:

- packaging materials to supply satellite partners do come back (in contrast to licensee supplies). Therefore, durable packaging material are only applied to supply satellite partners;
- the carrier used to transport supplies to satellite partners is ought to have infinite capacity (in volume and weight). Therefore, supplies to satellite partners are packed with less focus on volume/weight efficiency;
- in comparison to truck transportation (satellite partners), vessel and plane transportation (licensee partners) require more protection. Therefore, supplies to licensee partners are packed with more focus on component protection.

Figure 17 visualizes the physical appearance of supplies to satellite partners (left hand side) and supplies to licensee partners (right hand side). Appendix C provides more visualizations for both satellite and licensee supplies.

FIGURE 17: SUPPLIES TO SATELLITE PARTNERS (LEFT HAND SIDE) AND LICENSEE PARTNERS

3.5 PROCESS DESIGN

Like the product design, this section describes the process design of a Capitole 40 first from an in-house assembly perspective and subsequently from an OEM perspective.

Figure 18 visualises the layout of the in-house assembly process. This figure illustrates how the current in-house assembly process is subdivided into three sub processes: (1) panel assembly, (2) drawer assembly, and (3) final assembly and testing. All three sub processes function independently. In the panel assembly, panels are assembled per panel in a continuous flow. In the drawer assembly, drawers are assembled per drawer type per system. In the final assembly and testing, panels are linked up, drawers are installed, final components are added, and the total system is tested.

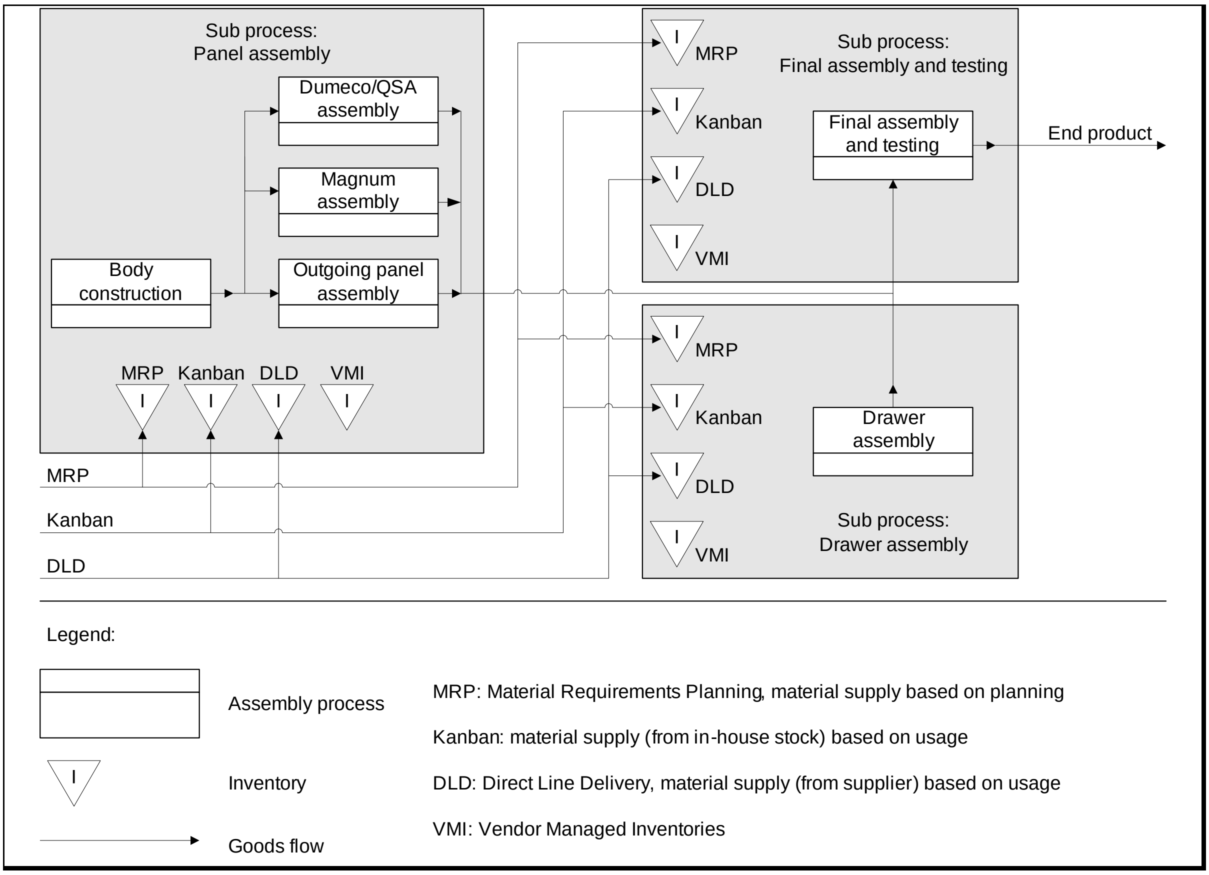


FIGURE 18: THE IN-HOUSE ASSEMBLY PROCESS LAYOUT

Figure 19 visualizes the process control design for the in-house assembly process. In this figure, materials are specified using customer specific project BOMs and master data supplemented by customer specific components. After specification, these material requirements are converted over one or more production orders (PRP-order in Figure 19). These production orders are linked to unique sales orders, as a sales order line. The project (or system) sales order specifies a due date, used in the Material Requirements Planning (MRP) calculations. Finally, the production planning uses production orders to release orders to the shop floor.

On the left hand side in Figure 19 the sequential BaaN activities and their application descriptions are listed. From top to bottom in Figure 19: (1) the input data (master data and order), (2) the specification of – customer specific – material requirements, (3) the conversion of material specifications to – hard – material requirements, (4) the relation between sales orders, PRP-orders, and MRP calculations, (5) and the planning and release of production orders.

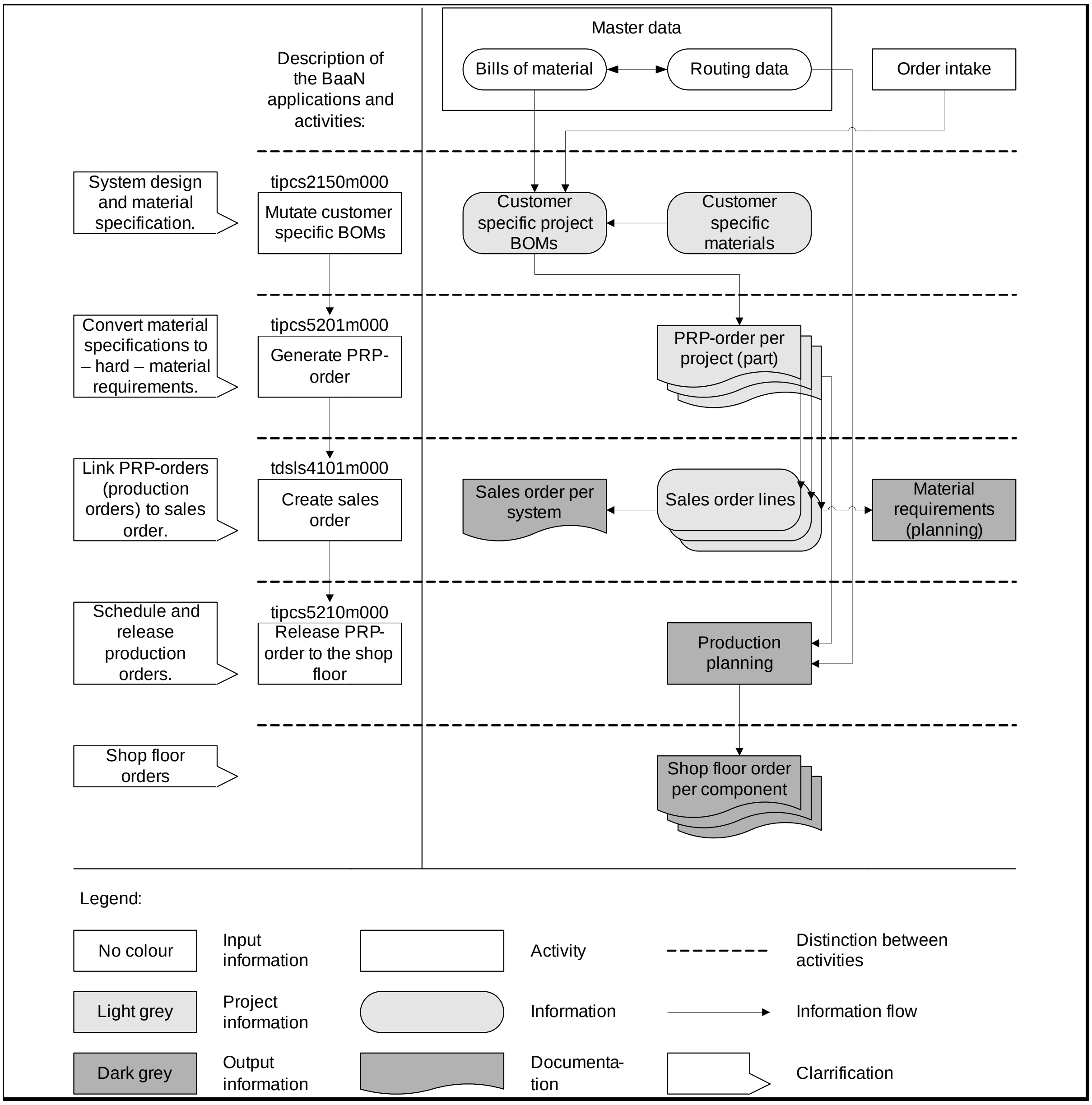


FIGURE 19: PROCESS CONTROL DESIGN FOR IN-HOUSE ASSEMBLY

Flow of materials

Eaton Industries B.V. applies four different methods to manage and control the supply materials in the Capitole 40 assembly process (visible in e.g. Figure 18):

- Kanban, an empty material bin triggers the replenishment of a new material bin from the main warehouse to a fast pick storage location;
- DLD (Direct Line Delivery), an empty bin trigger the replenishment of a new material bin from the external supplier to a fast pick storage location;
- MRP (Material Requirements Planning), scheduled material requirements triggers the supplies of components from either the main warehouse or the external supplier to the assembly line;
- VMI (Vendor Managed Inventories), material requirements, replenishments, availability are managed and controlled by the – external – supplier. In general an empty material bin triggers the replenishment of a new material bin from the external supplier to a fast pick storage location.

Kanban and DLD managed inventories are dedicated to an assembly line and assigned to a specific project or order on the moment of usage. On the other hand, MRP inventories are dedicated to a specific project or order, the release of production orders triggers the supply of components.

Job release and allocation policies

As discussed in Section 3.2, jobs are released based on: urgency, availability of capacity, availability of materials, and the production mix. When a job is released, the required, available, MRP controlled components are dedicated to this production order. MRP controlled components that are not available during the release of an order are listed on a shortage list Based on the contents of this shortage list, additional actions can be undertaken (e.g. contact supplier).

Both the scheduling and the releases of production orders are not supported by any resource-constrained, multi-project scheduling, or advanced planning tools. Production planners are responsible for the production schedules and the allocation of materials and capacities.

During interviews with planners and senior assembly operators, we observed that production orders are often released earlier that needed for assembly. Planners and senior managers use this method to improve the material availability for specific orders.

Order picking policies

Eaton Industries B.V. applies two types of storages: (1) line-stocks dedicated to one assembly line and (2) main warehouse not dedicated to one single assembly line. Kanban, DLD, and VMI managed components are stored in line-stocks, while MRP managed components are not dedicated stocks, stored in the main warehouse.

A component is Kanban or DLD managed and stored in a line-stock if this component respects the Kanban-worthy policies. Table 3 provides the Kanban-worthy policies, based on the expected annual sales volume, the component cost price, and the number of transactions during the last 13 weeks the Kanban-worthiness of a component is defined. If a component is Kanban-worthy and stored in a line-stock the assembly operator is responsible for picking the component from these line-stocks.

	Expected annual sales volume x cost price		Number of transactions last 13 weeks	Kanban-worthy
if	≥ € 100,000	and	> 26	yes
if	< € 100,000 & ≥ € 10,000	and	>13	yes
if	< € 10,000 & ≥ € 1,000	and	> 6	yes
if	< € 1,000	and	> 3	yes
else				no

TABLE 3: POLICIES TO DETERMINE KANBAN-WORTHINESS

If a component is not Kanban-worthy and stored in the main warehouse, order pickers pick the required components and supply these components to the assembly lines. Picking orders specify the material requirements per production order. The storage locations in the main warehouse determine the sequence of material requirements on the picking order.

In an ongoing project, the material handling department of Eaton Industries B.V. is exploring the feasibilities to implement barcode scanning. Barcode scanning improves the material picking accuracy through comparing and checking (1) the pick order and (2) the warehouse location.

Order picking workload

Chapter 4 discusses various material kit designs. These material kit designs affect the material handling process and we expected material kitting to influence the material handling workload. This section introduces a regression model to describe the – expected – material handling workload and to be of use determining the impact of material kitting on material handling workload in Chapter 4.

Currently, Eaton Industries B.V. uses the number of order lines as the only (independent) variable to determine the expected workload. Order pickers are expected to pick 20 order lines each hour.

Parikh & Meller (2008), however, assume a positive correlation between the number of order items and the order picking workload. Therefore, we define a regression model describing the expected workload using the number of order lines and the number of order items as independent variables. In Appendix D, we apply a stepwise procedure to define the best regression model:

1. identify and remove measurement outliers;
2. compose a scatter plot to visualize the type of relation between the independent variables and the dependent variable;
3. use SPSS to draw regression curves, determine regression parameters, and define the quality of these regression models;
4. plot the regression curves in the scatter plot and validate each valid regression model (based on the adjusted coefficient of determination and the curve);
5. define auxiliary variables to convert non-linear correlations to linear correlations;
6. define the best regression model by applying a stepwise procedure to include and exclude variables from the regression model.

We conclude that the order picking workload is best described using the regression model in Equation 1. The coefficient of variation of this regression models equals 0.575.

$$\hat{Y} = -7.604 + 2.621x_1^{0.363} + 2.790x_2^{0.136}$$

in which:
$\hat{Y}$ = the (estimate) workload
x_1 = the number of order lines
x_2 = the number of order items

EQUATION 1: REGRESSION MODEL TO DETERMINE THE EXPECTED WORKLOAD

In this model, the impact of both one additional order line and one additional order items decreases in proportion as the workload is higher. In order to determine the accuracy of this regression model we compared the observed workload to the predicted workload. On average this regression model over estimates the workload with 6.0% (1.6 hours). Furthermore, since the number of observations is limited (21). We conclude, with 10% uncertainty, that this regression model will on average not underestimate the workload with more than 25% and over estimate the workload with more than 37%.

To improve the accuracy of this regression model, more historical data should be used to compare the actual workload to the predicted workload. However, using more historical data increases the risk of using invalid measurement data (since working procedures and efficiencies do change over time).

3.5.1 PROCESS DESIGN FOR OEM ASSEMBLY

The process designs for both satellite and licensee partners differ. Figure 20 visualizes how satellite partners order a predefined range of components using Electronic Data Interchange (EDI). Figure 21 visualizes how systems are designed and specified for licensee partners. In these figures, activities on the left hand side marked light grey indicate a dissimilarity compared to in-house assembly (see Figure 19).

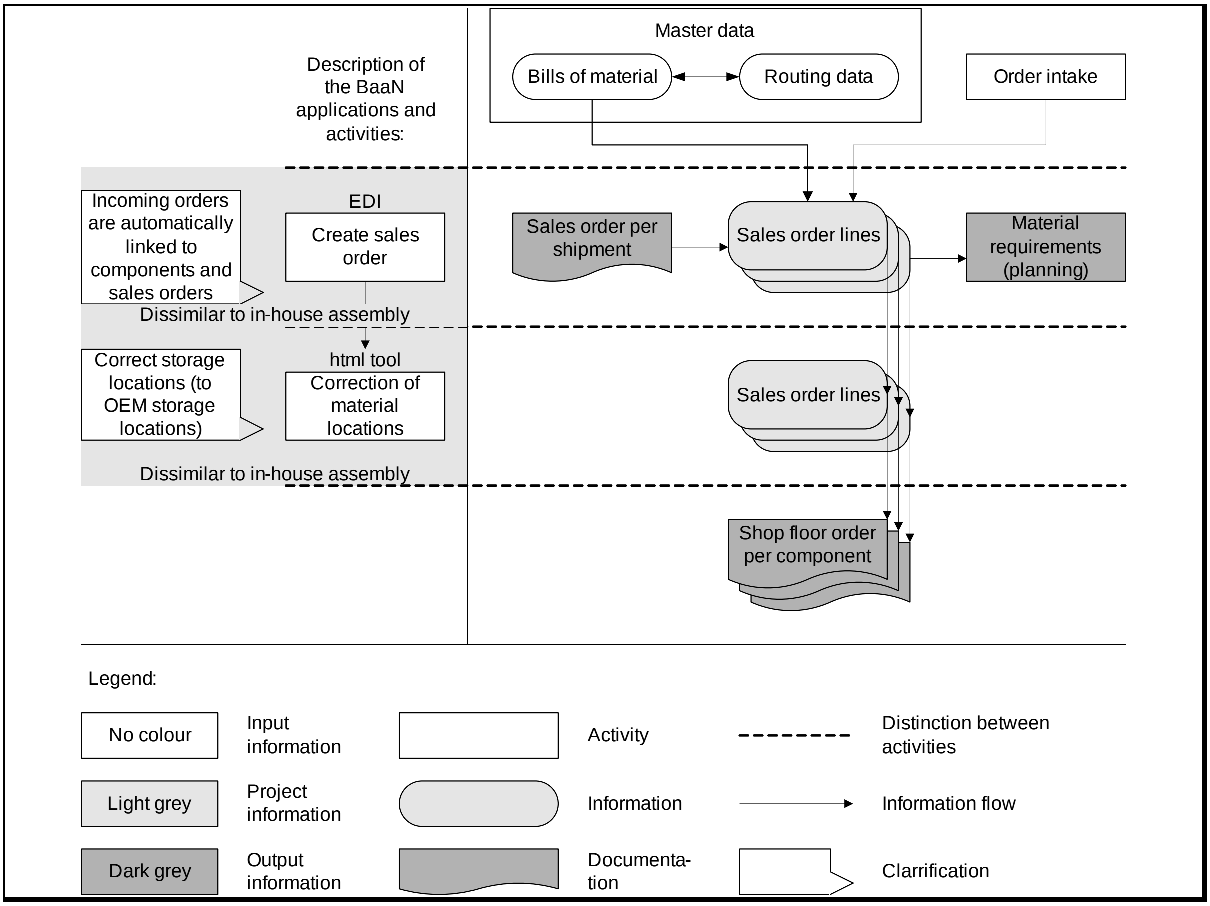


FIGURE 20: PROCESS CONTROL DESIGN FOR SATELLITE ASSEMBLY

The html tool in Figure 20 and Figure 21 is used to correct material locations. Since the OEM employees should not pick materials from the in-house assembly line-stocks, components can be sourced from: (1) the main warehouse, (2) from the supplier (on order), or (3) "shopped" from the line-stocks. The last case, shopping from the line-stocks, implies that components are administratively booked from the line-stock to the main warehouse, to the OEM department. Physically, however, OEM employees shop (pick) components from line-stocks dedicated to an in-house assembly line.

In contrast to satellite partners, licensee partners do not order a predefined range of components, but order components per project. Figure 21 visualizes how licensee orders are linked to customer specific project BOMs. These project BOMs contains the total material requirements. The power session "Platslaan" convert all material requirements of a hierarchical BOM structures to a new non-hierarchical BOM. This new customer specific BOM is generally characterized by the description VO_BOM (which stands for sales order Bill Of Material). In this power session, routing information, BOM headers, and BOM hierarchies are lost. VO_BOMs are used to specify material requirements per sales order.

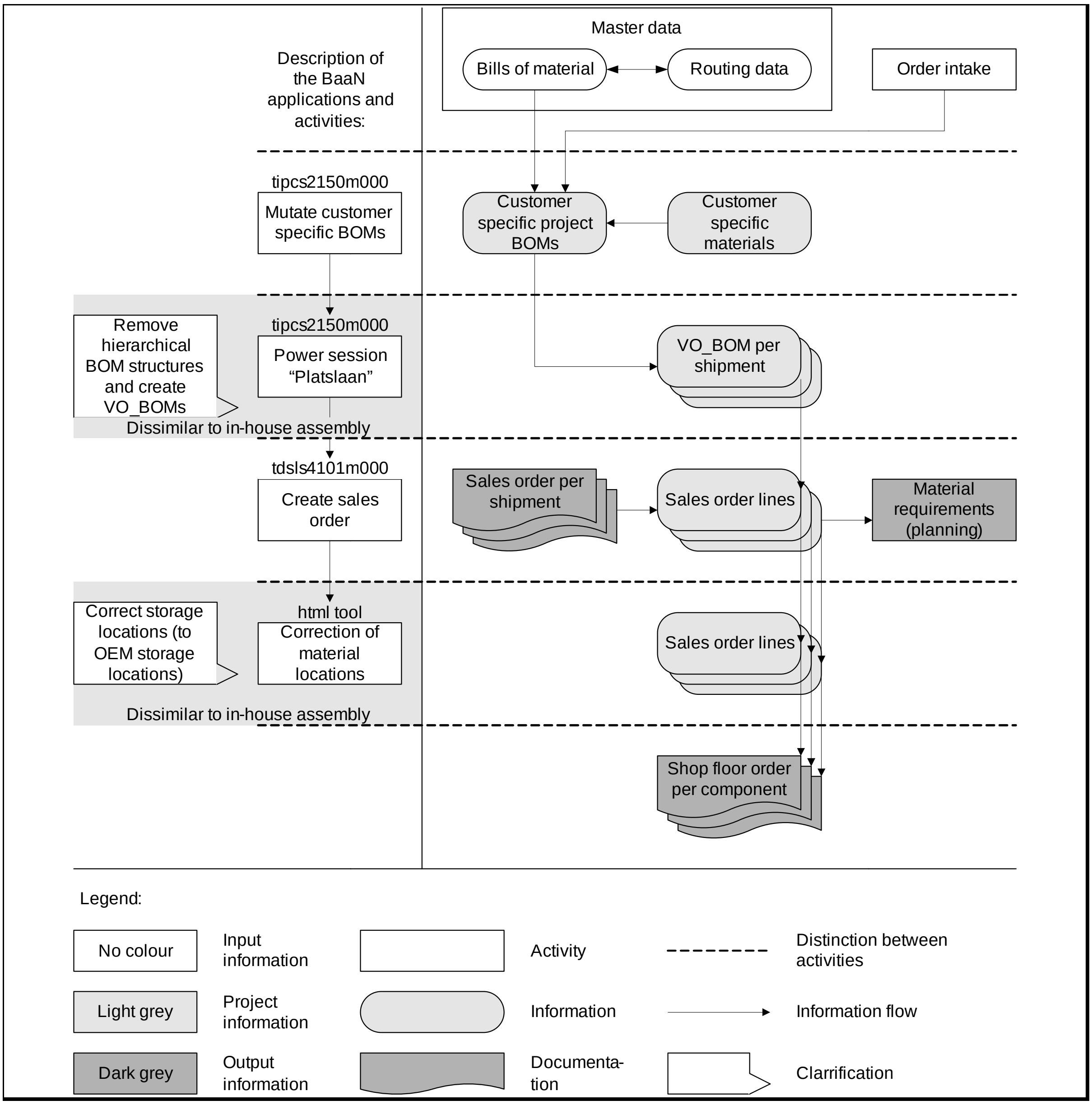


FIGURE 21: PROCESS CONTROL DESIGN FOR LICENSEE ASSEMBLY

3.6 SUPPLY CHAIN DESIGN

Like the product and process design, this section describes the supply chain design first form an in-house assembly perspective and subsequently from an OEM point of view.

Due to scope restriction, the attention devoted to the supply chain designs is restricted to describing the Customer Order Decoupling Point. A not customized Capitole 40 design can be classified as an Assembly To Order product. However, since generally customers request for customized engineering on the basic design, a typical Capitole 40 includes Engineer To Order components. At Eaton Industries B.V. ATO components are, depending on the supplier's lead-time, purchased or produced on forecast or on demand. ETO components are always purchased or produced on demand.

3.6.1 SUPPLY CHAIN DESIGN FOR OEM ASSEMBLY

The supply chain design of an OEM assembled Capitole 40 depends on whether this installation is assembled by a satellite partner or a licensee partner. Although it is not obligatory, there are two types of supply chain designs. One type is applied by all satellite partners the other type is applied by all licensee partners.

The supply chain design for satellite and licensee partners differ on two subjects: (1) satellite partners order a predetermined range of components, while licensee partners order all components per project and (2) satellite partners hold inventories, while licensee partners do not hold inventories.

Satellite partners hold inventories to reduce the market lead-time, in order to retain their competitive position. In order to control the holding costs associated to these inventories, satellite partners order and stock a predetermined range of components. Satellite partners order or produce customer specific parts without intervention of Eaton Industries B.V.

Two reasons for licensee partners to apply the above described supply chain design are: (1) in general licensee partners do not have the skills and knowledge to design systems and (2) demand of licensee partners is characterized by a high variability. Ordering all parts from Eaton Industries B.V. makes Eaton responsible for the accuracy of the system design and the supplies. This enables licensee partners to notify and report flaws in design or supplies, while Eaton Industries B.V. is responsible for solving these flaws.

3.7 IDENTIFY OPPORTUNITIES TO IMPROVE OEM PERFORMANCE

Described in Chapter 1, the management team of Eaton Industries B.V. is willing to improve OEM performance by implementing material kitting. According to them, changing the current product and process design offers the opportunity to better support the OEM processes. This section introduces a Root Cause Analysis (RCA) to clarify this point of view of the management team of Eaton Industries B.V. and reformulate this opportunity into various more concrete and specified sub opportunities (in the RCA referred to as root causes). The issue clarification, to be decomposed in more specific sub issues, states: The OEM product and process design do not support the strategic goals of Eaton Industries B.V (see Figure 22, page 34).

During interviews with – senior – managers we identified four widely accepted subjects for improvement. We define these issues as first grade contributory factors (FGCF), see Figure 22: (FGCF 1) the OEM product design does not support supply chain efficiency, (FGCF 2) OEM supplies score badly on OTP, (FGCF 3) the OEM process interferes with the in-house assembly process, and (FGCF 4) supplies fall short on accuracy.

During interviews with both managers and operational employees, we identified eight inferior contribution factors (ICF), see Figure 20: (ICF 1) project information (including BOMs and routings) is lost in the ERP process, (ICF 2) stock levels are not reliable, (ICF 3) OEM demand is satisfied from in-house line-stocks, (ICF 4) master date (BOMs and routings) information is not reliable, (ICF 5) process control is designed for in-house production and in-house assembly, (FGCF 6) OEM demand is batched to improve efficiency, (ICF 7) the OEM process requires OEM specialists, and (ICF 8) in-house usage of line-stocks guarantees material availability.

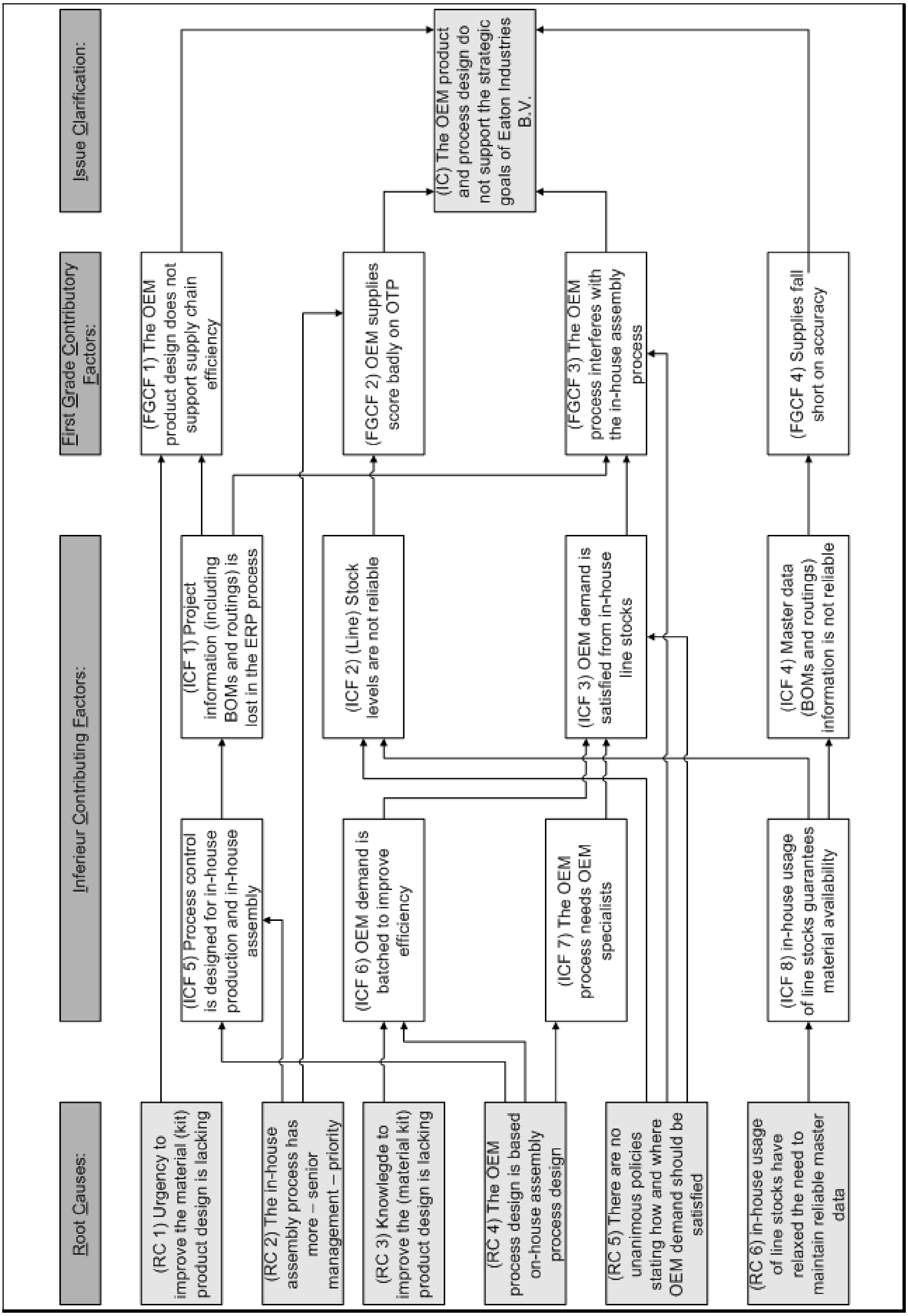


FIGURE 22: CAUSES AND ROOT CAUSES WHY THE OEM PRODUCT AND PROCESS DESIGN DO NOT SUPPORT THE STRATEGIC GOALS OF EATON INDUSTRIES B.V.

