The use of the DWV$^3$ classification system in manufacturing companies for evaluating a market-specific supply chain strategy

- A case study at Atlas Copco Industrial Technique

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Abstract

The research topic of this study is market-specific supply chain strategy, and the research problem is defined as, how manufacturing companies can use the DWV3 classification system to evaluate the opportunity for a market-specific supply chain strategy. What has been written about the DWV3 classification system is somewhat general in its nature and the practitioner is left without detailed instructions on how to proceed with the analytical analysis. Key elements of the DWV3 classification system that is not explicitly described in the literature is (1) how to measure each of the classification variables, (2) how to define a suitable limit for each measure in order to classify the products and (3) how to reason when sequencing the classification variables in the clustering analysis. Hence, the purpose of this thesis is to make the DWV3 classification system more available to practitioners, and thus the aim is to illustrate how to tackle the key elements of the framework by applying it on the Atlas Copco Industrial Technique Business Area product portfolio. A single-case study design was chosen as a suitable research approach for this thesis. The application of the DWV3 system to the ITBA product portfolio was considered as the phenomenon under investigation, the case, of this study. Two sets of quantitative data were collected, demand data and product master data. The qualitative data collected was related to the ITBA supply chain set-up and the products as well as the customers’ responsiveness requirements for each assortment included in the study. All qualitative data was collected through interviews. The findings of this study are summarized in a number of conclusions that can serve as guidelines for practitioners that are about to apply the DWV3 system. These are (1) as far as possible use measures at the single product level, (2) use measures that express each classification variable in a way that is relevant to the matching of demand characteristics and supply chain strategy, (3) be prepared to redefine initial measures in order to describe the studied products’ characteristics in the best possible way, (4) develop measures that are based on available data or data that is feasible to attain, (5) adjust the number of codification levels to find the best trade-off between the level of detail in the cluster analysis and the number of populated segments, (6) alter the sequencing and repeat the cluster analysis to gain insight into the demand characteristics of the product portfolio, (7) the final sequencing of the classification variables must produce clusters that are relevant for the chosen production philosophy concepts.

Key-words: market-specific supply chains, DWV3 classification system, supply chain management, demand chain management
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1 Introduction

This chapter provides an overview of the research area and the research topic of this thesis. Based on this the purpose and aim of the study is formulated, and finally, the research questions are defined and delimitations stated.

1.1 Background

Companies today face a business environment characterised by increased demand variability and product variety, shortened product lifecycles and uncertainty in supply. Add low forecast accuracy and those circumstances will either lead to increased supply chain cost and less operational efficiency when companies desperately use workarounds to keep up product availability, or result in a poor customer service level and ultimately unsatisfied customers (Mendes, 2011). Heikkilä (2002) capture this when he states, “One of the main challenges of today’s manufacturing is to be both efficient and contribute to high effectiveness, i.e. customer satisfaction.” (p. 747)

Several researchers have proposed that companies should embrace customers’ differing needs as the basis for supply chain strategy formulation and arrange the supply chain accordingly, thus adopting market-specific supply chain strategies and thereby achieve both efficiency and effectiveness (Christopher, 1998; Heikkilä 2002; Childerhouse et al. 2002). Companies that are demand driven can gain several benefits such as reduced inventory levels, less out-of-stocks, increased production efficiency, reduced obsolescence, shorter cash-to-cash cycle time, and