Finally, we identified six root causes (RC). These causes are labelled to be root cause since no foregoing cause is found during this Root Cause Analysis. These root causes are: (RC 1) urgency to improve the material (kit) product design is lacking, (RC 2) the in-house assembly process have more – senior management – priority, (RC 3) knowledge to improve the material (kit) product design is lacking, (RC 4) the OEM process design is based on in-house assembly process design, (RC 5) there are no unanimous policies stating how and where OEM demand should be satisfied, and (RC 6) in-house usage of line-stocks have relaxed the need to maintain reliable master data.

According to Staugaitis (2002), classifying root causes provides more insight into the nature of the problem. Based on these interviews and observations, we conclude that there are three different natures regarding the above described root causes:

- causes finding their roots in management policies and – lacking – management commitment, root causes 1 and 2;
- causes finding their roots the lack of knowledge on how to improve (material kit) product designs, root causes 3 and 6;
- causes finding their roots in inappropriate process design, root causes 4 and 5.

Chapter 4 and Chapter 5 focus on the material kit product and the material kit process design and will concentrate on solving (or improving) root causes 3, 4, 5, and 6. Chapter 6 focuses on the implementation of material kitting and includes issues related to root causes 1 and 2.

In Table 4, we define assessment criterion to each of the product and process related root causes. These assessment criterions will be used in Chapter 4 and Chapter 5 to compare various material kit product and process designs. Beside the assessment criterion related to the root causes, we define two financial assessment criterions to evaluate various material kit designs (see Table 5).

Root cause	Assessment criterion
The in-house assembly process has more – senior management – priority (RC 2) **The OEM process design is based on in-house assembly process design (RC 4)**	The material kit (process) design supports both the in-house assembly process and the OEM process.
Knowledge to improve the material (kit) product design is lacking (RC 3)	The material kit product and process design support continuous improvement on the material kit product design
In-house usage of line-stocks have relaxed the need to maintain reliable master data (RC 6)	The (material kit) process design should stimulate maintenance and continuous improvement on master data

TABLE 4: ROOT CAUSE ASSESSMENT CRITERION TO EVALUATE MATERIAL KIT DESIGNS

Financial goals	Assessment criterion
Impact on material handling costs	The material kit design contributes to reduce material handling costs
Impact on inventory costs	The material kit design contributes to reduce inventory costs

TABLE 5: FINANCIAL ASSESSMENT CRITERIA TO EVALUATE MATERIAL KIT DESIGNS

3.8 CONCLUSIONS FOR THIS CHAPTER

This chapter provides the answer to the research question: "*What are the current Capitole 40 product, process, and supply chain designs and what are differences between in-house and OEM* *assembly?"*. Second, this chapter provides insight into: (1) the consequences of the differences in the product, process, and supply chain designs and (2) defining the value of (new) material kitting product and process design for Eaton Industries B.V.

To answer the first part of the research question, what are the current Capitole 40 product, process, and supply chain designs, we conclude that Eaton Industries B.V. currently applies three types of product, process, and supply chain designs. These three different designs are applied to for in-house assembly, satellite assembly, and licensee assembly.

The reason for Eaton Industries B.V. to apply three variations of product, process, and supply chain designs can be traced back to the fact that Eaton Industries B.V. currently applies three different supply chain framework designs. These multiple supply chain frameworks are currently needed to cope with the differences in: (1) where take assembly place (in-house of by an OEM partner) and (2) quotation and design skills of OEM partners and the level of cooperation and integration.

To answer the second part of the research question, what are the difference between in-house and OEM assembly, we compared the in-house assembly process and the OEM assembly process. Most conspicuous observation is that the process control design, used for OEM assembly is initially designed for in-house assembly. Therefore, the OEM processes are a derivatives of the standard in-house process, causing various kinds of (process problems and) ad hoc solutions.

In the last part of this chapter, we conclude that there are six root causes to solve in order to let the OEM product and process design support the strategic goals of Eaton Industries B.V. These six root cause relate to three different categories: (1) problems finding their roots in the current management policies and the lacking management commitment, (2) problems finding their roots in the lack of knowledge on how to improve material (kit) product designs, and (3) problems finding their roots in inappropriate process design.

To compare and evaluate various material kit product and process designs in Chapter 4 and Chapter 5, we defined five assessment criterions. The degree to which:

1. the material kit (product) design is supporting both the in-house assembly process and the OEM process;
2. the material kit product and process design support continuous improvement on the material kit product design;
3. the (material kit) process design stimulate maintenance and continuous improvement on master data;
4. the material kit design contributes to reduce material handling cots;
5. the material kit design contributes to reduce inventory costs.

4 MATERIAL KIT DESIGN

This chapter introduces and discusses possible material kit product and process designs to answer the question: "*What are feasible material kit product and process designs for Eaton Industries B.V?*" What material kit – product and process – design is best for Eaton Industries B.V. is an additional sub question to be answered in this chapter.

This chapter discusses various material kit product and process designs. In Chapter 3, we concluded that Eaton Industries B.V. lacks the knowledge and experience to define material kit products designs. Therefore, literature is the major source of inspiration to define feasible material kit product designs. On the other hand, Eaton Industries B.V. has knowledge and experience in designing (OEM) processes. To reduce the differences between the in-house assembly process and the OEM process we will use the in-house process design as the major source of inspiration. Using terminology of Reijers et al. (2003), we use the in-house assembly process as the reference model.

Section 4.1 elaborates on the future state supply chain activities. Both the flow and management of supplies and the flow and management of demand information are subject of change. Section 4.2 discusses various material kit product, process, and supply chain designs. Section 4.3 discusses, considers, and determinates the best material kit design. Section 4.4 provides an answer to the material kit design issues defined in Chapter 2. The last section, Section 4.5, provides the conclusions for this chapter.

4.1 MANAGING THE FUTURE STATE SUPPLY CHAIN

As described in Chapter 2, we distinguish two SCM (Supply Chain Management) activities in a supply chain: (1) the flow and management of demand information and (2) the flow and management of supplies. As elaborated on in the problem introduction (see Chapter 1), parallel to this research the order intake processes and procedures are subject for change. Section 4.1.1 discusses the future state of the flow and management of demand information as envisioned by the management team of Eaton Industries B.V. Section 4.1.2 elaborates on the basic requirements regarding the flow and management of supplies.

4.1.1 MANAGEMENT OF DEMAND INFORMATION: ORDER INTAKE

As described in Chapter 1, the management of Eaton Industries B.V. has identified two key activities to improve the OEM process and performance. This section provides insight into first activity, redesign the order intake process and implement Bid Manager.

Figure 23 visualizes the envisioned order intake process design. In this envisioned future state, OEM partners themselves will be able to configure a functional Capitole 40 switch and distribution system using Bid Manager. Bid Manager uses a modular library to design Capitole 40 systems. The output of Bid Manager is a system design described in modules (BOM headers). Design Automation enable OEM partners to specify material requirements using Bid Manager output (BOM headers) and divide these material requirements into: (1) material requirements to be sourced from Eaton Industries B.V. and (2) material requirements not to be sourced from Eaton Industries B.V. Non performance, non quality, and non appearance defining components that can be sourced – cheaper – locally are candidate for the latter category. On the other hand, obligating OEM partners to source performance, quality, and appearance defining components from Eaton Industries B.V. should prevent that two Capitole 40 systems differ on performance, quality, or appearance (see Chapter 1).

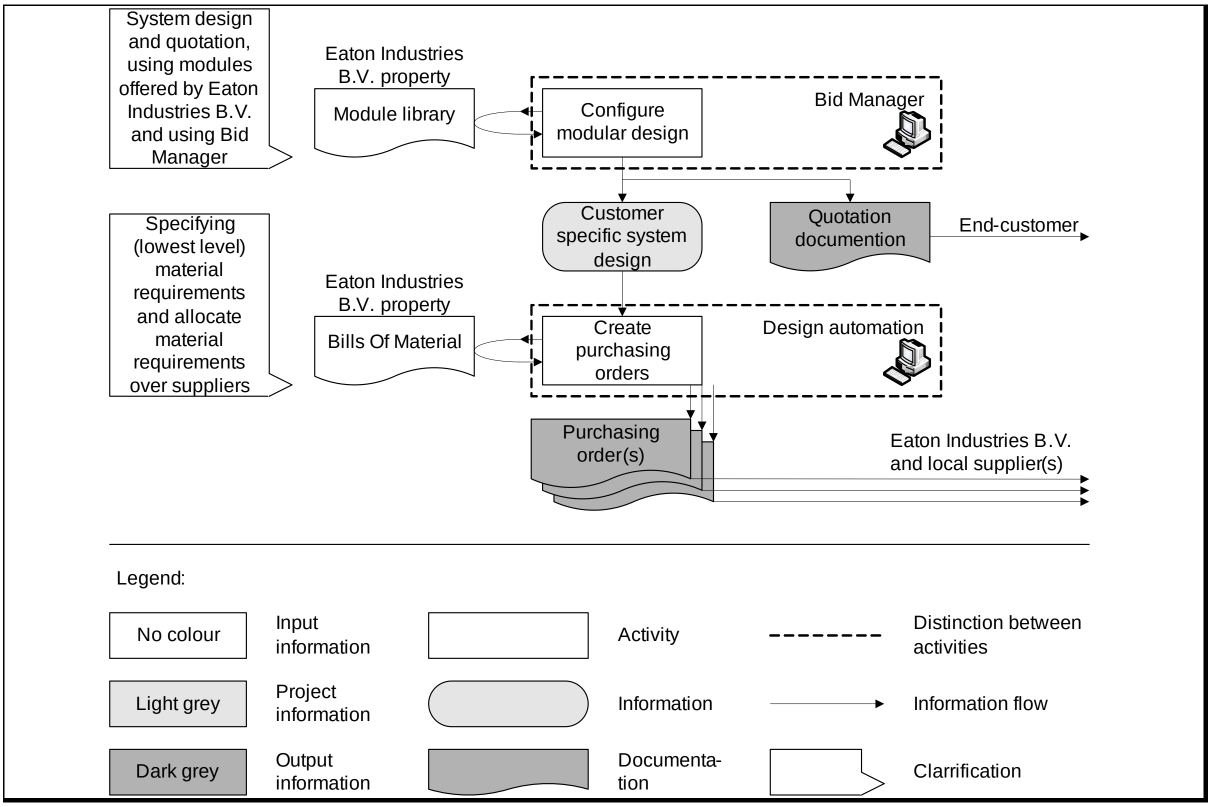


FIGURE 23: ENVISIONED ORDER INTAKE PROCESS DESIGN, USING BID MANAGER AND DESIGN AUTOMATION

Both Bid Manager and Design Automation are software applications Eaton Industries B.V. will offer to their OEM partners. The management team of Eaton Industries B.V. expects that OEM partners will be able to design and quote Capitole 40 systems when using Bid Manager and Design Automation. The invalid master data is currently considered as the biggest barrier to implement this order intake process design.

If Eaton Industries B.V. succeeds to implement Bid Manager and Design Automation successfully, communications between Eaton Industries B.V. and each of their OEM partners (including in-house assembly) will become consistent.

Detailed information on how Bid Manager and Design Automation works and handles data is lacking. In the scope of this research, we will assume that the total BOM hierarchy is inputted into BaaN. It is up to the Bid Manager project team to specify the detailed impact of Bid Manager and Design Automation in the process control design.

4.1.2 MANAGEMENT OF SUPPLIES: MARKET REQUIREMENTS

As discussed in Chapter 2, supply chain activities include demand focussed activities and supplies focussed activities. This section provides insight into the requirements, defined by the marketing department of Eaton Industries B.V., affecting the flow and management of supplies.

Figure 24 visualizes the maximum market lead-time defined by the marketing department of Eaton Industries B.V. The market lead-time is defined as the time between the moment an end-customer agrees on a quotation and the moment a system is delivered to the end-customer. According to the marketing department of Eaton Industries B.V., this marketing lead-time should be less of equal to 11 weeks, including: one week to specify order details, two weeks of transportation time from Eaton Industries B.V. to the OEM partner, four weeks of OEM assembly, and half a week of transportation from the OEM partner to the end-customer.

Concluding, to achieve a market lead-time of 11 weeks, the maximum internal lead-time for Eaton Industries B.V. (measured between the moment of order intake and the moment of dispatching) equals three weeks (visualized in Figure 24).

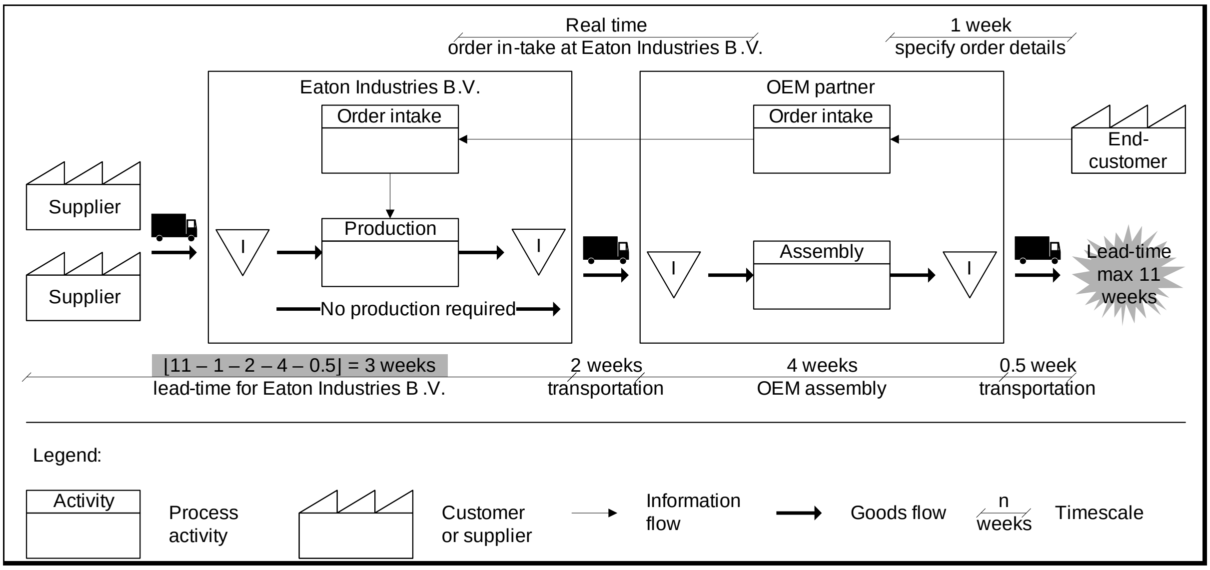


FIGURE 24: THE IMPACT OF MARKET LEAD-TIME ON INTERNAL LEAD-TIME

The lead-time objective of three weeks is approved on by the management team of Eaton Industries B.V. This lead-time objective does not apply to customer specific components (typically characterized by a long supplier lead-time).

4.2 DESIGN OF THE MATERIAL KIT

As concluded in Chapter 2, a material kit design is the aggregation of a material kit product design, a material kit process design, and a material kit supply chain design. Eaton Industries B.V. has limited knowledge regarding material kit product designs. Therefore, literature is the main source of inspiration on this design issue. On the other hand, Eaton Industries B.V. has knowledge and experience in (OEM) process designs. To reduce the differences between the in-house assembly process and the OEM process we will use the in-house assembly process design as the major source of inspiration. Regarding the material kit supply chain design, we accept the assumption of the management team of Eaton Industries B.V. and assume Eaton Industries B.V. is the last party in the supply chain holding forecast driven inventories.

4.2.1 DESIGN OF THE MATERIAL KIT PRODUCT

In Chapter 2, we concluded that the material kit product design can be described by answering two material kit product design issues: (1) define the preferred type of material kit, travelling or stationary and (2) define policies to identify components (and/or subassemblies) that are excluded from the preferred type of material kit). In this section we show that these material kit product design issues are highly interrelated. Therefore, we define two different material kit product designs, which both are a combination of a material kit type (Material Kit Product Design Issue 1) and a component exclusion policy (Material Kit Product Design Issue 2).

In Chapter 2, we introduced a number of authors describing material kit deigns: Bozer & McGinnis (1992), Medbo (2003), and Limère (2007). According to these authors, a material kit product design should be: (1) in alignment with both standardized work instructions and the cognition of assembly operators and (2) an aggregation of components or subassemblies to support one or more assembly operations. In Chapter 3, we discussed the flow of goods in the in-house assembly process and we concluded that a Capitole 40 system can be partitioned in two dimensions: (1) a system contains multiple panels and multiple drawers flowing apart from each other through the assembly process and (2) each panel is assembled in a fixed workstation-sequence.

In an ongoing project, Eaton Industries B.V. is designing a new in-house LVS (Low Voltage Systems) assembly process layout. This new process supports the assembly process of three Low Voltage Systems, including the Capitole 40. New in this process, there is an explicit distinction between seven workstations (described in Section 4.2.2): (1) body construction, (2) vertical support, (3) horizontal and vertical connections, (4) panel layout, (5) covers, (6) drawer installation, and (7) final assembly. Table 6 illustrates that each component required in the assembly process can be linked to (1) a panel and (2) a workstation.

→ Panel (allocation) ↓ Workstation (allocation)	Panel 1	…	Panel n
1 Body construction	Components for panel 1 at workstation 1	…	Components for panel n at workstation 1
2. Vertical support	Components for panel 1 at workstation 2	…	Components for panel n at workstation 2
…	…	…	…
7. Final assembly	Components for panel 1 at workstation 7	…	Components for panel n at workstation 7

TABLE 6: TWO DIMENSIONAL CAPITOLE 40 MATERIAL ALLOCATION

In the current process, routing information prevents the allocation of components to specific workstations. In the new in-house LVS assembly process control design, BOM and routing information will be adjusted and used to specify material requirements per workstation. In the material kit – product and process – designs we will use these new BOM and routing information sources.

According to Bozer & McGinnis (1992), we can apply two types of material kits: (1) apply travelling material kits or (2) apply stationary material kits. A travelling material kit is supplied to one workstation and consumed over more than one workstation, travelling along with the product. A stationary material kit is supplied to and totally consumed at one workstation (Bozer & McGinnis, 1992). Material Kit Product Design 1 is a travelling material kit design and Material Kit Product Design 2 is a stationary material kit design.

Material Kit Product Design 1: Travelling material kits

Applying Material Kit Product Design 1, travelling material kits, implies that components for one panel – and all workstations for –are preferably supplied to the OEM partner in one material kit. Therefore, the contents of material kits require some kind of component sequencing in order to support the operator's cognition as described by Medbo (2003). Components sequencing can be part of the applied process (control) policies, resulting in a sequenced picking order. On the other hand, components sequencing can also be a manual process, e.g. before components are packed, components are manually or semi automatically put into a predefined sequence. A visualization of a travelling and a stationary material kits design is provided in Chapter 2 (see Figure 5).

According to Medbo (2003), the most important quality defining issue of a material kit design is the ease and logic of usage. Therefore, excluding components from the travelling material kit, due to e.g. size, weight, or vulnerability will have deteriorating effect on the perceived quality of the material kit design. Considering the distribution of components usage over the distinct workstation, we observed that typically the first workstations in the in-house assembly process require large and heavy components (e.g. metal side walls or brass main busbars), while the last workstations require aesthetic and fragile components (e.g. coated covers or plastic indicators).

Therefore, applying Material Kit Product Design 1 would imply that either large and heavy components are packed on top of vulnerable components (increasing the risk for transportation damage) or one or more categories of components are excluded from the preferred travelling material kit (reducing the perceived quality from an assembly operator point of view).

Material Kit Product Design 2: Stationary material kits

Applying Material Kit Product Design 2, stationary material kits, implies that components are supplied in a kit dedicated to one panel and one workstation (see Table 6). As we discussed above, applying Material Kit Product Design 1 requires components sequencing during the release or packaging phase. In Material Kit Product Design 2, component sequencing is part of the material kit product design. Therefore, the set of components in a stationary material kit requires no further sequencing.

As described in the section elaborating on Material Kit Design 1, the distribution of components usage over the various workstations and the variety in weight, size, and vulnerability of components have to be taken into account during the material kit design phase. We observed that materials used at one workstation reveal similarities in size, weight, and vulnerability. Furthermore, because stationary material kits do not require component sequencing within a material kit, vulnerable components could be packed on top of heavy components without neglecting any sequencing prescriptions.

We argue that impact of excluding components in Material Kit Product Design 2 is reduced to a minimum (if not ruled out). Reducing the impact of excluding components will have a positive effect on the quality of the material kit design (Medbo, 2003).

4.2.2 DESIGN OF THE MATERIAL KIT PROCESS

In Chapter 2, we concluded that a material kit process design can be described by answering four material kit process design issues: (1) define the flow of materials, (2) define job release policies, (3) define order picking methods, and (4) define methods or policies to guarantee material kitting accuracy. In this section we show that these material kit process design issues are interrelated. Therefore, we distinct three material kit process designs, which are a combination of policies defining the flow of goods, job releases, order picking, and picking accuracy.

The first material kit process design is the “do not change” option: Material Kit Process Design 1, do not change the OEM process. Based on literature, e.g. Brynzér & Johansson (1995) stating that material kitting is an order picking activity, we define Material Kit Process Design 2, OEM activities seen as order picking activities. Meeting a majority of OEM employees wishes, stating that the importance of the OEM process is currently neglected, we define Material Kit Process Design 2, OEM activities seen as – material kit – assembly activities. Each of these three material kit process designs are described below.

Concluded in Chapter 3, increasing similarity between the in-house assembly process and the OEM process will have a positive effect on the value of the material kit process design. Since Eaton Industries B.V. is currently redesign the new LVS assembly process, we will use this new – conceptual – design, instead of the current in-house assembly process, to ensure the usefulness of the material kit design which will be most likely implemented after the implementation of the new in-house LVS assembly process.

The new in-house LVS assembly process

In the new in-house LVS (Low Voltage Systems) assembly line two previously separately assembled products (the Capitole 20 and the Capitole 40) and one new product (the Capitole CX) will be integrated into one assembly line. Appendix A visualizes the physical location of this assembly process.

In the design phase of the new in-house assembly line process (see Figure 25), two extreme layouts are proposed. Both designs include material pitching. Material pitching is defined as supplying materials to a downstream process in the exact pace of that process. In general material pitching is applied if upstream processes are not able to produce in the exact same flow of the downstream processes. Introducing a stock point and a material pitching mechanism decouples those processes and contributes to the flow and pace of the downstream process. One extreme LVS layout design uses material pitching only for the currently MRP managed components, while the other extreme LVS layout design uses material pitching for all currently MRP, Kanban, and DLD managed components.

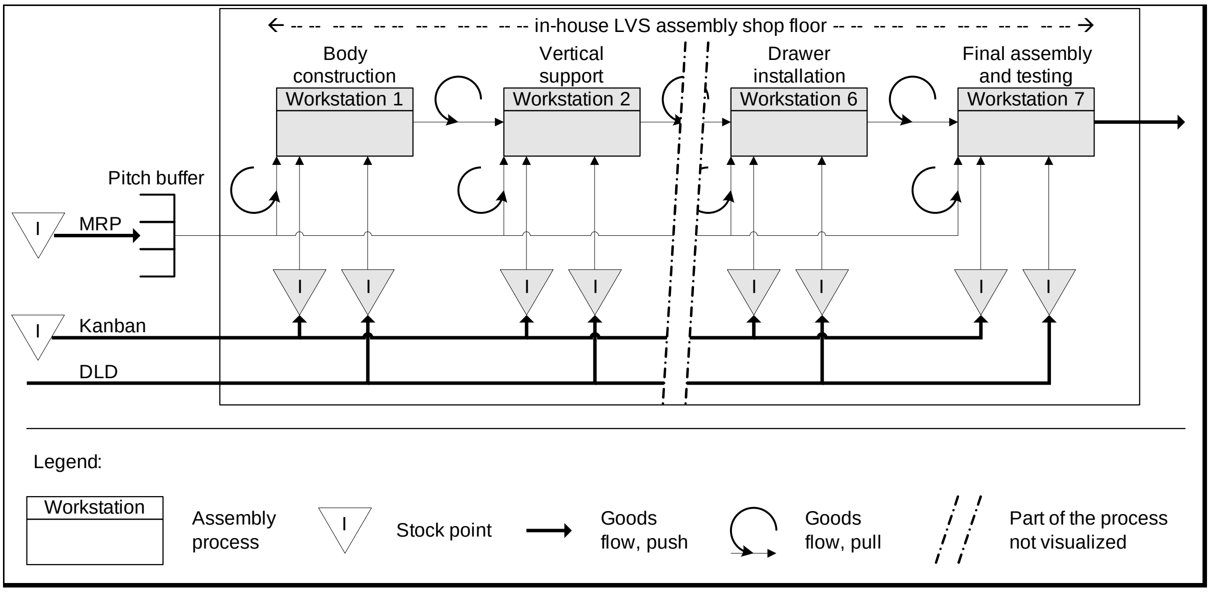


FIGURE 25: NEW IN-HOUSE LVS ASSEMBLY PROCESS LAYOUT

The project team dedicated to the design and implementation of the new LVS assembly process is still discussing the LVS layout design. What is known at this stage is: (1) the available space on the shop floor is not enough to store all currently Kanban or DLD managed items in a line-stock and (2) the management team of Eaton Industries B.V. will not allow removing extremely Kanban-worthy components from the line-stocks (to material pitching). We assume that the final in-house LVS design will be a mixture of both extremes. This implies that the current Kanban-worthy policies will be redefined to determine which components to stock in line-stocks.

Figure 25 visualizes the goods flow for this new in-house LVS assembly process. This figure visualizes the three types of material flows to the shop floor: (1) material pitching, (2) Kanban, and (3) direct line delivery (DLD).

Material Kit Process Design 1: Do not change the OEM process

Before discussing the options to change the OEM process, we discuss the first option: do not change the OEM process. Figure 26 visualizes the flow of goods in this material kit process design. Applying this material kit process design implies that materials are supplied or picked from: (1) the central warehouse, (2) the supplier, or (3) the dedicated line-stocks (shopped).

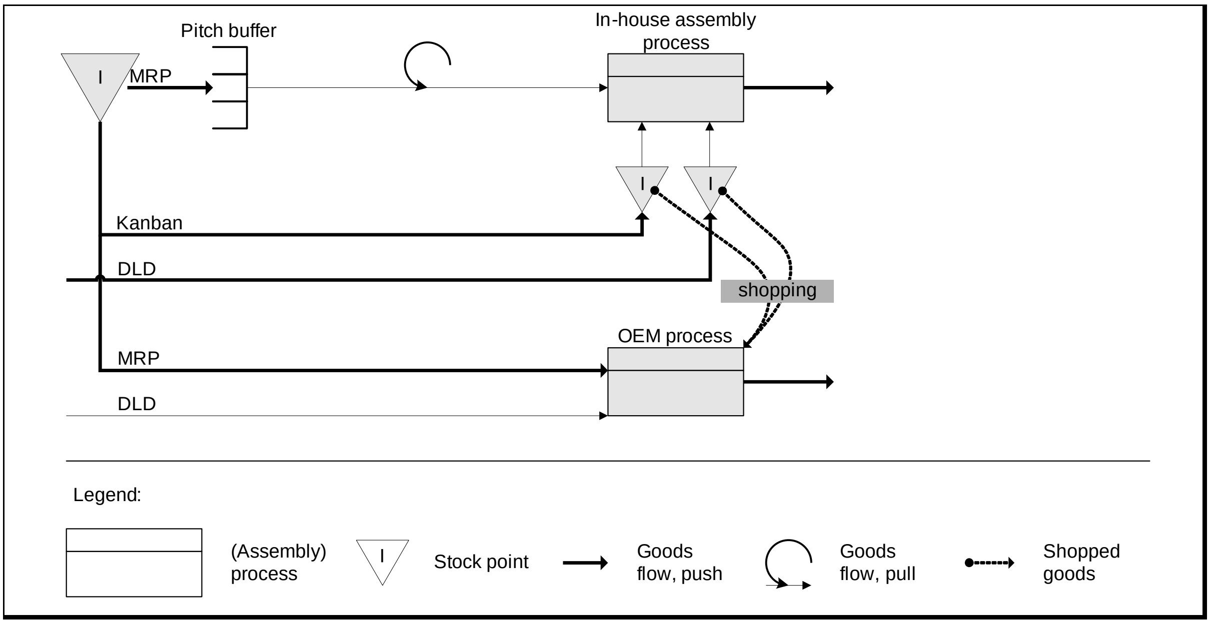


FIGURE 26: GOODS FLOW FOR MATERIAL KIT PROCESS DESIGN 1, DO NOT CHANGE THE OEM PROCESS

All materials that have a storage record in the main warehouse are – in principle – picked from the main warehouse. DLD managed components (that do not flow through the main warehouse) are ordered on demand or shopped. Current policies – to reduce the disturbance effect of the OEM process on the in-house assembly process – state that if the demand exceeds a quantity equal or larger than half a binsize, these components should be ordered from the supplier. If the demand is less than half a binsize the components are shopped from the in-house assembly line-stocks.

In principle Kanban components will be not be shopped from the line-stocks, since all Kanban managed components have a storage record in the central warehouse. However, like in the current situation, this cannot be ruled out.

Material Kit Process Design 2: OEM activities are order picking activities

According to Brynzér & Johansson (1995), the material kit process design can be considered as an order picking process. Applied to the case of Eaton Industries B.V., this would imply that all material kitting operations take place preferably in or close to the main warehouse (see Figure 27). In this case, a variety of picking techniques can be applied to make the material kitting order picking process more efficient. Brynzér & Johansson (1995) suggest batch picking and zone picking supplemented by various accuracy improving tools, e.g. weight checking, bar code scanning, or colour identifications.

Applying Material Kit Process Design 2 implies that all components needed for OEM deliveries are stored in the main warehouse (Appendix A provides a floor plan). Therefore, DLD policies (used to supply the in-house LVS assembly process) are substituted by Kanban policies, such that these components flow through the main warehouse. Figure 27 visualizes the flow of materials for this material kit process design. The effect of this material kit process design on the in-house LVS assembly process is limited to the replacement of DLD policies by Kanban policies. As visualized in Figure 27, all picking (except for customer specific components) activities take place in the main warehouse. Packaging activities do not necessary take place in the main warehouse, but preferably close to the main warehouse.

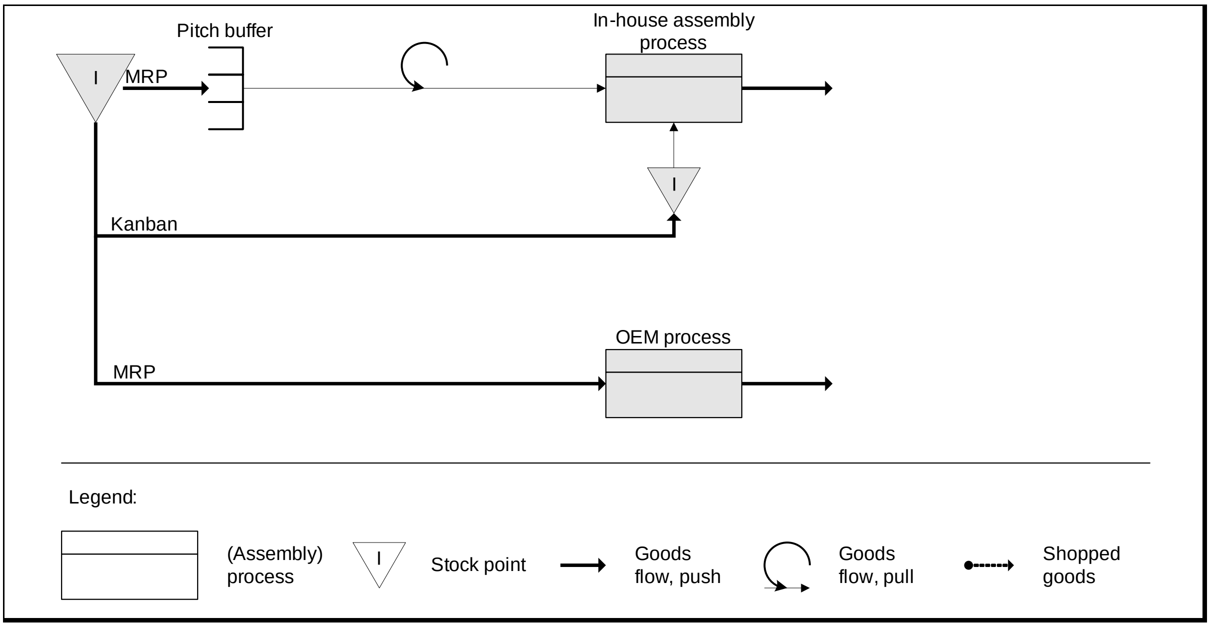


FIGURE 27: FLOW FOR MATERIAL KIT PROCESS DESIGN 2, OEM ACTIVITIES SEEN AS ORDER PICKING ACTIVITIES

Until the autumn of the year 2010, the OEM department was located in the main warehouse. The management team of Eaton Industries B.V., however, decided to move the OEM department to a separate location (Appendix A provides the floor plan, including the current location). Two ponderous arguments at that time were: (1) customer specific components (supplied from e.g. the internal metal supplier) could be delivered faster to a dedicated OEM packing area and (2) the OEM department was provided with a dedicated warehouse. During interviews with employees of the OEM department, we concluded that these arguments are still valid: (1) the need for direct delivery form internal suppliers to reduce material handling effort and time and (2) the need for a dedicated warehouse to safeguard material availability.

We conclude that if Eaton Industries B.V. would decide to apply Material Kit Process Design 2, the dedicated OEM packaging area and the dedicated OEM warehouse should not be eliminated.

Material Kit Process Design 3: OEM activities seen as – material kit – assembly activities

A point of view, widely supported within Eaton Industries B.V., is to physically separate the OEM process from the in-house assembly process and apply similar inventory and management policies for both processes. Figure 28 visualizes Material Kit Process Design 3, based on this point of view.

Similar to Material Kit Process Design 2, the implementation of Material Kit Process Design 3 replaces DLD policies by Kanban policies. In this material kit process design the OEM process is equipped with dedicated line-stocks. Dedicating line-stocks to the OEM process will not only affect the space requirements, but it also influences total inventory levels and material handling costs.

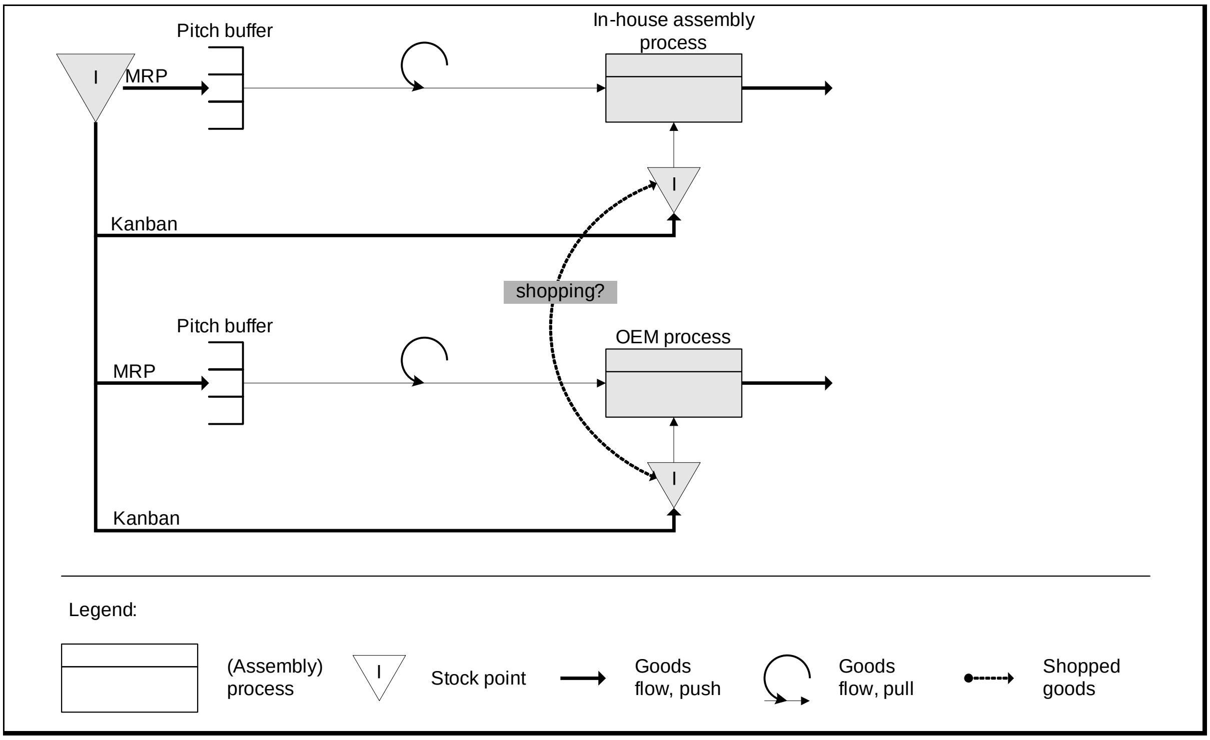


FIGURE 28: MATERIAL KIT PROCESS DESIGN 3: OEM ACTIVITIES SEEN AS – MATERIAL KIT – ASSEMBLY ACTIVITIES

In the current situation, shopping OEM employees (visible in Material Kit Process Design 1, shopping from in-house assembly line-stocks) are look upon as interfering and undesirable activities. Dedicating line-stocks to the OEM process (Material Kit Process Design 3) copes with this problem. However, two-way-shopping (in-house assembly employees shopping from OEM line-stocks and vice versa) could become a new – even more interfering – activity.

Job release and allocation policies

As discussed earlier in this section, the material kit product design and the job release and component allocation policies interrelate. In Material Kit Product Design 1 (travelling material kits) jobs are preferably released only if all materials are available.

As described in Chapter 3, Eaton Industries B.V. currently releases jobs regardless whether all component are available. Since material release policies influence both the OEM process and the in-house assembly process, we define the changing these policies to be out of scope (see Chapter 1).

Material Kit Product Design 2 (stationary material kits) is not interfering with the current job release and allocation policies. Since the collection components part of one stationary material kit require no further sequencing, subsequent deliveries do not obstruct the picking and packaging activities of on-time released components.

Order picking policies

As discussed earlier in this section, the material kit product design and the order picking policies interrelate. Material Kit Product Design 1 (travelling material kits) requires component sequencing, while Material Kit Product Design 2 (stationary material kits) requires no component sequencing. To implement Material Kit Product Design 1, component sequencing should be supported in either the order picking process or the packing process. Just as job release and allocation policies, order picking policies influence both the OEM process and the in-house assembly process. Therefore, we define changes in these policies to be out of scope.

4.2.3 DESIGN OF THE MATERIAL KIT SUPPLY CHAIN

As elaborated on in the problem introduction of this research (see Chapter 1), Eaton Industries B.V. made the strategic decision to be the last supply chain party holding forecast based inventories.

We do not object to this strategic decision for two reasons: (1) each Capitole 40 design is highly customer specific and (2) the Capitole 40 (product and) process design is not modular oriented (see Chapter 3). Accepting this strategic decision implies a change in the current material kit supply chain design for the satellite partners of Eaton Industries B.V. (see Chapter 3).

Allocating the CODP before the material kitting department, requires a flexible operating material kitting department (Bozer & McGinnis, 1992). According to Hans et al. (2007), proper rough-cut capacity planning and order acceptation (load levelling or Heijunka) can contribute to this ability. We advise Eaton Industries B.V. to include these topics (rough-cut capacity planning, order acceptation, and load levelling) in the – currently ongoing – central planning project.

4.3 SELECTING THE BEST MATERIAL KIT DESIGN FOR EATON INDUSTRIES B.V.

The best material kit design is the best compilation of a material kit product, process and supply chain design. Since we do not object the strategic decision of Eaton Industries B.V. defining the material kit supply chain design, the determination of the best material kit design is restricted to the determination of the best material kit product design and material kit process design.

Selecting the best material kit product design for Eaton Industries B.V.

As discussed in Section 4.2.1, we introduced two feasible material kit product designs: Material Kit Product Design 1 (travelling material kits) and Material Kit Product Design 2 (stationary material kits).

Chapter 3 describes the current job release and allocation policies and the current order picking policies. Unless Eaton Industries B.V. is willing to reconsider these policies, these policies will impact the feasibility of the material product designs.

Table 7 lists the currently applied policies, the requirements of Material Kit Product Design 1, and the requirements of Material Kit Product Design 2. As indicated in Table 7, Material Kit Product Design 1 (travelling material kits) conflicts with both current policies. On the other hand, Material Kit Product Design 2 does not conflict with either of both policies.

Therefore, based on the above described mismatch between Material Kit Product Design 1 and currently applied policies, we define Material Kit Product Design 2 (stationary material kits) to be best for Eaton Industries B.V.

As described in Chapter 3, currently drawers are batched per type per system for the in-house assembly process. Batching drawers per type per system is not in alignment with the Lean and the continuous flow philosophy. Therefore, in the new in-house LVS assembly line design, drawers will be assembled per type per panel.

	Currently applied	Material Kit Product Design 1	Material Kit Product Design 2
Job release and allocation policies	Components allocation on based on job releases	(Preferably) Job releases based on components availability	Compared to the current applied policies, no appreciable additional requirements
Order picking policies	Warehouse locations determines the sequence of order lines on a picking order	(Preferably) The sequence of order lines on a picking order is in accordance with the material kit product design	Compared to the current applied policies, no appreciable additional requirements

TABLE 7: CURRENTLY APPLIED POLICIES VERSUS MATERIAL KIT PRODUCT DESIGNS REQUIREMENTS

Since detailed information regarding the OEM assembly process is lacking, we have to assume whether OEM partners assembly drawers per system (equal to the current assembly process of Eaton Industries B.V.) or assembly drawer per type per panel (equal to the further state assembly process of Eaton Industries B.V.).

To approximate the effects of supplying drawer components per type per system or per type per panel, we consider the OEM material handling workload (for a representative Capitole 40 installation, see Appendix E). Equation 1 (see Chapter 3) is used to determine the total workload, these numbers are:

- Current method to supply components (see Appendix F), 27.1 hours;
- Supply components per drawer per panel (see Appendix G), 45.9 hours (69% increase);
- Supply components per drawer per system (see Appendix H), 40.4 hours (49% increase).

Table 8 visualizes the number of material kits and the number of order lines per material kit in case drawer components are supplied per type per system. Table 9 visualizes the number of material kits and the number of order lines per material kit in case drawer components are supplied per type per panel.

→ Panel / drawer ↓ Kit (workstation)	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
VMI	77																			
1 Body construction	21	20	20	20	16	16	5	16	20	20	20	20								
2. Vertical support	22	22	22	22	29	22	1	29	22	22	22	23								
3. Hor. and vert. connections	6	7	7	7	23	35	5	23	7	7	7	7								
4. Panel layout	18	18	18	18	45	40	2	45	18	18	18	17								
5. Covers	4	4	5	4	17	16		17	4	5	4	4								
6. Drawer installation													32	41	57	28	27	49	54	76
7. Final assembly	8	8	8	8	19	24	7	19	8	8	8	8								

TABLE 8: ORDER LINES PER MATERIAL KIT WHEN SUPPLYING DRAWERS PER TYPE PER SYSTEM

→ Panel / drawer ↓ Kit (work-station)	1	2	3	4	5	6	7	8	9	10	11	12
VMI	77											
1 Body construction	21	20	20	20	16	16	5	16	20	20	20	20
2. Vertical support	22	22	22	22	29	22	1	29	22	22	22	23
3. Hor. and vert. connections	6	7	7	7	23	35	5	23	7	7	7	7
4. Panel layout	18	18	18	18	45	40	2	45	18	18	18	17
5. Covers	4	4	5	4	17	16		17	5	5	4	4
6. Drawer installation (kit per drawer type)	32 41 54 76	32 28 49 76	32 41 28 27	32 41 28 27					32 41 28 27	32 57 27	32 27 49 76	41 27 54 76
7. Final assembly	8	8	8	8	19	24	7	19	8	8	8	8

TABLE 9: ORDER LINES PER MATERIAL KIT WHEN SUPPLYING DRAWERS PER TYPE PER PANEL

In Table 38 (see confidential Appendix N) we determine that currently the total annual OEM material handling costs currently equals € 58,434. According to the OEM supervisor, currently – approximately – one FTE is devoted to picking and packing Capitole 40 components. Dividing this € 58,434 by 220 (working days per year) and 7.6 (working hours per day) gives € 34.95 as an hourly labour cost of one OEM employee. This € 34.95 makes sense and validates the findings and conclusion in Appendix N.

Table 10 visualizes the estimated material handling costs for supplying drawers per type per panel and for supplying drawers per type per system. Based on the figures in Table 10, we can conclude that the annual cost for supplying drawers per type per panel costs approximately € 11,500 more compared to supplying drawers per type per system.

	Current situation	Supply drawers per type per panel	Supply drawers per type per system
Annual material handling costs	€ 58,434	€ 58,434 x 169% = € 98,753	€ 58,434 x 149% = € 87,067

TABLE 10: THE IMPACT OF HOW TO SUPPLY DRAWERS ON THE ANNUAL MATERIAL HANDLING COSTS

Based on (1) the extra investment in material handling process and (2) the uncertainty whether this investment will result in an increased perceived value by the OEM partner, we advise Eaton Industries B.V. to supply components per drawer type per system in stationary material kits (Material Kit Design 2). Implementing this material kit design will increases the annual material handling costs with approximately € 28,500 (assuming current OEM process efficiency).

In Chapter 3, we described that OEM demand is currently aggregated per component per order. Furthermore, the RCA in Chapter 3 concludes this aggregation of OEM demand is one of the causes why the OEM product and process design do not support the strategic goals of Eaton Industries B.V. Implementing Material Kit design 2, reduces this level of aggregation in OEM demand. Appendix I compares the current in-house demand pattern, the current OEM demand pattern, and the new OEM demand pattern. These demand patterns are measured in the magnitude in average demand (see Equation 2) and the magnitude in demand deviation (see Equation 3). Both equations are based on theory described by Zinn et al. (1989). We conclude that the implementation of Material Kit Design 2, supplying material kit per type per system, will increase the similarity of in-house and OEM demand patterns. This will positively influence the total – safety – stock levels.

$$M_{average} = \frac{\bar{X}_1}{\bar{X}_2}$$
in which:
$\bar{X}_1 \leq \bar{X}_2 \;\; \cap \;\; \bar{X}_2 \neq 0$
$\bar{X}_i$ = average demand measurement i

EQUATION 2: EXPRESSION FOR THE MAGNITUDE IN AVERAGE DEMAND

$$M_{deviation} = \frac{\sigma_1}{\sigma_2}$$
in which:
$\sigma_1 \leq \sigma_2 \;\; \cap \;\; \sigma_2 \neq 0$
σ_i = demand deviation measurement i

EQUATION 3: EXPRESSION FOR THE MAGNITUDE IN DEMAND DEVIATION (ZINN ET AL., 1989)

Selecting the best material kit process design for Eaton Industries B.V.

Section 4.2 discusses three feasible material kit process designs: Material Kit Process Design 1 (do not change the OEM process), Material Kit Process Design 2 (the OEM activities seen as order picking activities), and Material Kit Process Design 3 (OEM activities seen as - material kit – assembly activities).

To determine the best material kit process design we score each feasible material kits process designs on (1) the influence on the root causes assessment criterion identified in Chapter 3 and (2) the financial assessment criterion identified in Chapter 3. Table 10 and Table 11 visualize these assessment criterion and the corresponding scores. These scores are either based on calculations or based on evaluation of the researcher and are further discussed below.

+ most positive material kit process design □ neutral material kit process design - most negative material kit process design	Material Kit Process Design 1	 2	 3
The material kit (process) design should support both the in-house assembly process and the OEM process (root cause 2)	-	□	+
The material kit product and process design should support continuous improvement on the material kit product design (root cause 3)	-	□	+
The (material kit) process design should stimulate maintenance and continuous improvement on master data (root cause 6)	-	□	+

TABLE 11: THE MATERIAL KIT DESIGNS AND THEIR INFLUENCE ON THE ROOT CAUSES

We claim Material Kit Process Design 3 (OEM activities seen as – material kit – assembly activities) to have the most positive influence on all three root causes assessment criterion defined in Chapter 3 (visualized in Table 11).

In Material Kit Process Design 3 similar management and control policies are applied to the in-house assembly process and the OEM process. Therefore, the OEM process requires no derivatives on the –basic – in-house assembly process. We claim that using one process design for both the in-house assembly process and the OEM process attributes to the ability to implement incremental process improvements (gained in the in-house assembly process) in both processes. Furthermore, since this process design focuses on uniformity, the quality of material kitting can be validated (by means of a pilot) in the in-house assembly process.

We claim Material Kit Design 1 (do not change the OEM process) to have the most negative (or least positive) influence on all three root causes assessment criterion defined in Chapter 3 (visualizes in Table 11).

In Material Kit Process Design 1 the need for OEM employees to shop in the in-house assembly process remains. Furthermore, since the in-house assembly process and the OEM process remain to differ significantly, we argue that it will be more difficult for Eaton Industries B.V. to let the OEM process gain the benefits from in-house assembly continuous improvements. Furthermore, the OEM process (control) design remains to be a derivate of the in-house assembly process (control) design.

We claim Material Kit Process Design 2 (OEM activities seen as order picking activities) to have, compared to Material Kit Process Design 1 and Material Kit Process Design 3, a neutral impact on all three root causes assessment criterion defined in Chapter 3.

In Material Kit Process Design 2 there is no longer need for OEM employees to shop from the in-house assembly process line-stocks. On the other hand, the in-house assembly process and the OEM process will remain to differ significantly both on process (control) design and on management and control policies.

Table 12 visualizes the impact of all three material kit process designs on the financial assessment criterion (defined in Chapter 3). Using line-stocks (Material Kit Process Design 3) is expected to reduce material handling costs, since operators are provided with Kanban managed inventories, but is expected to increase inventory holding costs. On the other hand, Material Kit Process Design 1, in which the need for OEM employees to shop for materials, is expect to increase material handling costs and reduce total inventory costs.

+ most positive material kit process design □ neutral material kit process design - most negative material kit process design	Material Kit Design		
	1	2	3
The material kit design contributes to reduce material handling costs	-	□	+
The material kit design contributes to reduce inventory costs	+	□	-

TABLE 12: THE MATERIAL KIT DESIGNS AND THEIR INFLUENCE ON FINANCIAL SCORING CRITERIA

At Eaton Industries B.V. Kanban-worthy policies (see Chapter 3, page 29) are used, as a decision support, in the trade-off between reducing material handling costs and inventory costs.

Appendix J compares the currently – non economically driven – applied Kanban-worthy policies to an economic driven "Kanban-worthy test" based on the economic order quantity introduce by Camp (1922) and described by, among others, Winston (2004). This appendix concludes that Eaton Industries B.V. could save up to 14% on their material handling and inventory costs. Two notes to make, however, are: (1) these savings heavily depend on the chose parameters and (2) a vast majority of components each accounting for a minority in savings. What we can conclude from the figures in Appendix J is that Eaton Industries B.V. could save up to 5% on their material handling and inventory cost by focusing only on the high scoring components (in Appendix J 10 stock keeping units). What more we can conclude from the figures in Appendix J, is that the Kanban-worthy policies, currently applied at Eaton Industries B.V., are justified from an economically perspective (apart from a minority of acceptations).

Based on the findings in Appendix J, we conclude that applying Kanban-worthy policies to the OEM process will minimize total (material handling and inventory) costs. Therefore, we claim that Material Kit Process Design 3 – in which Kanban-worthy policies are applied – will minimize the total relevant costs, therefore Material Kit Design 3 scores the best overall score on the financial assessment criterion in Table 12.

Describing the best material kit – product and process – design

Given the above described findings, we advise Eaton Industries B.V. to implement Material Kit Product Design 2 (stationary material kits), supplying drawers per type per system, and implement Material Kit Process Design 3 (OEM activities seen as material kit assembly activities). Given this material kit design, we expect:

- the material kitting workload to increase with approximately 169%. Based on current efficiencies, increasing the annual material handling costs from (about) € 60,000 to (about) € 100,000;
- the inventory values to increase with € 85,000 (by applying Kanban-worthy policies to the new material kit process design, further elaborated on in Appendix K). Assuming the annual holding costs equals 25% of the inventory value, the annual inventory costs equal € 21,250.

Since the above described material kit design dedicates line-stocks inventories to the OEM process, we expected that the overall OEM material handling process will improve on efficiency. If Eaton Industries B.V. is able to double material handling pace in the OEM process, from currently 7 lines per hour to 14 lines per hour (which is still far less compared to the 20 line per hour for the in-house assembly process), the annual material handling costs will – instead of increase to (about) € 100,000 – decrease to (about) € 50,000.

Visualized in Table 13, the implementation of material kitting will increase the annual costs for Eaton Industries B.V. by approximately € 11,000. To indicate the magnitude of this costs increase, € 11,000 is equals less than 1% of the current OEM – Capitole 40 – turnover.

Cost drivers	Current annual costs	Change	New annual costs
OEM material handling	€ 60,000	(up) 69% & (down) 50% = 1.69 x 0.5 = 0.85	€ 50,000
OEM line-stock inventory (holding costs)	€ 0	(up) € 21,000	€ 21,000
Total	€ 60,000		€ 71,000
Additional annual costs when implementing material kitting			€ 11,000

TABLE 13: THE FINANCIAL EFFECT ASSOCIATED TO THE IMPLEMENTATION OF MATERIAL KITTING

Since the in-house assembly process is out of the scope of this research, the influence of the material kit design(s) on the in-house assembly process is kept to a minimum. However, if Eaton Industries B.V. decides extend the use of material pitching (for the definition see page 42), line-stock inventories can be aggregated and holding costs can be reduced. In Appendix K, we compared two situations: (1) the in-house assembly process and the OEM process each having dedicated line-stocks and (2) the in-houses assembly process and the OEM process have one aggregated stock. We conclude that the aggregation of line-stocks will:

- reduce the total inventory value by approximately € 50,000, reducing the annual holding costs by approximately € 12,500;
- further stress the emphases for – bottom-up – continuous improvements with respect to material coordination for the in-house assembly process. This will benefit both the in-house assembly process and the OEM process.

In Appendix L we discuses a different Kanban-worthy test. This Kanban-worthy test is far more complex compared to the current Kanban-worthy test, but includes a trade-off between component costs price, service levels (material availability), and stock levels. Although this new Kanban-worthy test will – most likely – never be implemented due to complexity, it can be useful gain insight into relation between demand variability, stock levels, and service levels. This should trigger new discussion (improvements incentives) concerning the current Kanban-worthy policies.

4.4 PROVIDING ANSWERS TO THE MATERIAL KIT DESIGN ISSUES

In Chapter 2, we defined seven material kit design issues to be answered in the material kit design phase. Below the answer to each of these material kit design issues is given. This enumeration provides clear and straightforward policies to of use during the material kit design, implementation, and maintenance phase.

Answer to Material Kit Product Design Issue 1: Define the preferred type of material kit, travelling or stationary

We define the preferred type of material kit to be Material Kit Design 2, a stationary material kit product design. One material kit contains the components needed to support the assembly operations for one panel or one drawer type and one workstation.

Answer to Material Kit Product Design Issue 2: Define policies to identify components (and/or subassemblies) that are excluded from the preferred material kit type.

VMI (Vendor Managed Inventory) components are excluded from the preferred material kit type. The reason to exclude these components is twofold: (1) according to senior management, VMI parts are non-core business and should, therefore, be excluded VMI for material kit supplies and (2) the combination of a low product value, poor master data accuracy, and common use are each valid arguments to exclude (and maybe over supply) these VMI parts from the preferred material kit type.

WMI components could be supplied per multiple of packing quantities (to reduce material handling costs), based on rough estimations of the component usage.

Answer to Material Kit Process Design Issues 1: Define the flow of materials

We define the flow of materials to be most optimal when implementing Material Kit Process Design 3. In Material Kit Process Design 3, OEM activities seen as – material kit – assembly activities (see page 44). This implies that the in-house assembly process and the OEM process are subject to similar management and control policies. Kanban-worthy policies will be used to dedicated line-stocks to the OEM process.

Answer to Material Kit Process Design Issue 2: Define job release policies

As elaborated on in Section 4.3, the currently applied job release policies do not interfere with the recommended Material Kit Product Design 2 (stationary material kits). Since the in-house assembly process is out of the scope of this research, job release policies – affecting both the in-house assembly process and the OEM process – are not altered.

Answer to Material Kit Process Design Issue 3: Define order picking methods

As elaborated on in Material Kit Process Design 3, OEM activities seen as – material kit - assembly activities (see 44), material kits are composed using (Kanban managed) line-stock components and (MRP managed) components. Kanban managed components will be picked by the OEM employee, MRP managed components will be picked – and supplied to the OEM department – by warehouse employees.

Answer to Material Kit Process Design Issue 4: Define methods and/or policies to guarantee material kitting accuracy

Material kitting accuracy can be interpreted in two ways: (1) the content of the material kit corresponds with the material kit material requirements and (2) the material prescriptions, defining the content of the material kits, are reliable.

The first case of accuracy can be supported manually (like in the current situation) or supported with the use of barcode scanning (currently under development). The second case of accuracy should be supported by making maximum use of – bottom-up – continuous improvements incentives gained in the in-house assembly process. Since the in-house assembly process is the only "real-time and observable" process, we advise Eaton Industries B.V. to design both processes such that in-house processes contribute to continuously improving the material (product) design.

Answer to Material Kit Supply Chain Design Issue 1: Define the position of the Customer Order Decoupling Point

In alignment with the strategic statement of Eaton Industries B.V., we define the composition of material kit to be the first demand driven activity. Therefore, the CODP will be allocated just before the material kitting process.

Long-lead time ATO components can be kept on stock to assure availability, while the need to order ETO components on customer request remains. Allocating the CODP before the material kitting process enable Eaton Industries B.V. to produce material kits on customer demand, according to customer specifications.

4.5 CONCLUSIONS FOR THIS CHAPTER

This chapter provides an answer to the research question: "*What are feasible material kit product and process designs for Eaton Industries B.V?*". Second, this chapter provides insight into how to select the best material kit product and process design for Eaton Industries B.V.

To answer the research question, we define two material kit product designs, three material kit process designs, and one material kit supply chain design. Regarding the material kit product design, we advise Eaton Industries B.V. to implement stationary material kits (Material Kit Product Design 2, see page 41) instead of travelling material kits. Implementing stationary material kits have compared to travelling material kits the following advantages:

- stationary material kits honour the Capitole 40 material characteristics and the assembly process. Therefore, this material kit design minimizes elimination of components from the preferred type of kit to a maximum extent (improving the material kit quality);
- stationary material kits do not require additional policies to be included in the order release and order picking process.

We advise Eaton Industries B.V. to manage and control the OEM process using similar management and control policies as applied in the in-house assembly process (Material Kit Process Design 3, see page 44). The advantages of this material kit process design, over Material Kit Process Design 1 (do not change OEM activities) and Material Kit Process Design 2 (OEM activities seen as order picking activities) are:

- the variation in process designs (in-house versus OEM) is reduced to a maximum extent, reducing the need for (in-house or OEM) specialists;
- observations and improvements gained in the in-house assembly process can easily be implemented into the OEM process;
- Kanban-worthy policies (supporting in the trade-off between material handling costs and inventory holding costs) can be applied. This further increases the level of similarities between both processes and reduces the total relevant costs.

We advise Eaton Industries B.V. not to change their strategic statement, stating that Eaton Industries B.V. should be the last supply chain party holding forecast driven inventories. Applying this supply chain design enables Eaton Industries B.V. to supply customer specific material kits, according to customer – specific – requirements. Implementing this material kit design will, however, require a flexible material kitting department.

We approximate the annual costs, associated to implementing of the above describe material kit design, to increase with approximately € 11,000. If Eaton Industries B.V. decides to charge their down steam OEM partners for this new material kitting service, the sales prices of material supplies will rise with less than 1%.

5 MATERIAL KIT PROCESS CONTROL DESIGN

This chapter discusses various process control designs to support the material kit product and process design (defined and discussed in Chapter 4) to provide an answer to the question: "*How can the chosen material kit design be managed and controlled in the current ERP system, BaaN?*"

The current Enterprise Resource Planning system of Eaton Industries B.V., BaaN, and the abilities offered by BaaN to managed and control information influences the feasibilities to managed and control material kitting. During the material kit product and process designs phase (outcome provided in Chapter 4) these restrictions had great influence on the final material kit design outcome.

This chapter discusses three material kit process control designs to support material kitting in BaaN. Each of these material kit process control designs is characterised by a set of strengths, weaknesses, and restrictions. The applicability of each of the described material kit process control designs heavily depends on commitments senior management is willing to take. Therefore, the main aim in this chapter is to gain insight into the feasible process control designs, their particular strengths, weaknesses, and restrictions.

Section 5.1 provides insight into the material coordination requirements, needed to support material kitting. Section 5.1 introduces a two dimensional material allocation: (1) material required per panel or drawer type, and (2) material required per material kit. Section 5.2 shows that material kitting requires no new BaaN applications. Section 5.3 introduces and discus three different process control designs, while Section 5.4 elaborates on load levelling in relation to material kitting. Finally, Section 5.5 provides the conclusions for this chapter.

5.1 TWO DIMENSIONS TO COORDINATE MATERIALS REQUIREMENTS

Chapter 3 discusses the distinction between the material specification phase and the material coordination phase. Materials requirements are specified during the project specification phase, while materials are coordinated during the shop floor control. The material specification phase and how information is used in this phase influence the feasibilities to coordinate materials.

In Chapter 4, we concluded that Eaton Industries B.V. should coordinate materials per panel and per drawer type, per workstation in order to support material kitting. We refer to this as two dimensional material allocation (and coordination). Figure 29 illustrates these two dimensions: the first dimension is the coordination of materials per panel and per drawer type (horizontal in Figure 29), the second dimension is the coordination of materials per workstation (vertical in Figure 29).

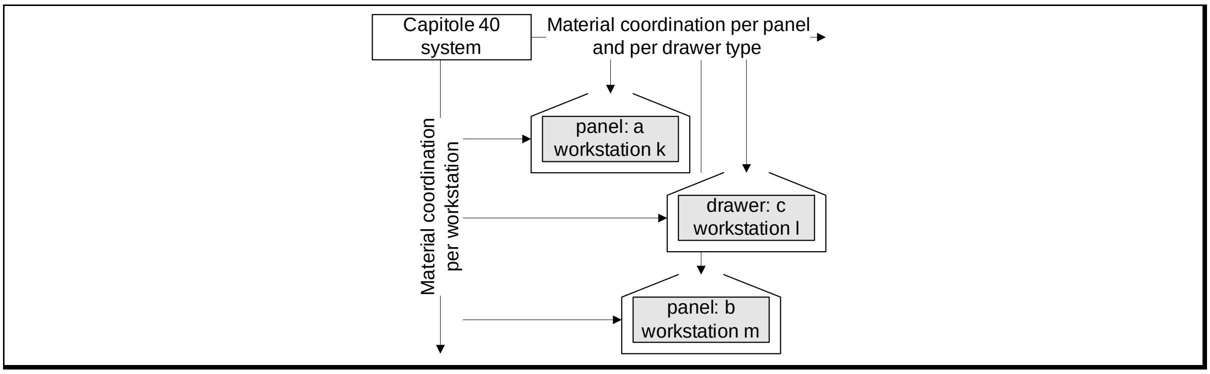


FIGURE 29: TWO DIMENSIONS TO COORDINATE AND MATERIAL REQUIREMENTS

Section 5.1.1and Section 5.1.2 provide insight into both dimensions and discusses the use of information to specify and coordinate materials in both dimensions.

5.1.1 SUPPORT MATERIAL COORDINATION PER PANEL AND PER DRAWER TYPE

In the material specification phase customer specific BOMs (Bills Of Material) will be used to distinguish materials needed for different panel and drawer type. This is the horizontal dimension in Figure 29.

The only option to introduce this distinction is in the first possible material specification phase, the project structure (see Figure 30). Figure 30 visualizes how customer specific BOMs per panel and per drawer type are structured (the currently used typicals and modules can be allocated to these new panel and drawer BOMs).

According to the work preparation department, responsible for the project designs and specifications, introducing a project structure as visualized in Figure 30 increases the number of customer specific BOMs. On the other hand, the work preparations department identifies the following benefits, when using this new project structure: (1) material specification can be checked easily on completeness, since material requirements are more clearly organized and (2) work preparations will be able to keep using typicals (typicals are frequently used customer specific BOMs).

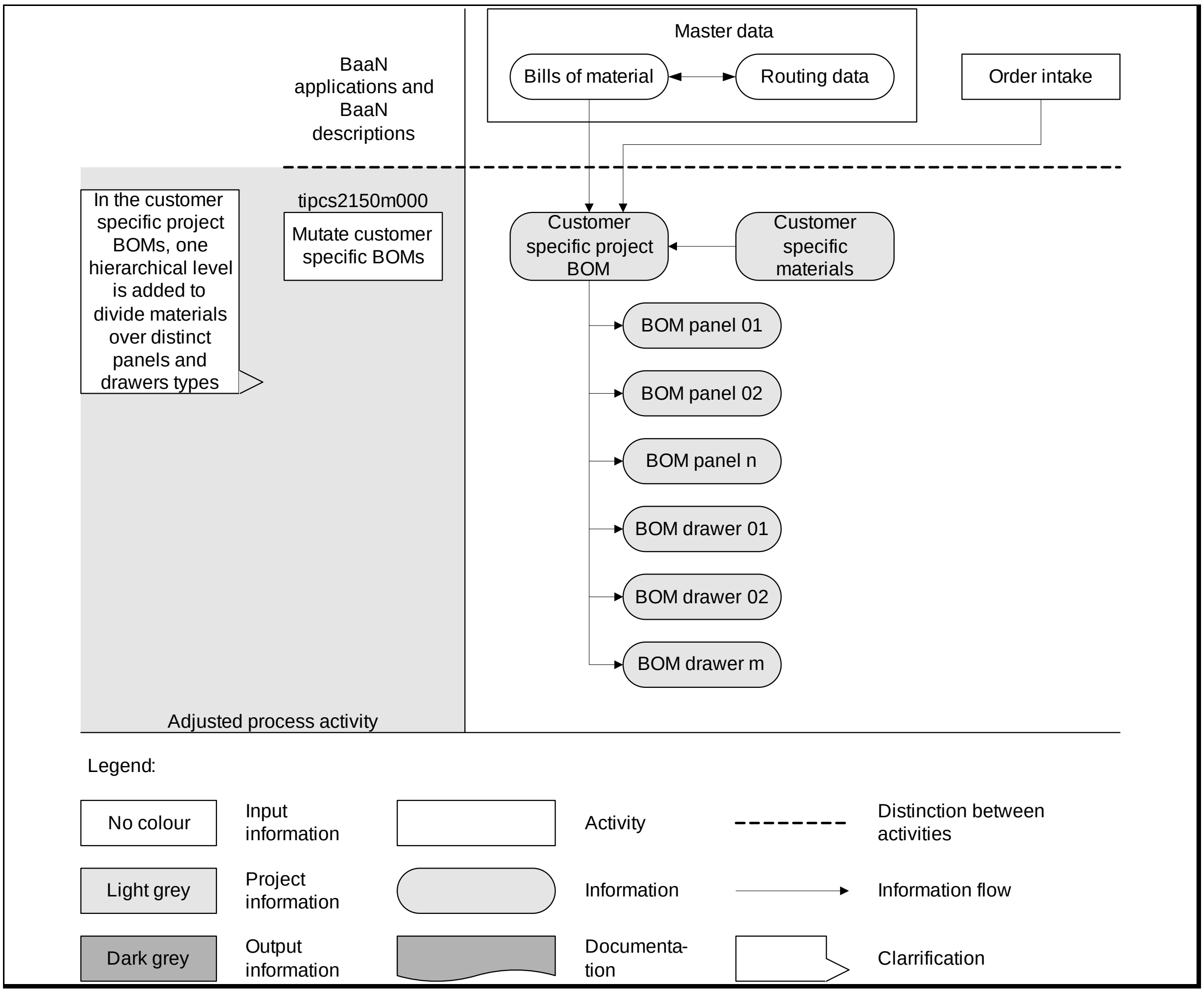


FIGURE 30: NEW PROJECT STRUCTURE TO COORDINATE MATERIALS PER PANEL AND DRAWER TYPE

5.1.2 SUPPORT MATERIAL COORDINATION PER WORKSTATION

The vertical dimension in Figure 29 focuses on separating material needed per material kit (or per workstation when considering the in-house assembly process).

In an early stage of this research, we considered the feasibility to used line-stock locations to link components to workstations (and material kits). This method is further discussed in Appendix M. Components which are not stored in a line-stock, on the assembly floor, require additional (manual) specification. Major drawback, when using line-stock locations to link components to material kit, is that a new OEM-special information source will be designed, used, and maintained.

The alternative method is to adapt routing data. Routing data, listed on the BOMs, specify where components are used in the assembly process. Initially we assumed that it would be impossible to adapt routing information merely to implement material kitting. Two reason why this seemed to be impossible were: (1) adapting routing information will affect the in-house assembly processes and (2) adapting routing information is an extremely labour intensive task.

However, as described in Chapter 4 (see page 42), the current in-house assembly process is subject for discussion at Eaton Industries B.V. New in the LVS assembly process is the ability to coordinate materials requirement per workstation. Therefore, routing information will be updated for the in-house process. The material kit product design (see Chapter 4), inspired by the in-house assembly process design, divides material requirements over various material kits based on the in-house assembly – workstation – layout. Given the fact that Eaton Industries B.V. will adapt the Capitole 40 routing information, we advise Eaton Industries B.V. to adapt these information sources such that it will be able support both the in-house assembly process and OEM process.

Figure 31 visualizes how routing information should be used to coordinate materials in the in-house assembly process and how this information supports material coordination in the OEM process. It is important to note that the material kitting process requires a clear distinction between MRP or Kanban managed component and VMI managed components, since VMI components are excluded from the stationary material kit. Furthermore, since the OEM operators do not notice incorrect material coordination, the in-house assembly process should contribute noticing and improving material coordination by adjusting master data. This will contribute to accurate and correct material coordination and supplies.

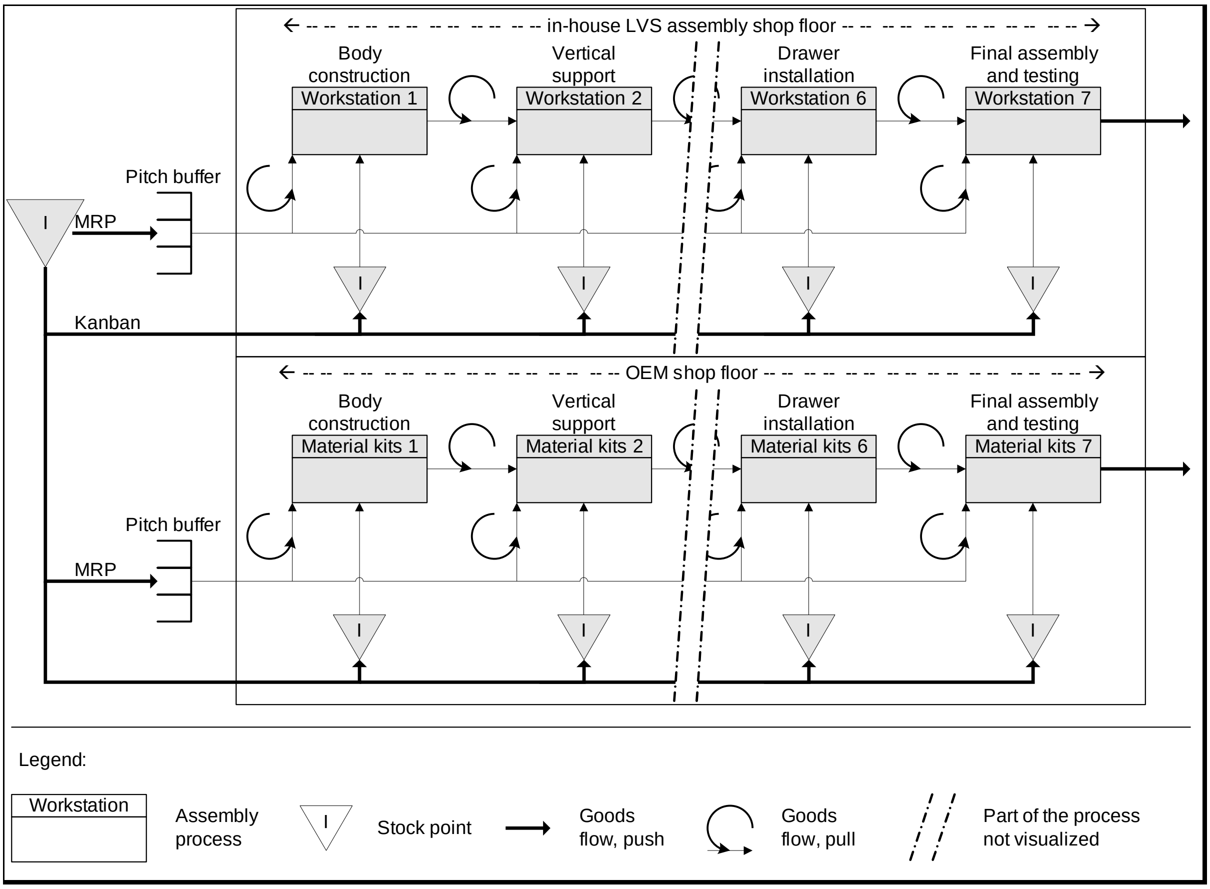


FIGURE 31: MATERIAL COORDINATION PER WORKSTATION FOR BOTH THE IN-HOUSE ASSEMBLY PROCESS AND THE OEM PROCESS

5.2 USING THE POWER SESSION “OMWERKEN” TO CONVERT BOMS TO MATERIAL REQUIREMENTS PER MATERIAL KIT

As described in Section 5.1, components can be specified per panel and per drawer type and, using routing information, be allocated to specific material kits (or workstations). As discussed in Chapter 3, the current power session “platslaan” do not uses routing information to (re-) structure sales-order-BOMs.

In close consultation with the IT department of Eaton Industries B.V., we formulated and discussed various methods how to use routing information in the new material kitting process control. For example, we thought of exporting BaaN information into Excel (retaining routing information), run a heuristic to reorder material requirements, and upload this information back into BaaN.

During this consultation with the IT department of Eaton Industries B.V. it became clear that for Medium Voltage Systems (MVS) material requirements are specified and coordinated using routing information. Reason why LVS and MVS use different applications can be traced back to the time LVS and MVS were different business units. Although, LVS and MVS could use the same material specification and coordination applications, the urgency to merge both product families never occurred.

Figure 32 illustrates how (currently MVS) projects are designed and how the “omwerken” power session reorders materials requirements. Reordering these material requirements is based on routing information. In this figure, the project design procedures are similar to the procedures in

Figure 30 (and the procedures discussed in Chapter 3). However, the “omwerken” power session (in Figure 32) reorders one project oriented BOM structures to multiple routing oriented BOM structures. In Figure 32, the customer specific BOM containing the material requirements for panel 1 is subdivided to a BOM containing the material requirements for (panel 1) kit 1, a BOM containing the material requirements for (panel 1) kit 2, until a BOM containing the material requirements for (panel 1) kit 7.

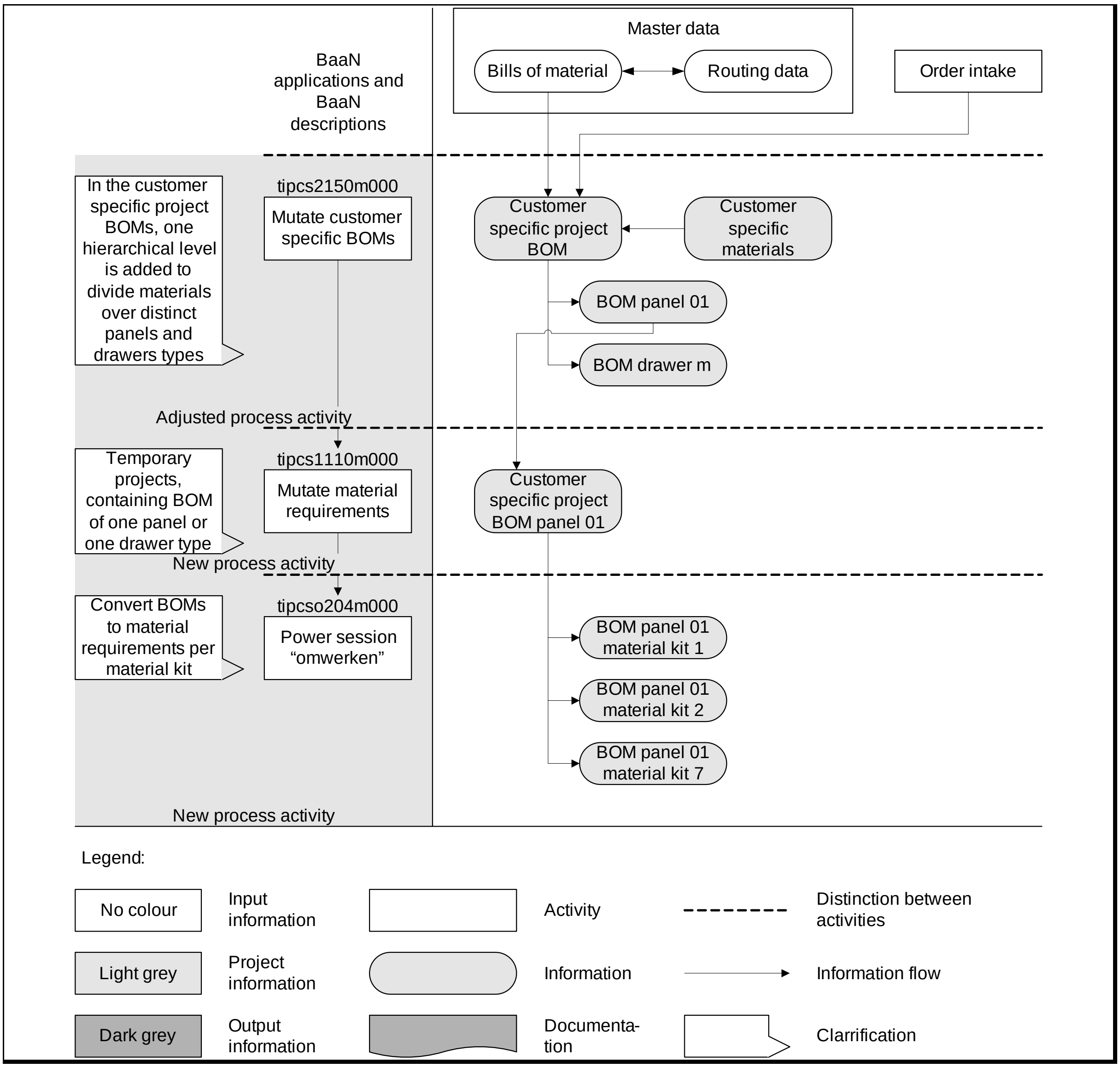


FIGURE 32: DESIGNING MVS PROJECT AND THE COORDINATION OF MATERIALS USING THE POWER SESSION “OMWERKEN”

Using this power session “omwerken” to manage and control material kitting requires one additional step: the project – containing all panels and drawers – have to be copied per panel and per drawer type. In these copies material requirements other than the panel or drawer type under consideration is removed before the – single – panel or drawer type is reconstructed in the “omwerken” power session.

As a result, components can be allocated to BOMs per panel and per drawer type, per material kit (or workstation, see Table 14). These BOMs, clusters of material requirements, can be used for material, sales order, and shop floor control and coordination. Various methods on how to use this new BOM information are discussed in the next section.

	(panel 1) Project no. 0002	…	(panel n) Project no. 0003	(drawer 1) Project no. 0004	…	(drawer m) Project no. 0005
(body construction) Customer specific BOM 1	BOM 0002_01		BOM 0003_01			
(vertical support) Customer specific BOM 2	BOM 0002_02		BOM 0003_02			
(hor. and vert. connections) Customer specific BOM 3	BOM 0002_03		BOM 0003_03			
(panel layout) Customer specific BOM 4	BOM 0002_04		BOM 0003_04			
(covers) Customer specific BOM 5	BOM 0002_05		BOM 0003_05			
(drawer installation) Customer specific BOM 6				BOM 0004_06		BOM 0004_06
(final assembly) Customer specific BOM 7	BOM 0002_07		BOM 0003_07			

TABLE 14: BOMS, CLUSTERS OF MATERIAL – KIT – REQUIREMENTS

5.3 THREE MATERIAL KITTING PROCESS CONTROL DESIGNS

Described in Chapter 3, material requirements are triggered by a sales order, possibly relating to a production order, relating to specific set of components. We have defined three process control designs: (1) one sales order per material kit, (2) one sales order per shipment, and (3) one sales order per shipment and one production order per material kit.

These material kit process control designs are discussed below. We show that the feasibility for each of the material kit process control designs heavily depends on commitment senior management of Eaton Industries B.V. is willing to take.

5.3.1 PROCESS CONTROL DESIGN 1: ONE SALES ORDER PER MATERIAL KIT

Figure 33 visualizes Process Control Design 1, one sales order per material kit. In this process control design, one sales order relates to one material kit. The most important advantage of this process control design is that materials are clearly coordinated. Since the trigger of demand (the sales order) relates to one single material kit, therefore confusion regarding the allocation of components to material kits is ruled out.

The most important drawback of Process Control Design 1, however, is that the increase in the number of sales orders will increase the administrative workload. For the representative project (in Appendix E) the number of sales orders increases from 3 to 80(!). To illustrate the impact of this increase, the customer support department estimates the fixed costs related to one sales order to equal € 300.

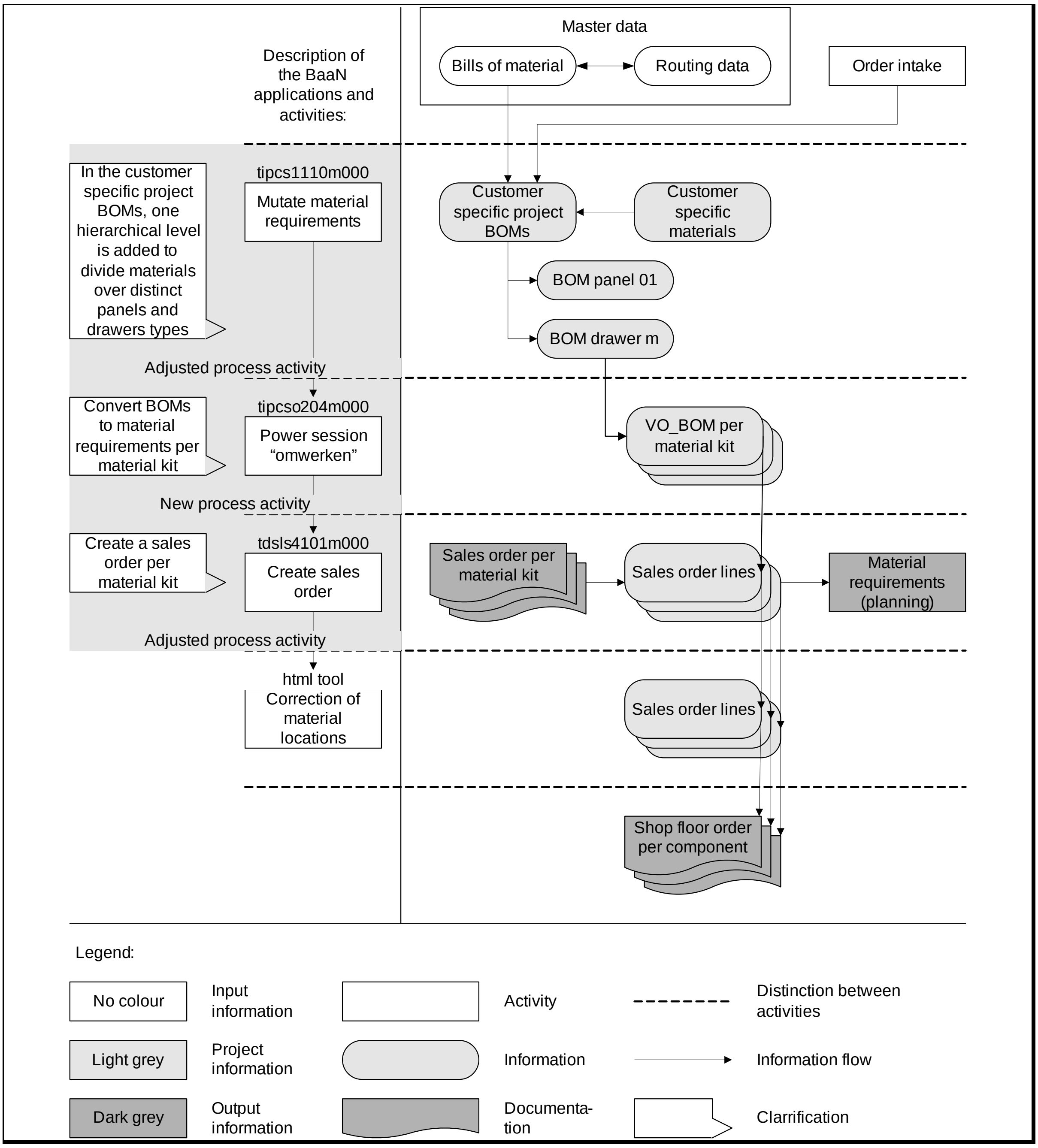


FIGURE 33: PROCESS CONTROL DESIGN 1: ONE SALES ORDER PER MATERIAL KIT

5.3.2 PROCESS CONTROL DESIGN 2: ONE SALES ORDER PER SHIPMENT

Figure 34 visualizes Process Control Design 2, one sales order per shipment. This process control design provides a solution to the increasing administrative workload problem of Process Control Design 1. In Process Control Design 2, customer specific BOMs (related to one material kit) are printed (or exported to Excel) before the BOMs are converted to one sales order per shipment.

In this process control design, there is no direct relation between the trigger of demand (the sales order) and the material kit. In this process control design OEM operators use printed (or electronic) versions of material kit BOMs to allocate components to the right material kit.

Advantage of this material kit process control design is the not increasing administrative workload. Most important drawback, however, is the reduction in clarity regarding the coordination of materials.

As described in Chapter 3, Eaton Industries B.V. is currently exploring the feasibilities to implement barcode scanning in the order picking process. If Eaton Industries B.V. decides to implement Process Control Design 2, barcode scanning could be implemented to safeguard the material kit accuracy.

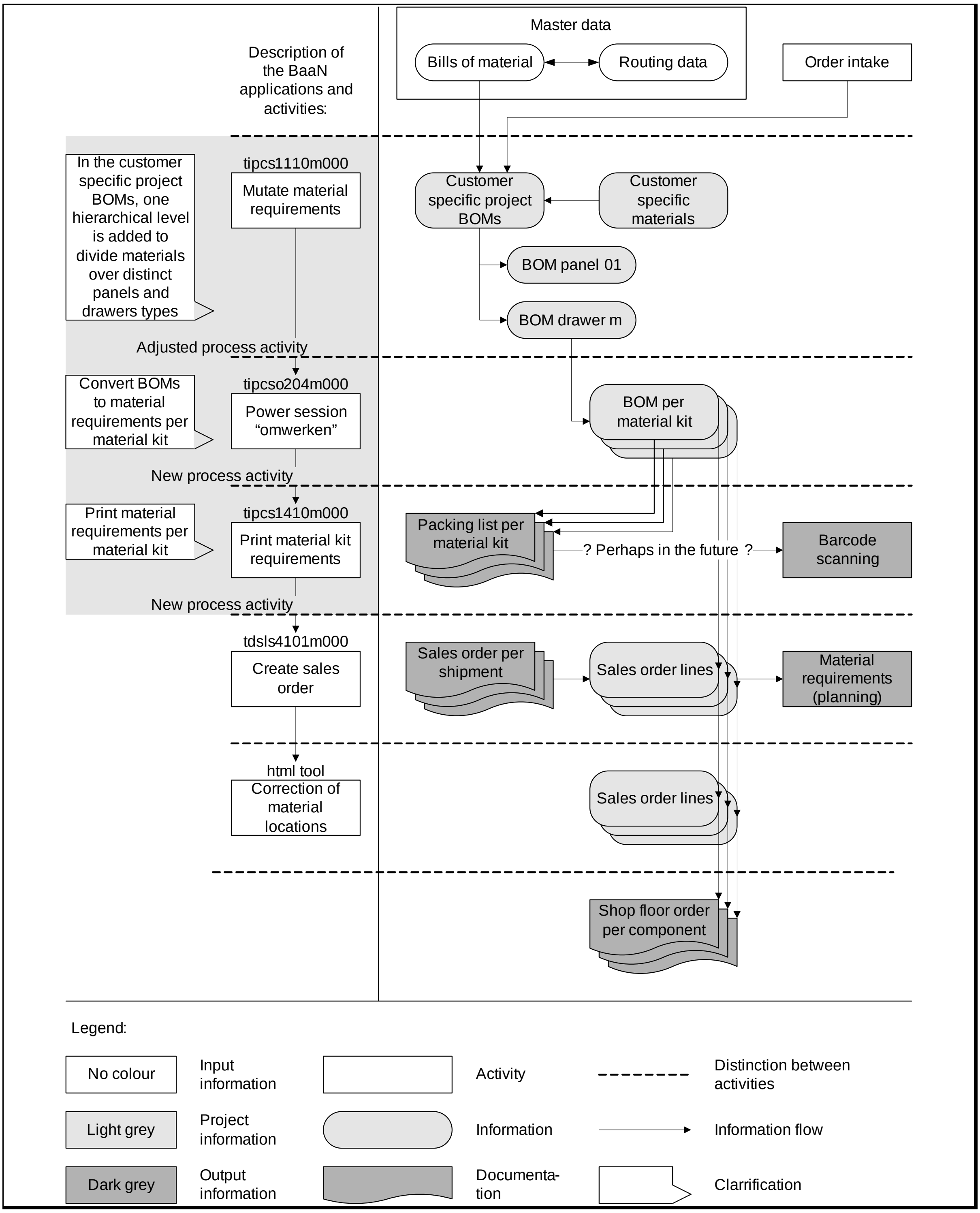


FIGURE 34: PROCESS CONTROL DESIGN 2: ONE SALES ORDER PER SHIPMENT

5.3.3 PROCESS CONTROL DESIGN 3: ONE SALES ORDER PER SHIPMENT AND ONE PRODUCTION ORDER PER MATERIAL KIT

Figure 35 visualizes Process Control Design 3, one sales order per shipment and one production order per material kit. In this process control design, material requirements are linked to a production order. The production order is listed on a sales order per shipment.

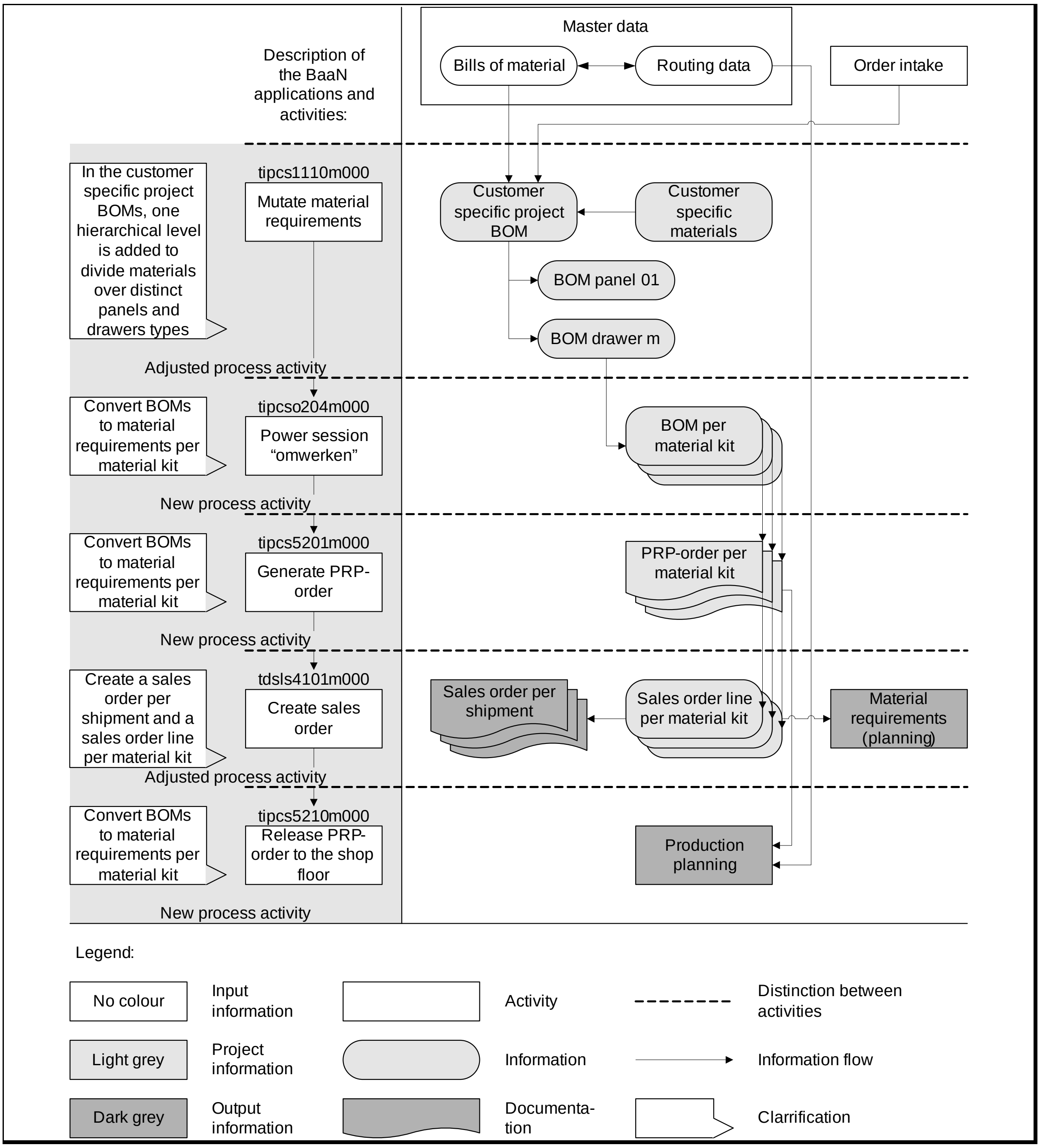


FIGURE 35: PROCESS CONTROL DESIGN 3: A PRODUCTION ORDER PER MATERIAL KIT

The most important benefit of this process control design is that BaaN is production oriented. Therefore, using production orders in the material kit process offers the opportunity for clear and straightforward material coordination while not increasing the number of sales orders. Furthermore, since in-house assembly also uses production orders, the process design gap between the in-house assembly process and the OEM process is further reduced.

The most important drawback of Process Control Design 3, however, is that production orders cannot be partially supplied. This implies that material kits can only be supplied when totally completed. From an assembly perspective this makes sense, since components in one kit are used at (about) the same time. However, from a financial perspective it could make sense to supply and charge partially completed material kits, since partial supplied material kits do increase turnover. Furthermore, sales orders will only list material kit (instead of component) information. This causes two difficulties: (1) shipping documentation cannot be a direct derivate of the sales order, and (2) information on component supply is not available in the sales order, but is listed in production order documentation.

Although this process control design provides the best possibilities for material coordination, the – not increasing – administrative workload, and the ability to reduce the organizational gap between the in-house assembly process and the OEM process, we observed lots of resistance amongst employees of Eaton Industries B.V. when discussing Process Control Design 3. The majority of this resistance is based on the doubt whether or not senior management at Eaton Industries B.V. is – truly – willing to commit and rule out partial material kit supplies.

5.4 THE IMPLEMENTATION OF MATERIAL KITTING CAN CONTRIBUTE TO A MORE CONTINUOUS FLOW

The two dimensional material kit design can be used to level and manage the production mix and pace, referred to as Heijunka in Chapter 2. Currently, shipments to licensee partners are possibly separated in more than one shipment (see Chapter 3). The logic currently applied to divide materials over the various shipments (see Chapter 3) is inspired by a – sort of – workstation partitioning (e.g. separated drawer, panels, and main busbars).

The implementation of material kits enables a two dimensional load levelling. Figure 36 serves as an illustrative example. This figure show the relation between the organization of the material supplies and the impact it has on the (flow of material in the) OEM partners' assembly process.

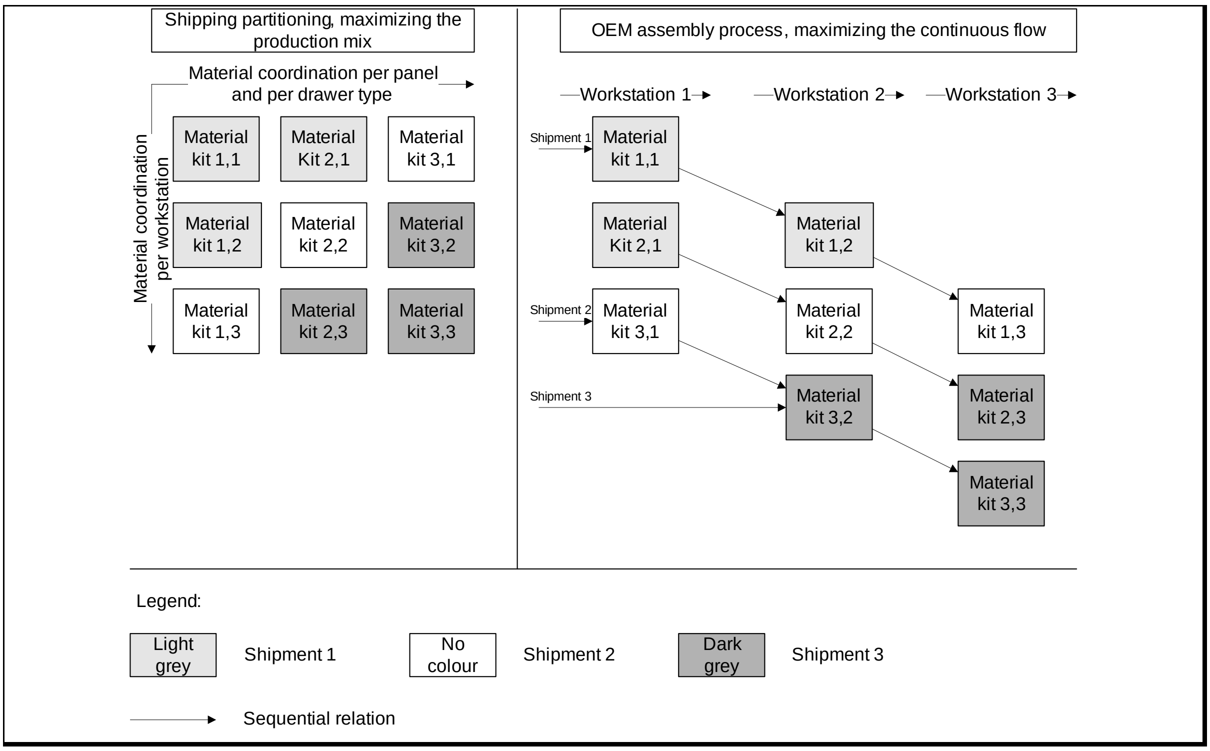


FIGURE 36: PARTITIONING OPTION TO IMPROVE THE PRODUCTION MIX

Supplying material kits using a partitioning method similar to the partitioning option visualized in Figure 36 offers two advantages: (1) the supplies of material kits to the OEM partner contributes to a continuous flow at the OEM partner and (2) the occupation of production capacity at Eaton Industries B.V. used to supply OEM is, compared to the current situation, spread over a longer time horizon.

5.5 CONCLUSIONS FOR THIS CHAPTER

This chapter provides an answer to the question: "*How can the chosen material kit design be managed and controlled in the current ERP system, BaaN*?".

To answer this research question, this chapter discussed how a currently used application for MVS can be used to coordinate materials in two dimensions: (1) components can be allocated to a panel and a drawer type and (2) components can be allocated to a workstation. Using the power session called "omwerken" provides the possibility to restructure systems' material requirements to material requirements per material kit.

To support material kitting in BaaN, we defined three process control designs: Process Control Design 1, one sales order per material kit, Process Control Design 2, one sales order per shipment, and Process Control Design 3, one sales order per shipment and one production order per material kit.

We concluded that Process Control Design 1 provides clear and straightforward abilities for material coordination but increases the administrative workload (measured in the number of sales orders). Applying Process Control Design 2 will not increase the number of sales order but makes material coordination more difficult.

Process Control Design 3, copes with both the administrative workload increase and the material coordination problem by using production orders for each material kit. This process control design uses the strengths of BaaN, managing and controlling production environments and further reduces the gap in process designs between the in-house assembly process and the OEM process. Using production orders in the material kitting process, however, rules out the ability to supply incomplete material kits and makes it impossible to use sales order information to define shipping documentation.

6 ROADMAP TO IMPLEMENT MATERIAL KITTING

This chapter provides an answer to the question: "*How can Eaton Industries B.V. implement the best material kit product and process design?*".

Section 6.1 describes the implementation of material kitting in terms of competitive elements introduced by McCann (1991) and discussed in Chapter 2. Section 6.2 discusses the current state of Eaton Industries B.V. regarding the material kitting change. Section 6.3 provides a roadmap for Eaton Industries B.V. to stimulate acceptance and commitment in order to successfully implement material kitting. The last section, Section 6.4, provides the conclusions for this chapter.

6.1 THE COMPETITIVE ELEMENTS AND THE IMPLEMENTATION OF MATERIAL KITTING

According to McCann (1991), business changes require adjustments in one or more of the four competitive elements of a business. These four competitive elements of a business and their implications are (see Chapter 2 for a more in-depth discussion):

- the products and services element, containing the total range of all products and services offered by a business;
- the structures and systems element, containing all the administrative domains, supervisions, and management functions of a business;
- the people element, containing the values, attitudes, expectations, beliefs, abilities, and behaviours of all individuals part of the business;
- the technologies element, containing all the tangible process technologies and all intangible knowledge embedded in a business.

The implementation of material kitting requires a change in the products and services element, the structures and systems element, and the people element. We claim that the new material kit product design (see Chapter 4) is a change in the products and services element, since the new material kit product design affects the current range of offered products and services. We argue that the new material kit process design (Chapter 4) and the new process control design (Chapter 5) are changes in the structures and systems elements, since this new process – control – design requires adjustments in the current administrative domain and management functions. The implementation of material kitting affects the people element since, according to Daft (2004), changes in both products and services and structures and systems always involve people to carry out and support changes.

6.2 THE CURRENT SITUATION DESCRIBED IN THE CONTEXT OF STAGES AND PHASES OF CHANGE

As discussed in Chapter 2 (Figure 10), Conner (1992) introduces a three phases and eight stages model to describe and manage commitment to change. This model can be used to monitor and control the change process. Furthermore, depending on the current stage of change, the model provides guidance to manage changes effectively and provides insight into the – the sequence of – change objectives.

The preparation phase focuses on making people aware of the change and making people understand the basic intentions of the change. Activities in the preparation phase emphasise the need and the urgency for the business to change, instead of devoting attention to how, or what the impact of the change will be for individuals in the organization, Conner (2011) refers to this as the disposition threshold.

Regarding the implementation of material kitting, we state that Eaton Industries B.V. finds itself in the preparation phase. To make people aware of the change and understand the intention of the change, Eaton Industries B.V. devotes attention to this topic in their all employee meetings, e.g. Eaton Industries B.V. (2011). Although communications in these all employee meetings do not focus specifically on the implementation of material kitting, awareness, the intention, and the urgency to change is pronounced.

Taking the awareness stage as the point of reference, Section 6.3 provides a material kit implementation roadmap to: (1) achieve acceptance in the acceptance phase and (2) explore activities to stimulate commitment in the commitment phase.

6.3 THE MATERIAL KITTING IMPLEMENTATION ROADMAP

Section 6.2 concludes that the implementation of material kitting for Eaton Industries B.V. is currently passing through the awareness stage. Therefore, this sections advises on how to achieve acceptance in the acceptance phase and provides an exploration of activities that contribute to achieve commitment in the commitment phase.

Table 15 lists the acceptance and commitment change phases, the change stages, and the objectives per stage as defined by Conner (2011). Furthermore, this table provides an overview of the – change – activities we advise Eaton Industries B.V. to carry out. Each of these activities is discussed in the upcoming sections.

Phase	Stage	Stage objective	Activity
Acceptance	Understanding	Provide insight into the consequences of the change	1. Define change objectives 2. Redefine the organisational layout
	Perception	Change mindset to stimulate positive perception	3. Define roles and responsibilities to support the new organisational layout
Commitment	Experimentation	Encourage discussion, find and solve entry problems, promote ownership, and build commitment	4. Develop tools and management functions to support the new organizational layout 5. Test material kitting to find and solve entry problems (pilot)
	Adoption	Find and solve long-term (organizational) problems	6. Adjust the wider organizational structure (plant layout, coordinating business functions)
	Institutionalization	Alter organizational structures, force commitment	7. Pronounce top-down commitment regarding the new organizational structure and organization 8. Enforce commitment
	Internalization	Continuous refinement and improvement	9. Define continuous improvements cycles and routines

TABLE 15: THE MATERIAL KITTING IMPLEMENTATION ROADMAP IN KEY ACTIVITIES

6.3.1 ACTIVITY 1: DEFINE CHANGE OBJECTIVES

Defining the change objectives is part of the understanding stage (acceptance phase). This objective in this stage is to involve those people affected by the change and to provide to them an objective – as possible – sketch regarding the change and the implications related to the change.

In order to stimulate commitment and involvement to the change, we advise Eaton Industries B.V. to set up a project team, including a project leader. Members of this project team should form a – unbiased – representation of those departments involved in the change and operational process. Departments to be represented in the project team include: customer support, work preparation, planning, material handling, material management, and IT. The project leader should be an individual with a positive attitude towards the changes and affected by the change.

First task of this project team is to discuss and define the objective of the change. During this activity discussions and dialogs stimulated project members to gain insight into the full implication of material kitting implementation. Furthermore, since the objectives describe the change outcome team members' commitment is stimulated.

The outcome of this activity, the change objectives, includes:

- a first draft of the planning, including project teams and milestones;
- the scope of the change (including which assembly or product lines to include and which business function to exclude);
- performance measurements, how to measure project progress and success.

We advise Eaton Industries B.V. to align the material kit implementation planning to the new LVS in-house assembly line planning. Since routing information and line-stock policies will be changed during the new LVS in-house assembly line project, it makes sense to wait for these new policies and updated routing information before implementing material kitting.

6.3.2 ACTIVITY 2: REDEFINE THE ORGANIZATIONAL LAYOUT

Defining a new organizational layout is the second (and last) activity in the understanding stage.

Currently, employees of the departments customer support, work preparation, planning, and material handling (OEM) work collaborative to supply OEM partners. In the current collaboration, roles, responsibilities, and communications procedures are well established and embedded into the roots of the organization and employees' mindsets.

The task of the project team is to redefine the organizational layout such that the material kit design (as defined in Chapter 4 and Chapter 5) is supported. This implies that roles, responsibilities, and communications will be discussed and – if necessary – redefined. Although, it is unlikely to expect that the outcome of this activity results in a suggestion to implement major organizational changes, the material kitting design and implementation discussion is further stimulated. This activity will increase understanding of material kitting implications and offers the opportunity to project members to raise questions and express their opinions.

After execution of this activity an organizational layout, defining which departments are involved in what stages of the project, is defined. In the end of this stage, not all details regarding roles and responsibilities are defined, this will be done in the subsequent activity.

6.3.3 ACTIVITY 3: DEFINE ROLES AND RESPONSIBILITIES TO SUPPORT THE NEW ORGANISATIONAL LAYOUT

Roles and responsibilities, based on the organizational layout defined in the previous activity, is an activity part of the acceptance phase and the perception stage. Goal this stage is to influence and align the mindsets of project members in order to stimulate an organization wide positive perception.

We advise Eaton Industries B.V. to instruct the project team to define the roles and the responsibilities in the new organizational layout. The new organizational layout and the process control design (see Chapter 5) serve as input for this activity.

The definition of roles and responsibilities should stimulate the in-depth discussion concerning details in the new material kitting process (control) design. Since this activity is the last activity before the action threshold (see Chapter 2, Figure 10), focus should be on influencing and aligning attitudes, behaviours, and opinions. Discussions, presentations, education, and workshops can be used to influence project members' attitudes, behaviours, and opinions in order to achieve agreement.

In the end of this activity and stage, the organizational layout is extended with roles and responsibilities. Furthermore, supportive tools (e.g. BaaN applications or new managerial functions) are listed and specified. Until completion of this activity no testing, trying, or practising takes place (the action threshold, see Figure 10 in Chapter 2).

6.3.4 ACTIVITY 4: DEVELOP TOOLS AND MANAGEMENT FUNCTIONS TO SUPPORT THE NEW ORGANIZATIONAL LAYOUT

The outcome of the previous stage (activity 3) lists requirements regarding the development of new tools and managerial functions. In this activity, practical and technical solutions are developed and defined, responding to the current lacks in the organizational layout. The objective of this stage is to promote ownership and build stakeholder commitment.

Although the development activities, part of this stage, are highly depending on the outcome of the previous activity, we conclude in Chapter 5 that the material kit process control design requires no additional BaaN applications. However, since the current process control design uses different BaaN applications compared to the process control design(s) described in Chapter 5, new working procedures have to be set up and employees should be trained on how to use these applications.

The new process control design supporting material kitting (see Chapter 5) uses routing information to allocate components to various material kits. The basic assumption in this new process control design is to use the same routing information for both in-house assembly and material kitting. Therefore, we advise Eaton Industries B.V. not to start on this activity after the new LVS assembly line is operational and entry problems – with regard to routing information – are noticed and solved.

In the end of this stage the organization layout as defined in an earlier stage is fully supported and technical operational. This implies that new working procedures are defined, educated, and supported within Eaton Industries B.V. as an organization.

6.3.5 ACTIVITY 5: TEST MATERIAL KITTING TO FIND AND SOLVE ENTRY PROBLEMS (PILOT)

In the previous stages activities focussed on the definition, construction, and preparation of the material kitting process. During this activity “test material kitting to find and solve entry problems (pilot)” the first material kits will be packed (and supplied). The objective in this stage is to find and solve entry problems, promote ownership, and build commitment.

During this activity project members concentrate on monitoring the progress and the quality of the material kitting process to identify and solve – process and product related – problems. We advise Eaton Industries B.V., to supply material kits to the in-house assembly process in this pilot. Making the in-house assembly process subject of the pilot improves (1) the traceability of information and supplies and (2) the possibilities to communicate problems and quality related issues.

Using the in-house LVS assembly line in the pilot does not only provides insight into the material kitting process, but also provides insight into the quality of the master data (and the reliability of the BOM and routing information). If the pilot concludes that the quality of the master data is deteriorating the quality and performance of the material kit (product) design, we advise Eaton Industries B.V. to first reconsider (and improve) the in-house LVS assembly line design and control mechanisms.

In the end of this stage, the pilot results should confirm that Eaton Industries B.V. can supply material kits to their OEM partners. This, however, does not mean that the process is fully supported and embedded into the organization.

6.3.6 ACTIVITY 6: ADJUST ORGANIZATIONAL STRUCTURE (PLANT LAYOUT, COORDINATING BUSINESS FUNCTIONS)

In the previous stage focus have been devoted to prove material kits can be supplied. At this stage, however, the focus is on effectively supporting material kitting in the organizational structures. Goal of the activities in this stage are to solve long-term organizational problems, to promote ownership, and support commitment.

The activities in this stage focus on solving all non-entry problems (since entry problems are dealt with in the previous stage). Activities in this stage could include: redesign the OEM department and layout, reconsidered the material flow through the central warehouse to the OEM department, define and implement OEM performance measures, and reconsider material allocation policies. All of these activities affect the efficiency of the material kitting process or affect the long-term prospect of the material kitting (OEM) department.

In the end of this stage, Eaton Industries B.V. is able to support material kitting both from a technical perspective and from an organizational perspective. According to Conner (2011), successfully passing through this stage marks the point of no return. Since the activities in this stage prove that the organization can – and is willing to – support the change.

6.3.7 ACTIVITY 7: PRONOUNCE TOP-DOWN COMMITMENT REGARDING THE NEW ORGANIZATIONAL STRUCTURE AND ORGANIZATION

In the preceding two stages attention have been devoted to solving both short term and long term problems to prove Eaton Industries B.V. is capable to supply material kits. In this activity, part of the institutionalization stage, the goals is to declare the new procedures and policies to be the new standard and to enforce people's commitment.

This activity has a formal gesture, stating that the activities carried out in the preceding stages will become the new standard. For Eaton Industries B.V. this could be put into practices by devoting attention to this topic in one of the all employee meetings. Statements of senior management should stimulate the remaining change opponents to commit to the new working standards.

The outcome of this activity is a written or spoken statement declaring top management commitment.

6.3.8 ACTIVITY 8: ENFORCE COMMITMENT

In the previous activity senior and top management of Eaton Industries B.V. declared their commitment to material kitting. This implies that the change will no longer be considered as a change but as the new standard. This activity, the enforcement of commitment, focuses on influencing the attitudes and behaviours of the remaining opponents of the change.

According to de Wit & Meyer (2004), enforcing commitment can be classified as a form of power and politics management. According to them, power and politics management stands for clarifying people they have to do something. Sanctions, countertrading, incentives, and personal dialogues are examples to enforce commitment.

6.3.9 ACTIVITY 9: DEFINE CONTINUOUS IMPROVEMENTS CYCLES AND ROUTINES

In the last project activity, which is part of the internalization stage, methods and procedures for continuous improvements are defined. Goals of these methods and procedures grasp bottom-up incentives for continuous refinement and improvements.

Since Eaton Industries B.V. strives for Lean-production, Kaizens are in place to gain these bottom-up improvements incentives. Therefore, we advise Eaton Industries B.V. to apply the same Lean-tools to both the in-house assembly process and the OEM process. Since the allocation of components to material kits is based on – in-house used – routing information, we recommend Eaton Industries B.V. to put extra emphasis on gaining bottom-up incentives in the in-house assembly process. According to Merrifield (1993), non bureaucratic systems contribute to the ability to benefit from this latent entrepreneurial spirit.

6.4 CONCLUSIONS FOR THIS CHAPTER

This chapter provides an answer to the question: "*How can Eaton Industries B.V. implement the best material kit product and process design?*".

In the answer to this question, we conclude that Eaton Industries B.V. is currently passing through the preparation phase. Therefore, this chapter advise Eaton Industries B.V. to carry out activities to pass through the acceptance and commitment phase successfully.

We advise Eaton Industries B.V. to set up an project team and instruct this team to carry out – at least – nine implementation activities. Three of these activities are part of the acceptance phase and focus on providing insight into the change, the consequences of the change, and should stimulate a positive perception. It is important to complete these activities before starting developing, testing, or practicing activities (the so called action threshold). In this chapter, we define six activities related to the commitment phase. Activities in this phase initially focus on demonstrating Eaton Industries B.V. is capable to supply material kits to promote ownership and commitment. Later activities in this stage focus on long-term organizational adjustments and the enforcement of people in the organization to commit to the change.

We concluded that the – new – LVS assembly line should not be considered in isolation from the OEM process. The material kit design (defined and described in Chapter 4 and Chapter 5) uses the same BOMs and routing information used in the in-house assembly process. Therefore, we advise Eaton Industries B.V. to:

- include the basic requirements related to the implementation of material kitting, during the (final) in-house LVS assembly line process (control) design;
- use the in-house LVS assembly line for testing both the quality and performance of the material kitting product and process design;
- use the in-house LVS assembly line as a source to gain bottom-up incentives to continuously improve both the in-house assembly process and the OEM process.

7 CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the conclusions and recommendations of this research. Chapter 1 states the problem definition of Eaton Industries B.V. to be:

> "*To achieve its strategic goals, Eaton Industries B.V. should increase the OEM related sales volume. Material kitting – a not previously pioneered practise for Eaton Industries B.V. – is expected to be valuable. Eaton Industries B.V., however, is lacking the knowledge and resources to determine what the impact of material kitting will be, how material kits should be designed, managed, and implemented.*"

Section 7.1 provides the research conclusions and Section 7.2 provides recommendations and suggestions for further research.

7.1 RESEARCH CONCLUSIONS

This research focuses on how Eaton Industries B.V. should design and implement material kits for their Capitole 40. We formulate the following – most important – conclusions:

1. from a technical point of view, Eaton Industries B.V. can implement material kitting;
2. the annual costs, associated to the implementation of material kitting, will be approximate € 11,000. To express the magnitude of this figure, € 11,000 is less than 1% of the current turnover;
3. the management of Eaton Industries B.V. should start realizing that both in-house assembly and OEM are highly interrelated processes (see recommendations, Section 7.2).

In this research, we define a material kit design to be the aggregation of a material kit product design, a material kit process (control) design, and a material kit supply chain design.

Material kit product design

Chapter 4 introduces and discuses two material kit product designs, the travelling material kit (in which components are supplied to one workstation and depleted over multiple workstations, traveling along with the product) and the stationary material kit (in which components are supplied and totally depleted at one workstation).

We recommend Eaton Industries B.V. to implement a stationary material kit product design (in Chapter 4 referred to as Material Kit Product Design 2). Crucial reasons to implement a stationary material kit product design are: (1) components supplied in one material kit do not require additional sequencing within a material kit and (2) picking orders can be released using current job release and allocation policies. Furthermore, comparing the new LVS in-house assembly design and the stationary material kit product design, components will be coordinated using a similar logic (components relate to a panel or drawer type and a material kit/workstation).

Using similar material allocation policies for the in-house assembly process and the OEM process, contributes to the ability to benefit from bottom-up continuous improvements – gained in the in-house assembly process. We estimate the material handling workload to increase with approximately 69% as a direct result of implementing the above described material kit product design.

Material kit process design

Chapter 4 introduces three feasible material kit process designs: Material Kit Process Design 1, do not change the OEM process, Material Kit Process Design 2, OEM activities seen as order picking activities, and Material Kit Process Design 3, OEM activities seen as – material kit – assembly activities.

We advise Eaton Industries B.V. to implement Material Kit Process Design 3, OEM activities seen as – material kit – assembly activities. Decisive characteristics to implement Material Kit Process Design 3 are: (1) this material kit process design stresses the alignment between the in-house assembly process and the OEM process and (2) the use of currently applied Kanban-worthy policies positivity influence the total relevant costs (material handling costs and inventory holding costs).

In Material Kit Process Design 3, line-stocks are dedicated to the OEM process. Therefore, we argue that it is valid to assume an increase in OEM material handling efficiency. If Eaton Industries B.V. is able to double the OEM handling pace (from 7 order lines an hour to 14 order lines an hour),we estimate the total annual costs, associated to the implementation of material kitting, to equal € 11,000 (see Table 13, page 51 for detailed information).

Material kit process control design

Chapter 5 provides three designs to manage and control the OEM process: Process Control Design 1, one sales order per material kit, Process Control Design 2, one sales order per shipment, and Process Control Design 3, one sales order per shipment and one production order per material kit.

Each material kit process design is characterized by a unique set of strengths and weaknesses. These strengths and weaknesses are not equally distributed over the functional department within Eaton Industries B.V. For example, strength of Process Control Design 1 is the ability to coordinate materials (benefit for the material handling and OEM department) weakness, however, is the increase in administrative workload (disadvantage for the customer support department). Therefore, we advise Eaton Industries B.V. to instruct the project team – responsible for the change and implementation – to decide on this matter.

All three material kit process control design use Medium Voltage System BaaN applications. This means, that the implementation of material kitting can be supporting in BaaN and does not require development of any supportive tools. Education, on these MVS applications, will have to take place.

Material kit supply chain design

Since this research focuses merely on activities carried out within Eaton Industries B.V., limited attention is devoted to the material kit supply chain design.

We advise Eaton Industries B.V. to supply each material kit according to customer specifications. This makes the material kitting department a demand driven activity in the supply chain. Drawback when making the material kitting department demand driven, is the need for a flexible OEM capacity.

7.2 RECOMMENDATIONS AND FURTHER RESEARCH

The focus in this research has been on how to design material kits, how to manage and control demand information, and how to implement material kitting. In addition to these topics, we have identified a number of adjacent issues that will strongly influence the success of material kitting.

Start realizing that both the in-house assembly process and the OEM process are highly interrelated

During this research we observed that employees of Eaton Industries B.V. strongly differentiate between in-house assembly processes and OEM processes. As we have seen in the previous chapters, a successful material kitting implementation focuses on more – process – alignment.

We empathize that employees of Eaton Industries B.V. should start realizing that the in-house assembly process and the OEM process are highly interrelated. Routing information, used to coordinate material for both the in-house assembly process and the OEM – material kitting – process is a good example to illustrate this strong relation. We advise Eaton Industries B.V. to:

- include the basic requirements related to the implementation of material kitting in the (final) in-house LVS assembly line process design;
- use the in-house LVS assembly line for testing both the quality and the performance of material kitting;
- use the in-house LVS assembly line as a source to gain bottom-up information to continuously improve both the in-house assembly process and the OEM process.

Gain insight into the interest of OEM partners

This research frequently refers to the OEM partners of Eaton Industries B.V., their processes, interests, and requirements. Since material kitting will impact the OEM partners' processes, they are a key stakeholder in the material kit implementation project.

It is important for Eaton Industries B.V. to gain insight into the interests of their OEM partners and to evaluate the – supply chain – value related to the implementation of material kitting. The problem definition in Chapter 1 states "*Eaton Industries B.V. should increase the OEM related sales volume*", this implies that downstream supply chain parties should be able to grasp and pass through the benefits derived from the supplies of material kits.

Ensure that Bid Manager contributes to align the input of information flows

In Chapter 3, we concluded that the three different supply chain frameworks – currently applied by Eaton Industries B.V. – is the single most important reasons why Eaton Industries B.V. applies different product, process, and supply chain designs for in-house, satellite, and licensee assembly.

We advise Eaton Industries B.V. to focus on more equality in flows of information. This recommendation relates directly to the currently ongoing Bid Manager and Design Automation project. We claim that the use of one format of input information will reduce the need for OEM specialist and increase the ability to focus on process improvements (instead of focusing on process adjustments and derivatives).

REFERENCES

1. Baker, K., Magazine, M., & Nuttle, H. (1986). The effect of commonality on safety stock in a simple inventory model. *Management Science, volume 32 (8)* , 982-988.
2. Beamon, B. (1999). Measuring supply chain performance. *International Journal of Operations and Production Management, volume 19 (3)* , 275-292.
3. Bozer, Y., & McGinnis, L. (1992). Kitting versus line stocking: A conceptual framework and a descriptive model. *International Journal of Production Economics, volume 28* , 1-19.
4. Brynzér, H., & Johansson, M. (1995). Design and performance of kitting and order picking systems. *International Journal of Production Economics, volume 41* , 115-125.
5. Camp, W. (1922). Determining the Production Order Quantity. *Management of Engineering, volume 2* , 17-18.
6. Chen, J., & Wilhelm, W. (1993). An evaluation of heuristics for allocating components to kits in small-lot, multi-echelon assembly systems. *International Journal of Production, volume 31 (12)* , 2835-2856.
7. Collier, D. (1982). Aggregate safety stock levels and component part commonality. *Management Science, volume 28 (11)* , 1296-1303.
8. Conner, D. (1992). *Managing at the speed of change.* New York: Villard Books.
9. Conner, D. (2011, Februari 22). *The eight stages of building commitment.* Retrieved June 8, 2011, from Change thinking: http://changethinking.net/commitment-in-change/the-eight-stages-of-building-commitment
10. Cooper, R. (1979). The dimensions of industrial new product success and failure. *Journal of Marketing, volume 43* , 93-103.
11. Daft, R. (2004). *Organization theory and design* (8th ed.). United States of America: Thomson.
12. de Koster, R., Le-Duc, T., & Roodbergen, K. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research, volume 182 (2)* , 481-501.
13. de Wit, B., & Meyer, R. (2004). *Strategy: Process, content, context* (3th ed.). North Yorkshire: Thomson.
14. Dobbie, J. (1961). A doubled-ended queuing problem of Kendall. *Operations research, volume 9 (5)* , 755-757.
15. Durlauf, S., & Blume, L. (2010). *Behavioural and experimental economics.* Basingstoke: Palgrave Macmillan.
16. Eaton Electric B.V. (2007). *Capitole 40, low voltage distribution and control systems.* Hengelo: Eaton Electric B.V.
17. Eaton Holec. (2004). *Eaton lean system.* Hengelo: Eaton Corporation.
18. Eaton Industries B.V. (2011). *All employee meeting: February 23, 2011.* Hengelo: Eaton Industries B.V.
19. Fixson, S. (2005). Product architecture assessment: A tool to link product, process, and supply chain decisions. *Journal of Operations Management, volume 23* , 345-369.
20. Frohlich, M., & Westbrook, R. (2001). Arcs of integration: An international study of supply chain strategies. *Journal of Operations Management, volume 19* , 185-200.
21. Gerchak, Y., Magazine, M., & Gamble, B. (1988). Component commonality with service level requirements. *Management Science, volume 34 (6)* , 753-760.
22. Gunasekaran, A., & Nath, B. (1997). The role of information technology in business process reengineering. *International Journal of Production Economics, volume 50* , 91-104.
23. Hans, E., Herroelen, W., Leus, R., & Wullink, G. (2007). A hierarchical approach to multi-project planning under uncertainty. *Omega, volume 35* , 563-577.
24. Hayes, J. (2007). *The theory and practice of change management* (2th ed.). Basingstoke: Palgrave.

25. Hoekstra, S., & Romme, J. (1992). *Integral logistic strucutres: Developing customer-oriented goods.* (S. M. Argelo, Trans.) Londen: McGraw-Hill.
26. Holmberg, S. (2000). A systems perspective on supply chain measurements. *International Journal of Physical Distribution and Logistics Management, volume 30 (10)* , 847-868.
27. Hopp, W. J., & Spearman, M. L. (2008). *Factory physics* (3th ed.). New York: McGraw-Hill Education.
28. Huizingh, E. (2004). *Inleding SPSS 12.0 for Windows.* Den Haag: Academic Service.
29. Kashyap, B. (1965). A double-ended queuing system with limited waiting space. *Proceedings of the National Institute of Science of India, volume 31 (6)* , 559-570.
30. Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review, volume 86 (3)* , 562-583.
31. Klocke, F., Fallböhme, M., Kopner, A., & Trommer, G. (2000). Methods and tools supporting modular process design. *Robotics and Computer Integrated Manufacturing, volume 16* , 411-423.
32. Kusiak, A. (2002). Integrated products and process design: A modularity perspective. *Journal of Engineering Design, volume 13 (3)* , 223-231.
33. Lambert, D., & Cooper, M. (2000). Issues in supply chain management. *Industrial Marketing Management, volume 29* , 65-83.
34. Limère, V. (2007). A decision model for kitting. *8th FirW PhD Symposium* (pp. 1-2). Gent: Gent University.
35. Lummus, R., & Vokurka, R. (1999). Defining supply chain management: A historical perspective and practical guidelines. *Industrial Management and Data Systems* , 11-17.
36. Mason-Jones, R., Naylor, B., & Towill, D. (2000). Engineering the leagile supply chain. *International Journal of Agile Management Systems* , 54-61.
37. McCann, J. (1991). Design principles for an innovating company. *Academy of Management Executive, volume 5 (2)* , 76-93.
38. Medbo, L. (2003). Assembly workexecution and materials kit functionality in parallel flow assembly systems. *International Journal of Industrial Ergonomics, volume 31* , 263-281.
39. Mentzer, J., De Witt, W., Keebler, J., Min, S., Nix, N., Smith, C., et al. (2001). Defining supply chain management. *Journal of Business Logistics, volume 22 (2)* , 1-25.
40. Merrifield, D. (1993). Intrapreneurial corporate renewal. *Journal of Business Venturing, volume 8* , 383-389.
41. Narusawa, T., & Shook, J. (2009). *Kaizen express: Fundamentals for your lean journey.* Cambridge: The Lean Enterprise Institute.
42. O'Neill, P., & Sohal, A. (1999). Business process reengineering a review of recent literature. *Technovation, volume 19* , 571-581.
43. Parikh, P., & Meller, R. (2008). Selecting between batch and zone order picking strategies in a distribution center. *Transportation Research Part E: Logistics and Transportation Review, volume 44 (5)* , 696-719.
44. Ramachandran, S., & Delen, D. (2005). Performance analysis of a kitting process in stochastic assembly systems. *Computers & Operations Research, volume 32* , 449-463.
45. Reijers, H., Limam, S., & van der Aalst, W. (2003). Product-based workflow design. *Journal of Management Information Systems, volume 20 (1)* , 229-262.
46. Silver, E., Pyke, D., & Peterson, R. (1998). *Inventory management and production planning and scheduling* (3th ed.). New York: John Wiley & Sons.
47. Som, P., Wilhelm, W., & Disney, R. (1994). Kitting process in a stochastic assembly system. *Queueing Systems, volume 17* , 471-490.
48. Stampfel, J. (2010). *Electrical solutions and services.* Hengelo: Electrical Sector - EMEA.
49. Staugaitis, S. (2002). Root cause analysis: A summary of root cause analysis and its use in state developmental disabilities agencies. *Centers for Medicare and Medicaid Services* , 1-42.

50. Stelzer, T., & Ulrich, J. (2010). No product design without process design (control)? *Chemical Engineering and Technology, volume 33 (5)* , 723-729.
51. Wilhelm, W., & Wang, L. (1986). Management of component accumulation in small-lot assembly systems. *Journal of Manufacturing Systems, volume 5 (1)* , 27-39.
52. Winston, W. (2004). *Operations research: Appliccations and algorithms* (4th ed.). Belmont: Thomson.
53. Zinn, W., Levy, M., & Bowersox, D. (1989). Measuring the effect of inventory centralization/decentralization on aggregate safety stock: The "square root law" revisited. *Journal of Business Logistics, volume 10 (1)* , 1-14.

ABBREVIATIONS, TERMS, AND CLARIFICATIONS

Abbre-viation	Term	Clarification
ATO	Assemble To Order	Refers to the CODP; only components or subassemblies are produced based on forecasts, end-products are assembled based on customer specifications.
BOM	Bill Of Material	List of material requirements (including raw materials, components, and sub-assemblies) each needed to manufacture an end-product or sub-assembly.
BPR	Business Process Reengineering	The design of a new process from scratch, often referred to as the clean sheet method.
	Component	A fabricated or purchased part that cannot be subdivided into distinct parts.
CODP	Customer Order Decoupling Point	Specifies the distinction between forecast driven process and demand driven processes.
DLD	Direct Line Delivery	Method applied by Eaton Industries B.V. to manage and control inventories, an empty material bin triggers the replenishment of a new material bin from the external supplier to the line stock.
ELS	Eaton Lean System	Eaton policies, describing Lean-tools and usage of these tools applied in Eaton processes
EDI	Electronic Data Interchange	A structured method to change – electronic – data between organizations.
	End-product	The result of one or more assembly operations that requires no further processing in the current facility.
ETO	Engineer To Order	Refers the CODP; for each end-product raw materials and components are purchased, produced, and assembled based on customer specifications.
ERP	Enterprise Resource Planning	Software application to manage internal and external information across an entire organization.
EMEA	Europe, Middle East, and Africa	One of the three market regions of the Eaton Corporation, Eaton Industries B.V. serves the EMEA region.
	In-house assembly process	The production and assembly process executed completely in-house at Eaton Industries B.V. (no OEM partner involved)
JIT	Just-In-Time	A lean-technique that focuses on the supply of material just when needed, just where needed, and just in the amount needed
	Licensee (OEM partner)	A not Eaton owned organization which has permission to sell and assemble Eaton Industries B.V. owned switch and distribution systems
LVC	Low Voltage Components	One of the three main product families within Eaton Industries B.V.
LVS	Low Voltage Systems	One of the three main product families within Eaton Industries B.V.
MTO	Make To Order	Refers to the CODP; raw materials are purchased based on forecasts, sub-assemblies and end-products are produced based on customer specifications.
MTS	Make To Stock	Refers to the CODP; end-products are assembled based on forecasts, customers are supplied from stock.
MRP II	Manufacturing Resources Planning	Planning and control system, supports the planning and control of all business resources.

MPS	Master Production Schedule	Long-term oriented production schedule, most often forecast driven
	Material kit	A specific collection of components or subassemblies that together support one or more assembly operations for a given product
	Material kit process design	The intangible policies that describe the material kit composition process
	Material Kit Process Design 1	Do not change the OEM process
	Material Kit Process Design 2	OEM activities seen as order picking activities
	Material Kit Process Design 3	OEM activities are – material kit – assembly activities
	Material kit product design	The intangible policies that describe the composition and allocation of components (and subassemblies) to material kits.
	Material Kit Product Design 1	Travelling material kits, containing (preferably) all the components needed during the assembly process of an end-product.
	Material Kit Product Design 2	Stationary material kit, containing all the components needed to support the assembly task at one workstation.
	Material kit supply chain design	The intangible policies and agreements that describe the sourcing, production, distribution, and storage network in the material kitting supply chain.
	Material pitching	Supplying material kits such that the flow of supplies, originating from an upstream processes, is adapted to the exact flow and pace of the downstream process.
MRP	Material Requirements Planning	Production planning and inventory control system, supportive to manufacturing processes.
MVS	Medium Voltage Systems	One of the three main product families within Eaton Industries B.V.
	OEM (assembly) process	The in-house production and OEM assembly process. In this process, OEM partners execute the assembly activities.
OTP	On-Time Performance	A performance measure, measuring customer satisfactions and supply reliability. Expresses the number of early or on-time supplies relative to the total number of supplies.
OEM	Original Equipment Manufacturer	A supplier supplying critical and complex components or subassemblies working very closely during the development phases of – new – products. Used at Eaton Industries B.V. to refer to satellite and licensee partners.
RCA	Root Cause Analysis	Method to address the root cause of a problem or an event.
RCA	Root Cause Analysis	A structured procedure to find the non evident – root – cause(s) for major systems failures
SIOP	Sales Inventory and Operations Planning	Methodology in use at Eaton Industries B.V.; forms the pivot between forecasting and the complication of the – business wide – MPS
	Satellite (partner)	An Eaton owned organization which has the permission to sell, quote, and build Eaton Industries B.V. owned switch and distribution systems
	Subassembly	The aggregation of two or more components or other subassemblies through an assembly process
SCM	Supply Chain Management	Management of a network of interconnected businesses, referring to both upstream and downstream partners.

TPM	Total Productive Maintenance	A Lean-method to improve machine availability through better utilization of maintenance and production resources.
VSM	Value Stream Mapping	Lean-technique used to analyse (and redesign) the flow of materials and information through a system.
VMI	Vendor Managed Inventory	Method applied by Eaton Industries B.V. to manage and control inventories, the vendor is responsible for the management and control of these inventories.

TABLE 16: LIST OF ABBREVIATIONS, TERMS, AND CLARIFICATIONS

OVERVIEW OF FIGURES AND TABLES

Figures;

Tables;

- Table 1: Organizational differences between satellite and licensee partners;
- Table 2: Example to illustrate licensee delivery agreements and OTP measurement;
- Table 3: Policies to determine Kanban-worthiness;
- Table 4: Root cause assessment criterion to evaluate material kit designs;
- Table 5: Financial assessment criteria to evaluate material kit designs;
- Table 6: Two dimensional Capitole 40 material allocation;
- Table 7: Currently applied policies versus material kit product designs requirements;
- Table 8: Order lines per material kit when supplying drawers per type per system;
- Table 9: Order lines per material kit when supplying drawers per type per panel;
- Table 10: The impact of how to supply drawers on the annual material handling costs;
- Table 11: The material kit designs and their influence on the root causes;
- Table 12: The material kit designs and their influence on financial scoring criteria;
- Table 14: BOMs, clusters of material – kit – requirements;
- Table 15: The material kitting implementation roadmap in key activities;
- Table 16: List of Abbreviations, terms, and clarifications.

APPENDIX A FLOOR PLAN EATON INDUSTRIES B.V.

Figure 37 visualizes the floor plan of Eaton Industries B.V. Directly related department are marked dark gray, while (indirectly) related departments are marked light gray.

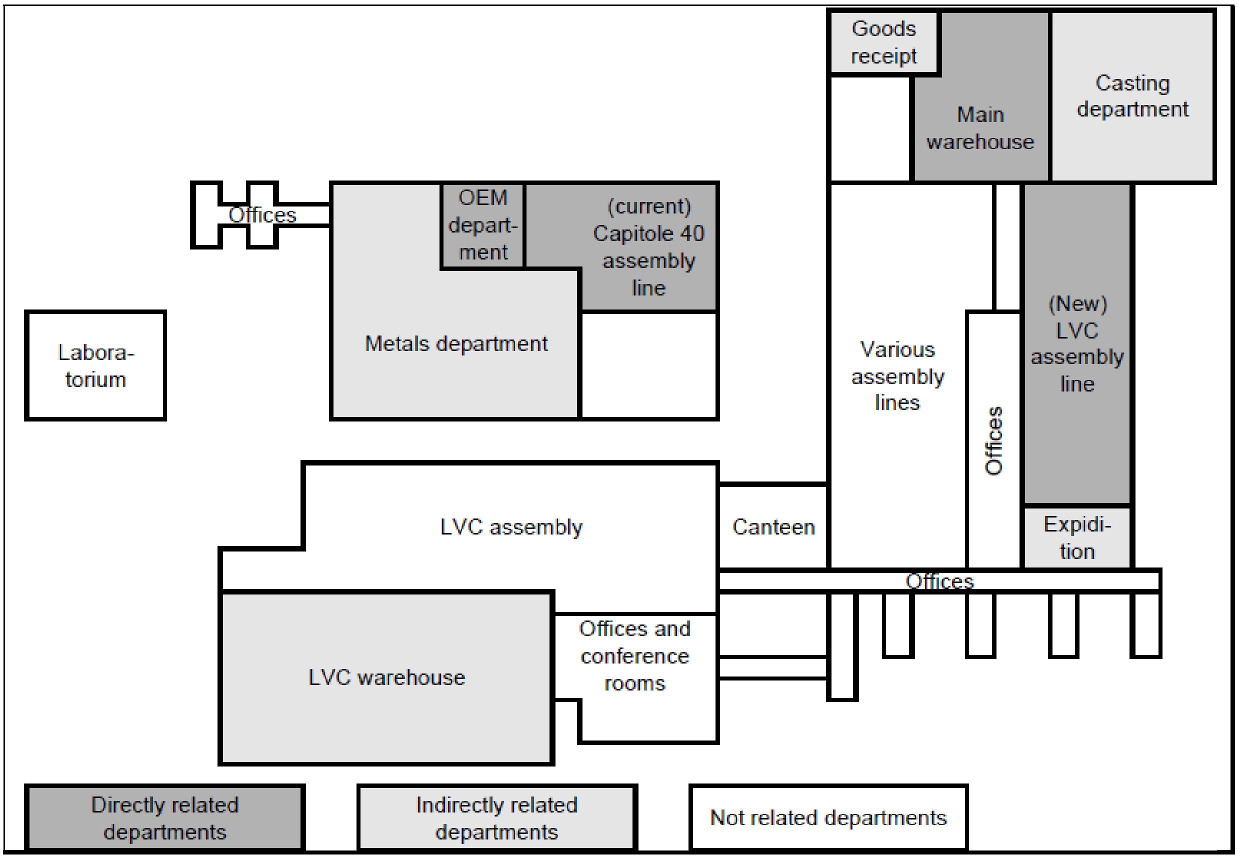


FIGURE 37: FLOOR PLAN OF EATON INDUSTRIES B.V.

APPENDIX B PERFORMANCE MEASUREMENT

At Eaton Industries B.V. performance measures are divided into four key drivers: (1) growth and customer satisfaction, (2) achieve profit plan, (3) operational excellence, and (4) build organisational capability. Table 17 provides an overview of the plant performance over the years 2009, 2010, and 2011. In Table 17 values between brackets state objectives, while blanks indicate an unknown performance measure score.

Key drivers	Strategic Objectives	Performance measures (goal) versus actual 2009	2010	2011
Growth and customer satisfaction	Sales (x 1 million)	(€167) €135	(€159) €138	(€155)
	Components OTP	(95%) 92%	(95%) 92%	(95%)
	Systems OTP	(90%) 90%	(90%) 83%	(90%)
	Time to solve customer complains (days)	32	(22) 40	(30)
Achieve profit plan	Manufacturing result (% of sales)	20.2%	(21.2%) 20%	(21.3%)
	Inventory DOH (days)	(71) 79	(72.6) 81.4	(73.2)
	Cost out (x 1 million)	€5.05	(€3.81) €5.63	(€4.24)
Operational excellence	Productivity (sales / labour costs)	4.7	(5.2) 4.7	(4.8)
	Cost of non-conformance (% of sales)	(2.1%) 2.4%	(1.9%) 2.9%	(2.1%)
	Employee involvement in process improvement (Kaizens)		122	(240)
Build organiza-tional capability	Employee engagement	(66%) 67%	(70%) 70%	(73%)
	Injuries (number of recordable incidents)	(0) 11	(0) 11	(0)
	Lifelong learning (all employees have a training plan)	No	(Yes) No	(Yes)

TABLE 17: PERFORMANCE MEASURES OF EATON INDUSTRIES B.V.

Additional clarification regarding the performance measurements (provided in Table 17), OTP (On-Time Performance) measures the percentage of on-time or to early delivered orders as a percentage of the total number of orders. Manufacturing result measures the value added in the Hengelo plant as a percentage of the sales price. Inventory DOH (Days On-Hand) measures the average inventory value divided by the average throughput. Cost of non-conformance measures the costs made as a result of non-performance (warranties, scrap, rework, premium freights, etc.). Employee engagement measures a value derived from an annual employee survey.

APPENDIX C PICTURES OF SUPPLIES TO OEM PARTNERS

Figure 38 visualizes the method to supply materials to satellite partners. As the right hand side of Figure 38 reveals, most goods are pick directly out of the main warehouse, supplemented with additional protection materials, brought to expedition, ready for transportation.

FIGURE 38: SUPPLIES TO SATELLITE PARTNERS

Figure 39 visualizes how components are received by the OEM department (before packaging). At the OEM department components are supplemented with protection materials (more compared to supplies to satellite partners), components are packed into carton boxes (see Figure 40), brought to expedition, closed, ready for transportation.

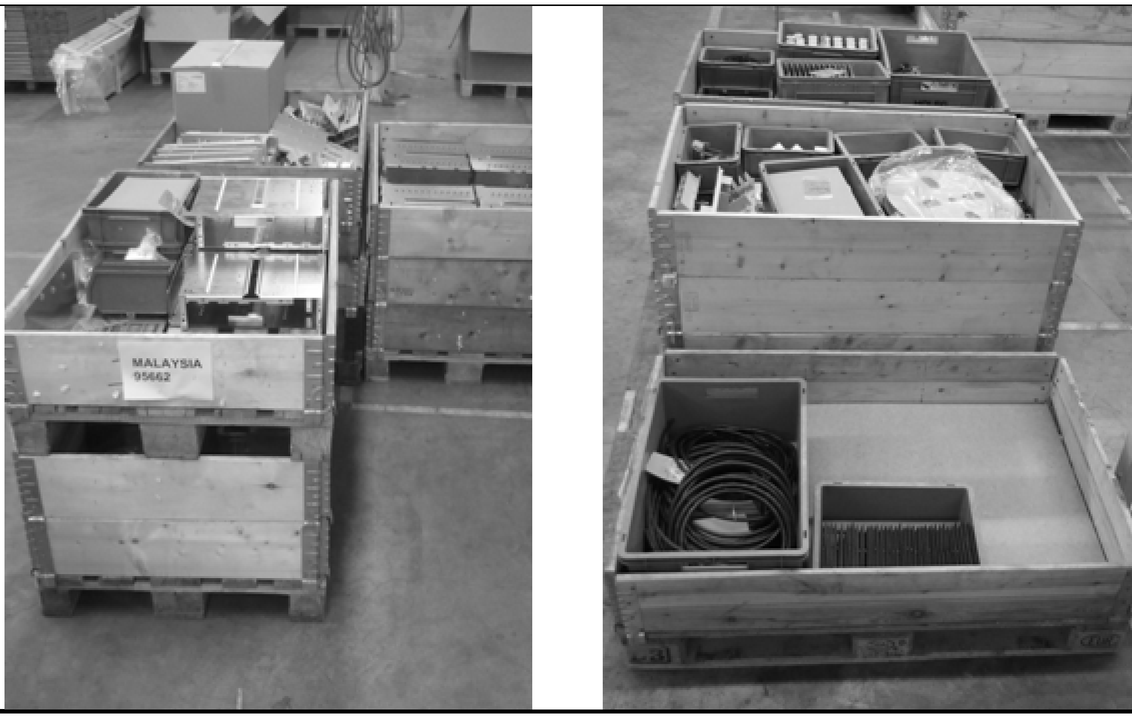


FIGURE 39: SUPPLIES TO LICENSEE PARTNERS, BEFORE PACKAGING

FIGURE 40: SUPPLIES TO LICENSEE PARTNERS, AFTER PACKING

APPENDIX D DEFINING THE REGRESSION MODEL TO ESTIMATE MATERIAL HANDLING WORKLOAD

Currently, Eaton Industries B.V. expresses the material handling workload in the number of order lines. However, the number of order items is expected to influence the workload as well (Parikh & Meller, 2008). Therefore, this appendix discusses various models to predict the expected workload using the number of order lines and the number of order items. Table 18 visualizes the set of historical data measures used in this appendix.

Observation	Independent variable: Number of order Lines	Independent variable: Number of order items	Dependent variable: Workload [hours]
1	447	5831	28
2 x	743	154004	27
3	322	11654	25
4	395	15081	23
5	161	4274	20
6	171	13058	14
7 x	794	143782	26
8	302	31137	26
9	326	6773	26
10	393	2423	20
11	101	2575	17
12	621	20147	35
13	627	21195	28
14	416	33666	28
15	326	8339	23
16	414	7543	21
17	600	13936	36
18	1224	16599	35
19	483	36677	35
20	769	9018	31
21	426	5682	21
22	410	36925	19
23	438	9110	28

TABLE 18: INPUT DATA FOR THE REGRESSION MODEL

The quality of regression models can be evaluated using the coefficient of determination (R^2), see Equation 4. This R^2 expresses the amount of explained variance relative to the total variance of the dependent variable. The adjusted R^2 (R_a^2) is a derivative of the R^2 correcting for the number of used independent variables, see Equation 5.

We use the R_a^2 to determine and compare the quality of various regression models. This R_a^2 is calculated using SPSS Statistics 17.0.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{\sum_{i=1}^{n}\left(\hat{Y}_i - \bar{Y}\right)^2 + \sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}$$

in which:
Y_i = the i^{th} observed workload
$\hat{Y}_i$ = the i^{th} expected workload
n = the number of observations

EQUATION 4: COEFFICIENT OF DETERMINATION (R^2) (SOURCE: HUIZINGH, 2004)

$$R_a^2 = 1 - \left(\frac{n-1}{n-(k+1)}\right)\left(\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{\sum_{i=1}^{n}\left(\hat{Y}_i - \bar{Y}\right)^2 + \sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}\right)$$

in which:
k = the number of dependent variables

EQUATION 5: ADJUSTED COEFFICIENT OF DETERMINATION (R_a^2) (SOURCE: HUIZINGH, 2004)

Figure 41 visualizes a boxplot of the data. This boxplot provides a first impression of the data range (e.g. positioning, distribution, skewness, and outliers). Figure 41 visualizes the boxplot of the number of order items. In this figure, we identified two observations to be outliers ($\geq$ upper quartile + 3 x interquartile range), observation 2 and 7 in Table 18. These two observations are excluded during the definition of the regression model.

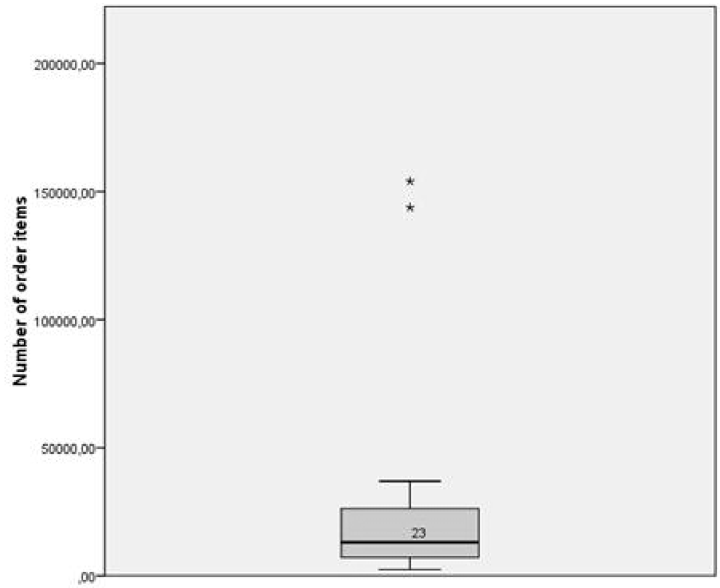


FIGURE 41: OUTLIER IDENTIFICATION FOR THE NUMBER OF ORDER ITEMS

SPSS can be used to analyse multiple linear regression models and analyse single non-linear regression models. Auxiliary variables can be used to convert non-linear correlations to linear correlations. This provides a possibility to analyse multiple linear and non-linear regression models. According to Huizingh (2004), a scatter plot can be used to identify the type of relation between the independent variable and the dependent variable. Figure 42 and Figure 43 visualize respectively the scatter plots of the number of order lines and the number of order items. These figures do not show an obvious (linear) relation between the independent variables and the dependent variable. Therefore, we will use SPSS Statistics 17.0 to explore non-linear regression models.

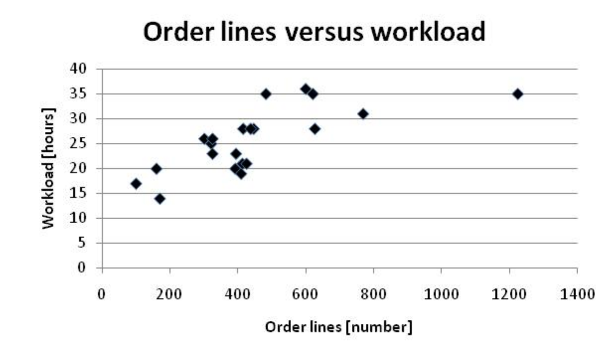


FIGURE 42: SCATTER PLOT, THE NUMBER OF ORDER LINES VERSUS THE WORKLOAD IN HOURS

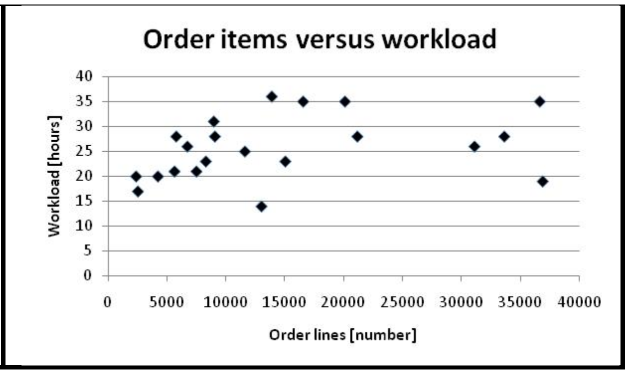
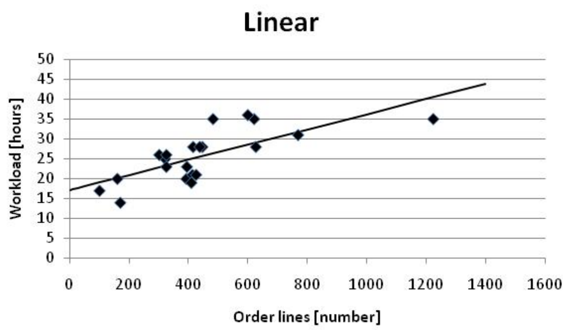


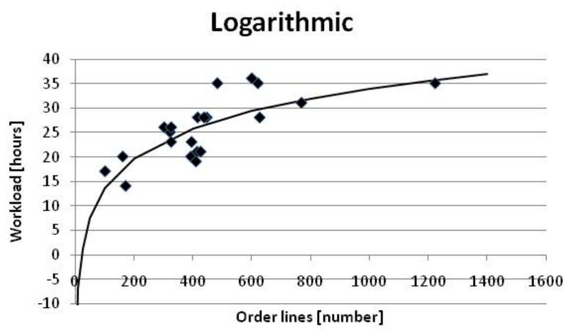
FIGURE 43: SCATTER PLOT, THE NUMBER OF ORDER ITEMS VERSUS THE WORKLOAD IN HOURS

Figure 44 visualises a linear and three non-linear regression models describing the correlation between the number of order lines and the workload. Figure 45 visualises a linear and five non-linear regression models to describe the correlation between the number of order items and the workload.

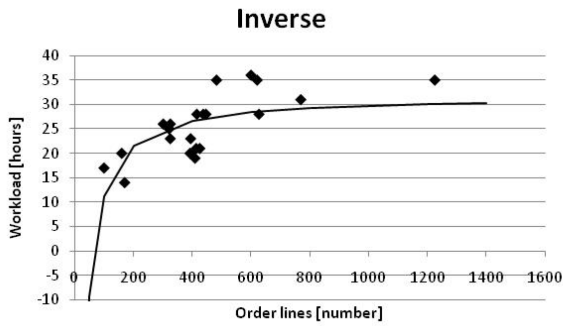
SPSS Statistics 17.0 can be used to describe non-linear regression using various models (logarithmic, inverse, quadratic, cubic, compound, power, S-curve, growth, and exponential). Figure 44 and Figure 45 only visualize regression models that are consistent with our intuition (shape and curve of the regression line) and scoring a relatively high R_a^2 measure.



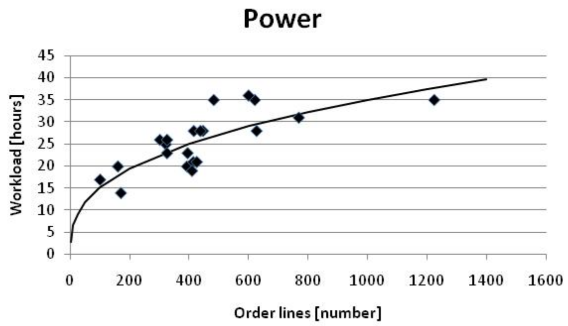
$$\hat{Y} = \beta_0 + \beta_1 x_1$$
$$R_a^2 = 0.501$$



$$\hat{Y} = \beta_0 + \beta_1 \ln(x_1)$$
$$R_a^2 = 0.563$$



$$\hat{Y} = \beta_0 + \frac{\beta_1}{x_1}$$
$$R_a^2 = 0.411$$



$$\hat{Y} = \beta_0 {x_1}^{\beta_1}$$
$$R_a^2 = 0.578$$

FIGURE 44: REGRESSION MODELS FOR THE NUMBER OF ORDER LINES AND WORKLOAD

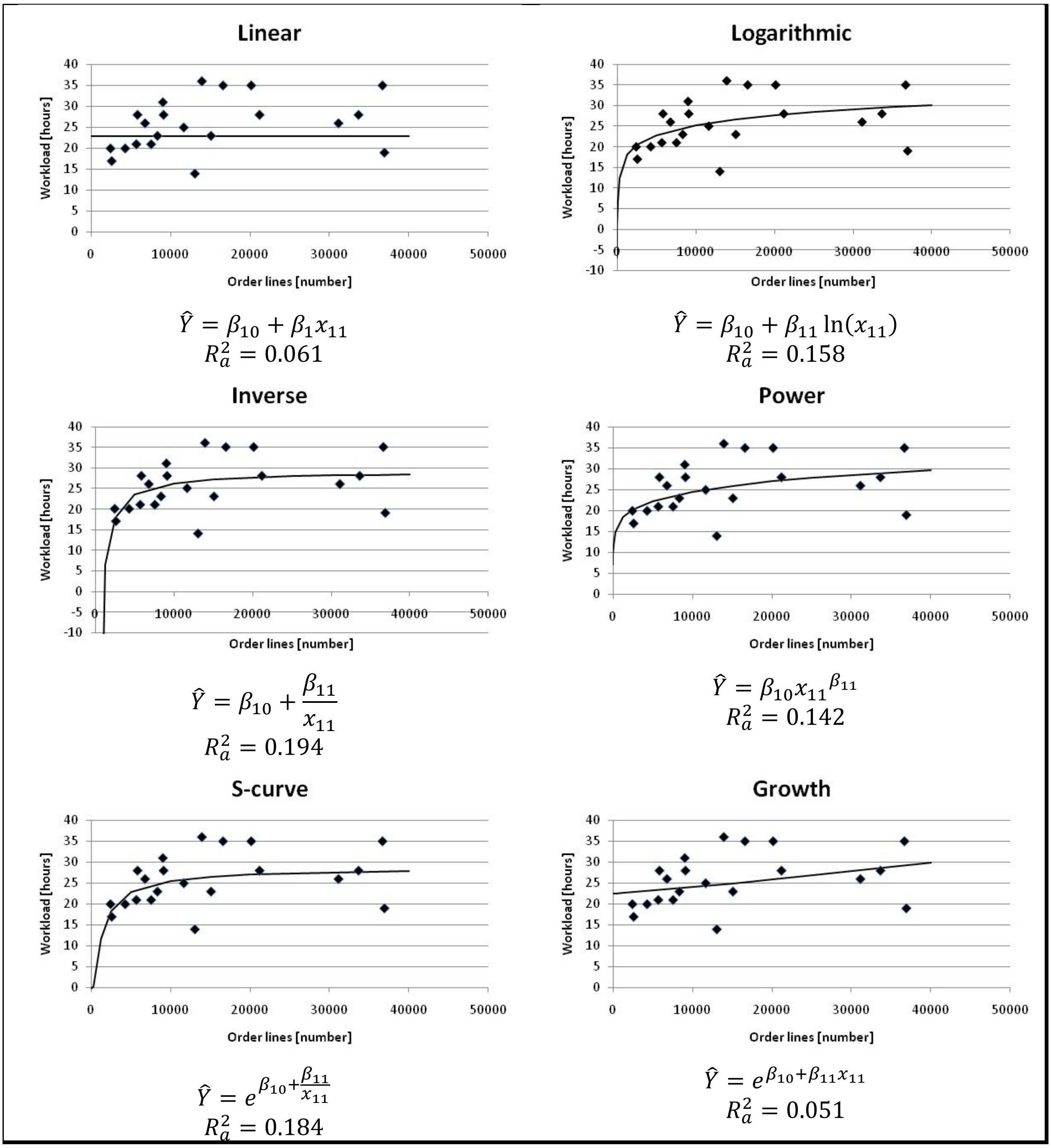


FIGURE 45: REGRESSION MODELS FOR THE NUMBER OF ORDER ITEMS AND WORKLOAD

As elaborated on above, SPSS only supports multiple linear regression models. To include non-linear correlation, we use auxiliary variables. Table 19 provides an overview of all the – linear – variables.

Variable	Type of correlation	Original equation	Value
$\boldsymbol{x_1}$	Linear	$\hat{Y} = \beta_0 + \beta_1 x_1$	x_1 = number of order lines
$\boldsymbol{x_2}$	Logarithmic	$\hat{Y} = \beta_0 + \beta_1 \ln(x_1)$	$x_2 = \ln(x_1)$
$\boldsymbol{x_3}$	Inverse	$\hat{Y} = \beta_0 + \frac{\beta_1}{x_1}$	$x_3 = \frac{1}{x_1}$
$\boldsymbol{x_4}$	Power	$\hat{Y} = \beta_0 {x_1}^{\beta_1}$	$x_4 = {x_1}^{\beta_1} = {x_1}^{0.363}$
$\boldsymbol{x_{11}}$	Linear	$\hat{Y} = \beta_{10} + \beta_{11} x_{11}$	x_{11}= number of order items
$\boldsymbol{x_{12}}$	Logarithmic	$\hat{Y} = \beta_{10} + \beta_{11} \ln(x_{11})$	$x_{12} = \ln(x_{11})$
$\boldsymbol{x_{13}}$	Inverse	$\hat{Y} = \beta_{10} + \frac{\beta_{11}}{x_{11}}$	$x_{13} = \frac{1}{x_{11}}$
$\boldsymbol{x_{14}}$	Power	$\hat{Y} = \beta_{10} {x_{11}}^{\beta_{11}}$	$x_{14} = {x_{11}}^{\beta_{11}} = {x_{11}}^{0.136}$
$\boldsymbol{x_{15}}$	S-curve	$\hat{Y} = e^{\beta_{10} + \frac{\beta_{11}}{x_{11}}}$	$x_{15} = e^{\beta_{10} + \frac{\beta_{11}}{x_{11}}} = e^{3.352 - \frac{1124.246}{x_{11}}}$
$\boldsymbol{x_{16}}$	Growth	$\hat{Y} = e^{\beta_{10} + \beta_{11} x_{11}}$	$x_{16} = e^{\beta_{10} + \beta_{11} x_{11}} = e^{3.108 + 7.206E-6 x_{11}}$

TABLE 19: VARIABLES IN THE MULTIPLE LINEAR REGRESSION MODEL

According to Huizingh (2004), stepwise regression is a method to determine the most valuable independent variables, from a set of independent variables. In stepwise regression F-values are used to evaluate the – added – value of each independent variable included and not included in the regression model. Stepwise regression, however, requires an arbitrary judgment concerning the values F-to-Remove and the F-to-Enter.

To define the best regression model, we use the logic of the stepwise regression, but apply a different method the define the best regression model. We will:

1. list the regression coefficients of the independent variables and the dependent variable;
2. include the variable with the highest absolute correlation coefficient;
3. calculate the R_a^2 value;
4. list the regression coefficients for all the independent variables not in the model and the dependent variable, controlling for the independent variables in the model;
5. include the variable with the highest correlation coefficient;
6. calculate the new R_a^2 value;
7. calculate the R_a^2 value for all cases leaving out one of the included independent variable;
8. determine the best regression model using the R_a^2 values (using measures from step 6 and 7);
9. if the model in step 8 differs from step 8 in the previous cycle go to step 4, else stop the model in step 8 is the best regression model.

Applying this logic values and compares various regression models using R_a^2 (instead of arbitrary F-to-Remove and F-to-Enter definitions).

1. Table 20 lists the regression coefficients for the independent variables and the dependent variable;
2. variable x_4 reveals the highest absolute correlation coefficient and is included in the regression model;
   $\hat{Y}_i = \beta_0 + \beta_4 x_4 = 0.254 + 2.858 x_4 = 0.254 + 2.858 {x_1}^{0.363}$
3. the R_a^2 value equals 0.570

Pearson correlation	x_1	x_2	x_3	x_4	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}
Workload [hours]	0. 725	0.765	-0.574	0.769	0.329	0.448	-0.484	0.434	0.487	0.315

TABLE 20: STEP ONE, x_4 REVEALS THE HIGHEST CORRELATION COEFFICIENT

4. Table 21 lists the regression coefficients for the not included independent variables and the dependent variable, controlling for x_4;
5. variable x_{15} reveals the highest absolute correlation coefficient and is included in the regression model;
   $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{15} x_{15} = -6.966 + 2.567 x_4 + 0.392 x_{15}$
   $= -6.966 + 2.567 {x_1}^{0.363} + 0.392 e^{3.352 - \frac{1124.246}{x_{11}}}$
6. the R_a^2 value equals 0.572;
7. the R_a^2 for the regression model $\hat{Y}_i = \beta_0 + \beta_4 x_4$ equals 0.570 (deterioration)
   the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_{15} x_{15}$ equals 0.197 (deterioration);
8. the best regression model at this stage is $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{15} x_{15}$;
9. the model in step 8 differs from the model in step 8 of the previous cycle, go to step 4;

Pearson correlation: control for x_4	x_1	x_2	x_3	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}
Workload [hours]	-0.108	0.050	-0.078	0.230	0.251	-0.235	0.250	0.239	0.226

TABLE 21: STEP TWO, x_{15} REVEALS THE HIGHEST CORRELATION COEFFICIENT

4. Table 22 lists the regression coefficients for the non included independent variables and the dependent variable, controlling for x_4 and x_{15};
5. variable x_{14} reveals the highest absolute correlation coefficient and is included in the regression model;
   $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{14} x_{14} + \beta_{15} x_{15} = -7.733 + 2.595 x_4 + 2.067 x_{14} + 0.117 x_{15}$
   $= -7.733 + 2.595 {x_1}^{0.363} + 2.067 {x_{11}}^{0.136} + 0.117 e^{3.352 - \frac{1124.246}{x_{11}}}$
6. the R_a^2 value equals 0.550;
7. the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{14} x_{14}$ equals 0.575 (improvement)
   the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{15} x_{15}$ equals 0.572 (improvement)
   the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_{14} x_{14} + \beta_{15} x_{15}$ equals 0.154 (deterioration);
8. the best regression model at this stage is $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{14} x_{14}$;
   $\hat{Y} = -7.604 + 2.621 x_1^{0.363} + 2.790 x_{11}^{0.136}$
9. the model in step 8 differs from the model in step 8 of the previous cycle, go to step 4;

Pearson correlation: control for x_4, x_{15}	x_1	x_2	x_3	x_{11}	x_{12}	x_{13}	x_{14}	x_{16}
Workload [hours]	-0.044	-0.031	-0.038	0.080	0.081	0.042	0.082	0.078

TABLE 22: STEP THREE, x_{14} REVEALS THE HIGHEST CORRELATION COEFFICIENT

4. Table 23 lists the regression coefficients for the not included independent variables and the dependent variable, controlling for x_4 and x_{14};
5. variable x_1 reveals the highest absolute correlation coefficient and is included in the regression model;
   $\hat{Y} = \beta_0 + \beta_1 x_1 + \beta_4 x_4 + \beta_{14} x_{14} = -9.767 - 0.003 x_1 + 3.087 x_4 + 2.653 x_{14} =$

$= -9.767 - 0.003x_1 + 3.087{x_1}^{0.363} + 2.653{x_{11}}^{0.136}$

6. the R_a^2 value equals 0.551;
7. the R_a^2 for the regression model $\hat{Y}_i = \beta_0 + \beta_1 x_1 + \beta_4 x_4$ equals 0.552 (improvement)
   the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_1 x_1 + \beta_{14} x_{14}$ equals 0.530 (deterioration)
   the R_a^2 for the regression model $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{14} x_{14}$ equals 0.575 (improvement);
8. the best regression model at this stage is $\hat{Y} = \beta_0 + \beta_4 x_4 + \beta_{14} x_{14}$;
9. the model in step 8 is equal to the model in step 8 of the previous cycle. Stop, the best regression model is the model in step 8;

Pearson correlation: control for x_4, x_{15}	x_1	x_2	x_3	x_{11}	x_{12}	x_{13}	x_{15}	x_{16}
Workload [hours]	-0.051	-0.018	-0.034	-0.031	0.029	-0.037	0.032	-0.033

TABLE 23: STEP FOUR, x_1 REVEALS THE HIGHEST CORRELATION COEFFICIENT

Figure 46 visualizes the impact of the independent variables (the number of order lines, and the number of order items) on the dependent variable (the expected workload).

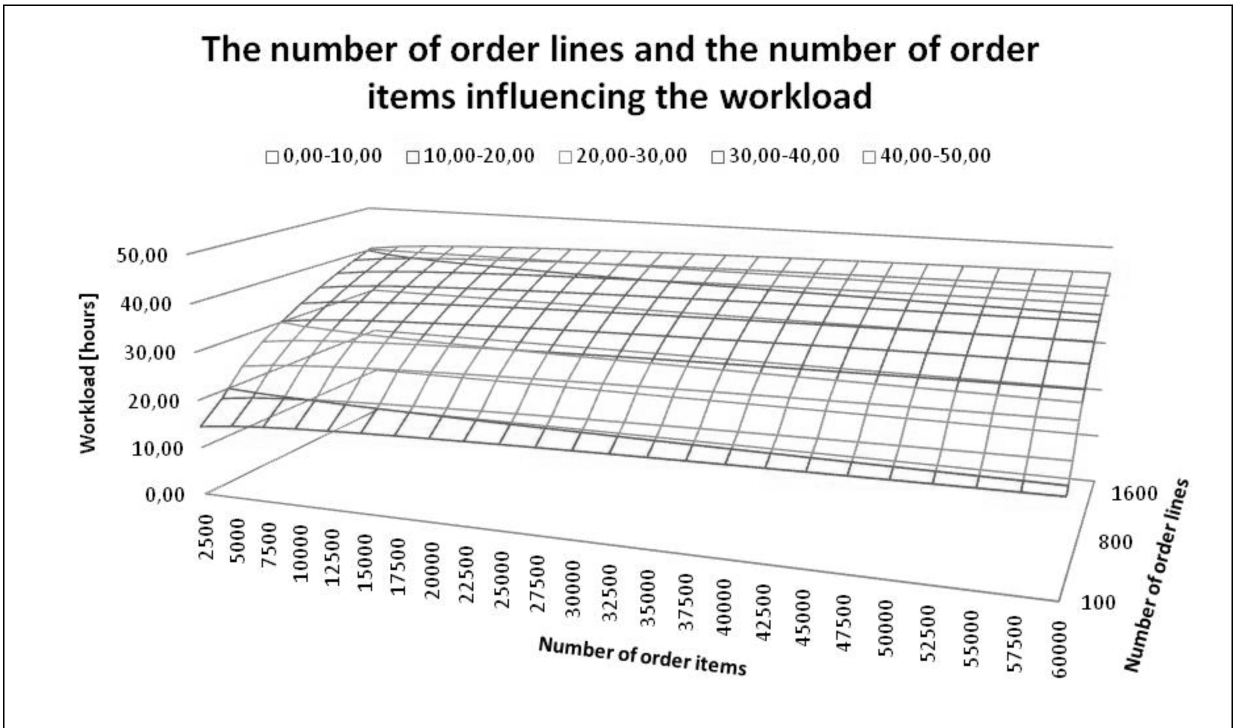


FIGURE 46: VISUALISATION OF THE REGRESSION MODEL

The quality and accuracy of this regression model is determined by comparing the relative differences between the observed workload (see Table 18) and the predicted workload. Comparing the observations and predictions results in an average overestimation of the workload with 6.0% (approximately 1.6 hours), marked by a standard deviation of 18.9% (5.0 hours).

With an uncertainty of 10%, this regression model will on average not underestimate the order picking workload with more than 25.2% (6,7 hours) and will not overestimate the workload with more than 37.1% (9.9 hours). In order to reduce the distance between the lower and the upper bound of this confidence interval more historical data is required. As a rule of thumb, to reduce the distance between the lower and upper bound in this confidence interval with a factor n, n^2 more data is required.

APPENDIX E REPRESENTATIVE CAPITOLE 40 INSTALLATION

In this research we approximate the impact of changes using the representative Capitole 40 installation as described in Table 24.

Pos.	Article number	Article description	Quantity
10	T100	Panel CT4.2-T PAN. 1	1
20	T101	Panel CT4.2-T PAN. 2	1
30	T102	Panel CT4.2-T PAN. 3	6
40	T103	Panel CT4.2-T PAN. 4	2
50	T104	Panel CT4-T-D-VP PAN. 5	1
60	T105	Panel CT4-T-D-VP PAN. 6	1
70	T200	C014 Dummy A EMPTY compartment	8
80	T201	C014 A EMPTY compartment	6
85	T202	C024 A EMPTY compartment	7
86	T203	C034 A EMPTY compartment	3
90	T300	C014 Distr. V/S 63A SDF1	22
100	T301	C024 Distr. V/S 160A SDF1	4
110	T302	C034 Distr. V/S 315A SDF1	2
120	T303	C034 Distr. V/S 315/150A SDF2	3
130	T304	C034 Distr. V/S 315/250A SDF2	6
140	T305	C014 MCC 0.75KW MS1	2
150	T306	C014 MCC 3.7KW MS2	6
160	T307	C054 MCC 110KW MS3	4
180	T600	C054 1600A FEEDER ACB	2
190	T601	C054 1600A COUPLER ACB	1
200	T650	C064 1600A METERING FEED	2
210	T651	C064 1600A METERING COUPLER	1

TABLE 24: ILLUSTRATIVE CAPITOLE 40 INSTALLATION

The costs, as stated in the quotation document, of this installation are provided in – the confidential – Appendix N.

APPENDIX F WORKLOAD CALCULATION FOR THE CURRENT SITUATION

To calculate the workload in the current situation we use a representative Capitole 40 installation (see Appendix E). Table 25 visualizes the current picking order(s) for this representative Capitole 40. In this order demand per component is aggregated over all panels, over all drawers, and over all workstations. The workload, estimated based on the total number of order lines (462) and the total number of order items (15454), equals 27.1 hours. The formula to determine this workload is provided in Equation 1 (on page 30).

Pos.	Quantity	Unit	Part no.	Description	AC	Store	Rout.
10	130	st	1024907	KABELLUSVOET ABMM-A	St	VMI	300
20	555	st	1024919	CABLE LUG L92 B2,4 TY23M	St	VMI	300
30	80	st	1024920	CABLE TIE L186 W4,8 TY25M	St	VMI	300
40	11	st	1024943	CABLE TIE L140 W3,6 TY24M	St	VMI	300
50	75	st	1024947	KABELLUSVOET ABM2S-A	St	VMI	300
				... ...			
1960	1	st	1376134	BRANCH BUSBAR L1 PC COUPLER	Kl	OEM	330
1970	1	st	1376135	BRANCH BUSBAR L2 PC COUPLER	Kl	OEM	330
1980	1	st	1376136	BRANCH BUSBAR L3 PC COUPLER	Kl	OEM	330
1990	75	m	1932623	CABLE 2,5 MM2 HET3000 BLACK	St	003	330
2000	1	st	6058840	HOR.BUSBAR COUPLER NUL	Kl	OEM	330
2010	1	st	6058865	VERT.BUSBAR COUPLER NUL	Kl	OEM	330
2020	6	st	6058931	VERT.BUSBAR COUPLER L1-2-3	Kl	OEM	330
2030	6	st	6058933	HOR.BUSBAR COUPLER L1-2-3	Kl	OEM	330
				... ...			
3920	38	st	1374042	TOGGLE KEY	St	003	360
3930	30	st	1374047	STRIP 12X53 ST3,2 1G6 E 8	St	003	360
3940	6	st	1374048	PLATE 12X127 ST3,2 1G6 E 8	St	003	360
3950	10	st	1374049	BEV.PROF.LADE250V.CONT.STOP L.	St	003	360
3960	8	st	1374554	HPROF.35X 7/ 95V.CONTACTOR	St	76A	360
3970	2	st	1374557	MONT.PLAAT C034 VEIL./SCHAK.	St	003	360
3980	4	st	1374563	MONT.PLAAT C024 VEIL./SCHAK.	St	003	360
3990	6	st	1374578	FIXING PLATE Z127X107 FUSE H.P	St	003	360
				... ...			
4580	1	st	1374773	BUSBAR COVER REAR CT2	St	003	370
4590	6	st	1374971	PROFILE L 11X60 45 F.BANDEAU	St	003	370
4600	18	m	1973213	RU.STRIP 5X2 ZWZ155SCHUIM ZK	St	003	370
4610	2	st	6059016	COVER C064 1x96 4KN 1C2 1TE20	Kl	OEM	370
4620	1	st	6059019	COVER C064 2x96 3KN	Kl	OEM	370

TABLE 25: CURRENT PICKING ORDER

APPENDIX G WORKLOAD CALCULATION IN CASE DRAWERS ARE SUPPLIED PER TYPE PER PANEL

The workload, in case drawers are supplied per panel, is calculated using the same representative Capitole 40 as in Appendix F. Table 26 visualizes the picking order for material kit 1 of panel 1, Table 27 for material kit 3 of panel 1, and Table 28 for material kit 6a of panel 1. The workload, estimated based on the total number of order lines (2240) and the total number of order items (15454), equals 45.9 hours. This workload is 69% higher compared to the current workload.

Pos.	Quantity	Unit	Part no.	Description	AC	Store	Rout.
10	5	st	1034802	SYMBOLS EARTH ADHESIVE	St	CW2	310
20	1	st	1372051	SEALING PLATE F.BUSBAR DUCT	St	003	310
30	1	st	1373245	SIDE WALL L+R PAN.625 450	St	76A	310
40	2	st	1373247	DEPTH POST L+R	St	003	310
50	1	st	1373248	PROFILE -L 17X22/1950 ST2	St	76A	310
				... ...			
180	1	st	1374810	BUSBAR COVER 700REAR CT42	St	003	310
190	1	st	1374908	SEALING PLATE BARR.IN CAP 698	St	76A	310
200	1	st	1374962	PROFILE L.14X18/ 675F.BUSB.SUP	St	003	310
210	1	st	6001376	SIDE WALL SIDE WALL COMPLETE I	St	76A	310

TABLE 26: MATERIAL KIT 1 FOR PANEL 1

Pos.	Quantity	Unit	Part no.	Description	AC	Store	Rout.
10	1	st	1370003	CONN.STRIP L2HOR.-VERT.BUSB	St	76A	330
20	1	st	1370004	CONN.STRIP L3 HOR.-VERT.BUSB	St	76A	330
30	1	st	1370005	CONN.STRIP NEUTRHOR.-VERT.BUSB	St	76A	330
40	1	st	1370006	CONN.STR. L1HOR.-VERT.BUSB	St	003	330
50	1	st	1372108	SCREENING CAP CTF.VERT.BUSBARS	St	003	330
60	4	st	1372523	SHROUD 13X25 CONT.HOLDER	St	003	330

TABLE 27: MATERIAL KIT 3 FOR PANEL 1

Pos.	Quantity	Unit	Part no.	Description	AC	Store	Rout.
10	2	st	1373727	DRAWER	St	003	360
20	2	st	1372757	STRIP FOR TRAY	St	003	360
30	2	st	1374042	TOGGLE KEY	St	003	360
40	6	st	1322144	FUSE HOLDER 160PI85-00	St	CW2	360
50	2	st	1373386	MOUNTING PLATE C014 FUSE/SWITC	St	003	360
60	2	st	1314164	DUMECO DMM63/4 H H	St	003	360
				... ...			
290	2	st	1373740	COVER C014 TRAY MCC DMM63	St	76A	360
300	2	st	1818031	DOORV.K1D 25 GS/GS/GS.HH	St	DCC	360
310	2	st	1370800	BEV.STUK ST.STR.DOOS	St	003	360
320	2	st	1373857	SCHARNIERLIP	St	003	360

TABLE 28: MATERIAL KIT 6A (DRAWER KIT) FOR PANEL 1

APPENDIX H WORKLOAD CALCULATION INCREASE IN CASE DRAWERS ARE SUPPLIED PER TYPE PER SYSTEM

The workload, in case drawers are supplied per system, is calculated using the same representative Capitole 40 as in Appendix F and Appendix G. In case drawers are supplied per system, instead of per panel, the material kits 6a, 6b, 6c, and/or 6d for each panel are replace by a material kit 6T300, 6T301, 6T302. 6T303, 6T304, 6T305, 6T306, and 6T307. In this way drawers are aggregated per type over the total system. The workload, estimated based on the total number of order lines (1546) and the total number of order items (15454), equals 40.4 hours. This workload is 49% higher compared to the current workload (but 14% lower compared to the case in which components are supplied per type per panel).

APPENDIX I ANALYSIS OF THE CURRENT AND NEW DEMAND PATTERNS

Table 29 visualizes a part of the demand log over January and February 2011 as recorded in BaaN. Goal is to express the differences between in-house demand and OEM demand. This analysis includes both the average demand pattern and the deviation in demand, using the magnitude calculation as proposed by Zinn et al. (1989). Based on the work of Zinn et al. (1989) we define the magnitude in average demand as:

$$M_{average} = \frac{\bar{X}_1}{\bar{X}_2}$$
in which:
$\bar{X}_1 \leq \bar{X}_2 \;\; \cap \;\; \bar{X}_2 \neq 0$
$\bar{X}_i$ = average demand measurement i

EQUATION 6: EXPRESSION FOR THE MAGNITUDE IN AVERAGE DEMAND

As proposed by Zinn et al. (1989) we define the Magnitude in deviation as:

$$M_{deviation} = \frac{\sigma_1}{\sigma_2}$$
in which:
$\sigma_1 \leq \sigma_2 \;\; \cap \;\; \sigma_2 \neq 0$
σ_i = demand deviation measurement i

EQUATION 7: EXPRESSION FOR THE MAGNITUDE IN DEMAND DEVIATION (ZINN ET AL., 1989)

Both the magnitude in average demand and the magnitude in deviation are larger or equal to 1. The closer both magnitudes approach the number 1, the more similar both demand patterns are. Plotting each point with on the X-aisle the magnitude in average demand and on the Y-aisle the magnitude in demand deviation enables us to calculate the distance between these points and the point (1, 1), the most equivalent point. Therefore, we define the equivalency to be express by Equation 8.

$$Equivalency = \sqrt{M_{average}^2 + M_{deviaion}^2} - \sqrt{2}$$

EQUATION 8: DEMAND EQUIVALENCY

Table 29 provides a part of the equivalency calculations for the current situation. The sum of the equivalencies equals 1900. Table 30 provides the equivalence calculation for the new situation. The new demand patterns are – the best – approximations based on changes as concluded in Appendix H. The sum of the equation-distance in the new situation equals 1513.

In case Eaton Industries B.V. implements Material Kit Product Design 2, this will positively affect the equivalency of both demand patterns. In these calculations, the equivalency improved with 17%, not that this number is influenced by both: (1) in-house demand and (2) OEM demand.

Article	In-house $\bar{d}$	In-house σ	OEM $\bar{d}$	OEM σ	$M_{average}$	M_{stdev}	Distance
1010925	1.8	1.8	3.8	2.8	2.13	1.56	1.22
1014013	28.1	32.9	455.0	151.3	16.18	4.60	15.41
1014038	4.1	2.0	54.0	4.2	13.20	2.15	11.96
1014042	40.7	32.6	66.0	25.5	1.62	1.28	0.65
1014066	23.0	24.0	108.0	8.5	4.70	2.83	4.07
1014108	28.6	21.4	514.0	70.7	17.99	3.30	16.88
… …							
1960043	8.0	4.6	8.0	2.0	1.00	2.29	1.09
1960515	0.7	0.8	5.9	0.1	8.05	5.35	8.25
1966501	11.9	15.9	123.4	133.2	10.35	8.37	11.89
1973213	18.1	17.0	112.3	45.4	6.19	2.67	5.33
1973214	0.9	0.9	6.2	0.8	7.27	1.01	5.92
6037309	3.6	3.9	51.0	43.5	14.30	11.08	16.68

TABLE 29: ANALYSIS OF THE CURRENT DEMAND PATTERN

Article	In-house $\bar{d}$	In-house σ	factor	OEM $\bar{d}$	OEM σ	$M_{average}$	M_{stdev}	Distance
1010925	1.8	1.8	3.16	1.2	1.6	1.15	1.14	0.20
1014013	28.1	32.9	1.82	250.0	112.2	3.99	3.41	3.83
1014038	4.1	2.0	1.82	29.7	3.1	1.30	1.59	0.64
1014042	40.7	32.6	1.82	36.3	18.9	2.16	1.73	1.35
1014066	23.0	24.0	1.82	59.3	6.3	3.66	3.82	3.88
1014108	28.6	21.4	1.82	282.4	52.4	1.83	2.44	1.64
… …								
1960043	8.0	4.6	3.44	2.3	1.1	7.42	4.25	7.13
1960515	0.7	0.8	1.55	3.8	0.1	6.46	6.67	7.87
1966501	11.9	15.9	3.44	35.9	71.8	6.02	4.51	6.11
1973213	18.1	17.0	3.16	35.5	25.5	1.41	1.50	0.64
1973214	0.9	0.9	3.16	2.0	0.5	1.79	1.79	1.11
6037309	3.6	3.9	1.55	32.9	35.0	9.80	8.90	11.83

TABLE 30: ANALYSIS OF THE NEW DEMAND PATTERN

APPENDIX J KANBAN-WORTHY POLICIES VERSUS A COST BASED FORMULA

To evaluate the Kanban-worthy policies, we compared two supply methods. The fist method is based on the Kanban policies, reducing the number of replenishments but introducing inventories. The second method is based on a lot for lot replenishment, increasing the number of replenishments but eliminating inventories (see Table 31).

	Replenishment costs	Holding costs
Apply Kanban replenishments	$\frac{D}{Binsize} \times T_{costs}$	$(1.5 \times Binsize) \times v \times h$
Apply lot for lot replenishments	$T \times T_{costs}$	$D \times \frac{h}{250} \times v$

TABLE 31: COST DRIVERS PER SUPPLY POLICY

The numbers in Table 31 imply:

D = demand per year
T = number of transaction per year
v = product value
$Binsize$ = number of components per bin
T_{costs} = cost per transaction, estimated to equal € 5
h = holding per year in percentage, estimated to equal 25%

If a component is stored in a line-stock (Kanban), the annual number of replenishments equals the annual demand divided by the binsize. Multiplying this number by the fixed cost per transaction result is the total annual transaction costs. The average inventory, if managed Kanban, is expected to equal one and half a binsize. Multiplying this number by the product value and the holding costs percentage results in the total annual holding costs. The sum of both is the total (relevant) annual costs to store a component in a line-stock.

If lot for lot replenishment is applied, the annual number of replenishments equals the number of requests for demand each year. Multiplying this number by the fixed cost per transaction result is the total annual transaction costs. One average, we expected lot-for-lot supplies to be delivered one day (to) early, incurring one day of holding costs for each item. The sum of both is the total (relevant) annual costs to apply lot-for-lot replenishment.

The minimum of the above described totals is the minimum the total holding cost per component and determines whether a component is – financially – worth to be stored in a line-stock.

In an Excel calculation we compared the Kanban-worthy judgement based on the currently applied policies and the above described minimize total annual costs. Comparing the financial test to the Kanban-worthy test, results in changed judgement for 169 out of the 627 components (27%). Although 27% seems to be a large part of the total components, the maximum feasible cost reduction equals 14.3% (€ 11,800). Table 32 summarizes these results. This table shows that the majority of components are responsible for a minority in savings. While only adjusting the top 10 components could result in a 5.5% (€ 4,500) annual cost reduction.

Annual cost saving	Number of components	Total feasible saving
< € 50	107	€ 2,228.96
> € 50 and < € 100	33	€ 2,383.95
> € 100 and < € 250	23	€ 3,626.28
> € 250 and < € 500	3	€ 1,047.34
> € 500	3	€ 2,575.77

TABLE 32: COMPARISON RESULTS IN APPROXIMATED ANNUAL SAVINGS

The arguments at Eaton Industries B.V., not to apply financially oriented models to determine whether components are Kanban-worthy are: (1) the used parameters can only be estimated and calls for discussion and (2) financial models are ought to be harder to understand, especially for the operators who are directly involved by each change.

Based on calculations and observations, we judge that the currently applied Kanban-worthy test suits its needs. Gross of the savings derived in case Eaton Industries B.V. applies the above described financial models is heavily depending on the parameter settings. However, we do advise to run this (simple) double check to notice flaws in the currently applied Kanban-worthy test. This double check could, for example, be restricted to identify the top 10 components for reconsideration.

APPENDIX K THE EFFECT OF AGGREGATING KANBAN STOCKS

Using data records in BaaN, we classified components to be Kanban-worthy or not using the policies as provided in Table 3 (page 29). In case a component is classified as Kanban-worthy, we looked up the currently used binsize in order to estimate the expected average inventory level. In Table 33 and Table 34, we determined the Kanban-worthiness for the in-house assembly process and the OEM process separately. In Table 35, we calculated the Kanban-worthiness for the case stocks are aggregated. As we show, aggregating demand of both processes results in a €12,274 reduction on annual holding costs.

The policies of Eaton Industries B.V. are used to determine whether components are Kanban-worthy (see Table 3). If a component is Kanban-worthy, we expect that on average 1.5 binsize is stored in the line-stock. Multiplying the expected inventory by the cost price of the component provides insight regarding the expected inventory value.

Table 33 visualize the Kanban-worthy determination and line-stock inventory calculation for the in-house process. 307 components (out of the 565 components that register demand) are classified Kanban-worthy. Resulting in an expected average inventory value equalling € 84,161 (approximately € 21,040 annual holding costs).

Part number	Expected annual demand x cost price	# transactions last 13 weeks	Kanban-worthy	Expected inventory	Expected inventory value
1010539	€ 11,765	8	no		
1010540	€ 10,928	8	no		
1010925	€ 1,004	8	yes	75	€ 96.76
1012391	€ 4,048	3	no		
1012392	€ 4,389	3	no		
1012394	€ 2,493	2	no		
1012396	€ 4,444	6	yes	75	€ 547.50
1012398	€ 2,237	3	no		
1012399	€ 1,555	3	no		
1014031	€ 183	5	yes	150	€ 60.87
… …					
1960911	€ 192	2	no		
1966501	€ 3,817	105	yes	150	€ 57.00
1966503	€ 256	6	yes	75	€ 31.50
1967575	€ 3,135	6	yes	37,5	€ 193.13
1973209	€ 269	5	yes	15	€ 8.10
1973213	€ 1,148	41	yes	150	€ 43.50
1973214	€ 936	24	yes	150	€ 61.50
6019977	€ 1,085	2	no		
6037309	€ 2,345	36	yes	300	€ 201.00
6602654	€ 3,195	2	no		

TABLE 33: EXPECTED INVENTORY CALCULATION FOR THE IN-HOUSE ASSEMBLY PROCESS

Table 34 visualizes the Kanban-worthy determination and line-stock inventory calculation for the OEM process. 273 components (out of the 322 components that registered demand) are classified Kanban-worthy. We expect an average inventory value equalling € 84,161 (approximately € 21,128 annual holding costs).

Part number	Expected annual demand x cost price	# Transactions last 13 weeks	Kanban-worthy	Expected inventory	Expected inventory value
1010925	€ 193	30	yes	75	€ 96.76
1014036	€ 187	3	yes	450	€ 416.39
1014037	€ 6	6	yes	300	€ 150.87
1014038	€ 418	6	yes	300	€ 185.34
1014039	€ 336	6	yes	300	€ 294.00
1014042	€ 1,289	6	yes	150	€ 232.13
1014046	€ 88	6	yes	375	€ 108.98
1014066	€ 822	6	yes	375	€ 228.71
1015485	€ 33	32	yes	300	€ 8.73
1015486	€ 140	5	yes	450	€ 52.34
		... ...			
1960043	€ 371	16	yes	72	€ 174.96
1960215	€ 68	4	yes	1500	€ 675.00
1960515	€ 73	5	yes	37,5	€ 36.78
1966501	€ 1,190	22	yes	150	€ 57.00
1966503	€ 96	11	yes	75	€ 31.50
1973209	€ 34	10	yes	15	€ 8.10
1973213	€ 620	15	yes	150	€ 43.50
1973214	€ 32	10	yes	150	€ 61.50
6019977	€ 904	7	yes	7,5	€ 49.50
6037309	€ 1,083	12	yes	300	€ 201.00

TABLE 34: EXPECTED INVENTORY CALCULATION FOR THE OEM PROCESS

Table 35 visualizes the Kanban-worthy determination and line-stock inventory calculation for the aggregated in-house and OEM process. 410 components (out of the 565 components that registered demand) are determined to be Kanban-worthy. We expect an average inventory value equalling € 119,577 (approximately € 29,894 annual holding costs).

Part number	Expected annual demand x cost price	# transactions last 13 weeks	Kanban-worthy	Expected inventory	Expected inventory value
1010539	€ 11.765	8	no		
1010540	€ 10.928	8	no		
1010925	€ 1.197	38	yes	75	€ 96,76
1012391	€ 4.048	3	no		
1012392	€ 4.389	3	no		
1012394	€ 2.493	2	no		
1012396	€ 4.444	6	yes	75	€ 547,50
1012398	€ 2.237	3	no		
1012399	€ 1.555	3	no		
1014031	€ 183	5	yes	150	€ 60,87
		... ...			
1960911	€ 192	2	no		
1966501	€ 5.007	127	yes	150	€ 57,00
1966503	€ 352	17	yes	75	€ 31,50
1967575	€ 3.135	6	yes	37,5	€ 193,13
1973209	€ 303	15	yes	15	€ 8,10
1973213	€ 1.767	56	yes	150	€ 43,50
1973214	€ 968	34	yes	150	€ 61,50
6019977	€ 1.989	9	yes	7,5	€ 49,50
6037309	€ 3.429	48	yes	300	€ 201,00
6602654	€ 3.195	2	no		

TABLE 35: EXPECTED INVENTORY CALCULATION FOR THE AGGREGATED PROCESSES

Aggregating inventories for the in-house and OEM process will yield in a € 49,097 inventory reduction and an approximated annual holding costs reduction of € 12,274.

APPENDIX L ALTERNATIVE KANBAN-WORTHY TEST

Currently Eaton Industries B.V. determines whether components are Kanban-worthy based on the (expected) annual sales volume, the cost price, and the number of transactions (see **Fout! Verwijzingsbron niet gevonden.**). The annual sales volume times the cost price of a component determines the amount of tied up capital in case a component is managed using Kanban (and stored in a line-stock). On the other hand, the number of transactions influences the material handling costs in case a component is managed lot-for-lot. The reason why **Fout! Verwijzingsbron niet gevonden.** not includes any type of costs (e.g. holding costs or material handling costs) is that costs – estimations – call for discussion.

	Expected annual sales volume x cost price		Number of transactions last 13 weeks	Kanban-worthy
if	≥ € 100,000	and	> 26	yes
if	< € 100,000 & ≥ € 10,000	and	>13	yes
if	< € 10,000 & ≥ € 1,000	and	> 6	yes
if	< € 1,000	and	> 3	yes
else				no

TABLE 36: POLICIES TO DETERMINE KANBAN-WORTHINESS

If a component is Kanban-worthy the number of bins is determined using Equation 9.

$$\left\lceil \frac{l \cdot d \cdot f}{binsize} \right\rceil + 1 = \#\, of\ bins$$

In which:
l = lead-time in days
d = expected average daily demand
f = the safety factor (currently fixed at 1.2)

EQUATION 9: THE NUMBER OF BINS REQUIRED WHEN A COMPONENT IS KANBAN-WORHTY

Assuming a normal distribution, we can calculate the out of stock probability. This is the case if the demand during the lead-time exceeds the binsize. As an example, we use a component characterized by a lead-time of 6 days, an averaged demand of 5 units per day, a binsize of 36 units, a factor f equal to 1.2, and a standard deviation in demand of 1.5 units per day.

Assume 2 bins in the system, currently the minimum binsize should (at least) be:

$$l \cdot d \cdot f = binsize$$

Determining the binsize using a statistical formulation, e.g. Silver et al. (1998), reveals:

$$l \cdot d + \Phi^{-1}(P) \cdot \sigma_l = binsize$$

Comparing both equations enables us to determine P, equally the stock out probability:

$$l \cdot d + \Phi^{-1}(P) \cdot \sqrt{l \cdot \sigma^2} = binsize$$
$$6 \cdot 5 + \Phi^{-1}(P) \cdot \sqrt{6 \cdot 1.5^2} = 36$$
$$\Phi^{-1}(P) = \frac{6}{\sqrt{13.5}}$$
$$P \approx 0.95$$

A P value equal to 0.95 means a stock out probability of 5% during each replenishment cycle. For this example this implies that we expect one stock out during each 20 replenishment cycles, or one every 120 (working) days.

We have defined a Kanban-worthy test that determines the Kanban-worthiness based on information including the standard deviation in demand. Based on the standard deviation and predefined classes (see **Fout! Verwijzingsbron niet gevonden.**) we provide equation to determine f. n the calculations below all gray hatched figures are subject for discussion and should be determined based on system requirements (supplemented by knowledge and experience).

Define the stock out probability for each class in **Fout! Verwijzingsbron niet gevonden.** (since the cost price for products in different product classes differ, holding costs will be influenced by this out of stock probability, and will influence the total inventory levels):

$P_A = 0.900$
$P_B = 0.950$
$P_C = 0.975$
$P_D = 0.990$

Define distinct coefficient classes of variation:

1: $c < 0.40$
2: $0.40 \leq c < 0.75$
3: $0.75 \leq c < 1.33$
4: $c \geq 1.33$

Determine the expected demand during the lead-time and the standard deviation during the lead-time:

$\bar{d}_l = l \cdot d$
$\sigma_l = \sqrt{l \cdot \sigma_1}$

Determine the coefficient of variation (Hopp & Spearman, 2008):
$c = {}^{\sigma_l}/_{\bar{d}_l}$

Determine whether the component is (still) Kanban-worthy based on the classifications in Table 37.

Sales volume x cost price class	**Coefficient of variation class**			
	1	**2**	**3**	**4**
A			Not Kanban-worthy	
B				
C		Kanban-worthy		
D				

TABLE 37: PROPOSED NEW (LOGIC) TO DETERMINE COMPONENT KANBAN-WORTHINESS

If the component is (still) Kanban-worthy determine the proper factor f:

$$\bar{d}_l + \Phi^{-1}(P) \cdot \sigma_l = l \cdot d \cdot f$$
$$l \cdot d \cdot \left(1 + \frac{\Phi^{-1}(P) \cdot \sigma_l}{l \cdot d}\right) = l \cdot d \cdot f$$
$$f = 1 + c \cdot \Phi^{-1}(P)$$

We propose the following method to determine d_l and σ_l using monthly demand data (available in BaaN). In these calculations we assume that each month contains 20 working days.

$X_1. \dots. X_{12}$ are the monthly demand records retrieved from BaaN.

$d_l = d \cdot l$ in which $d = \frac{\sum_i (X_i)}{12 \cdot 20}$

$\sigma_l = \sqrt{l \cdot \sigma_1^2}$, in which:

$\sigma_1 = \sqrt{\frac{\sigma_{20}^2}{20}}$, in which:

$\sigma_{20} = \sqrt{\frac{\sum_i (X_i - \bar{X})^2}{11}}$

APPENDIX M COMPONENT ALLOCATION BASED ON LINE-STOCKS DESIGN

Figure 47 visualizes a method we developed during this research. In a later stadium of this research, at the time we concluded: (1) the new in-house LVS process was being redesigned and (2) the realization we should not add more difficulty to the OEM process controls, we dropped this solution. Since the routing information, to be of used in the final material kit design, was and currently still is not available we did used this method to define (fictive) routing information to test and validate functioning of the material kit design.

Components are ought to be used at one workstation. Therefore, the design of the current line-stocks provides a good starting point to link workstations (with line-stocks) with components. Figure 47 visualizes how a "parts to kit table" could be used to specify relations between components and material kits (workstations).

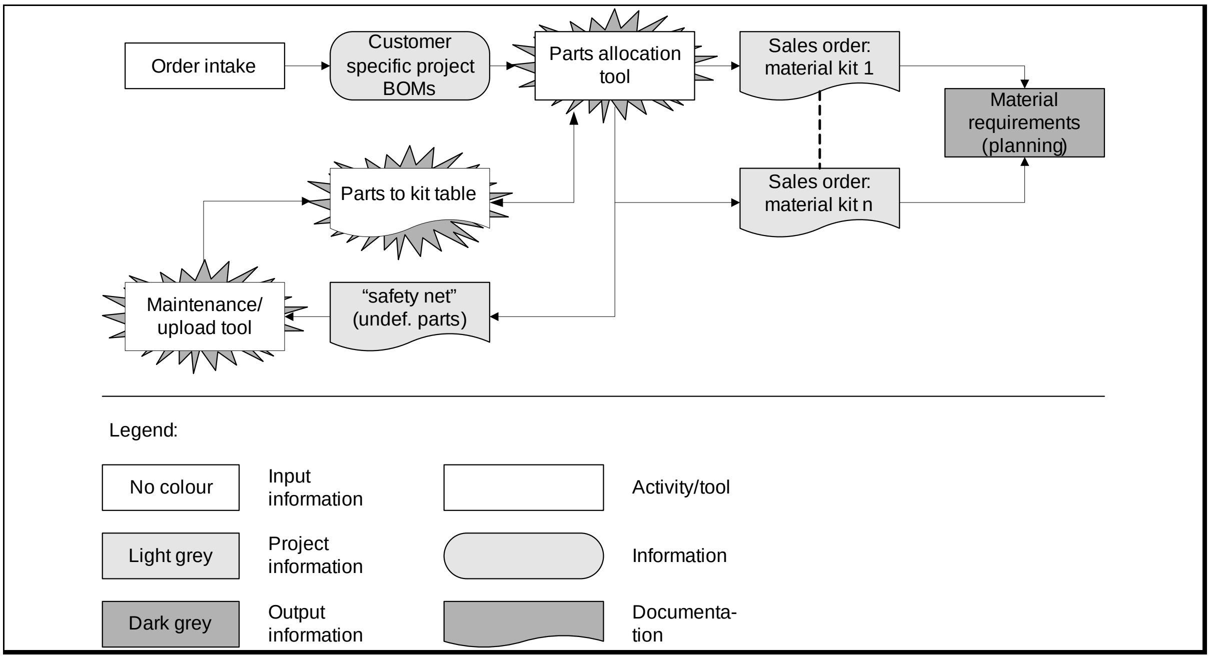


FIGURE 47: MATERIAL PARTITIONING BASED ON LINE-STOCK STORAGE SHELVES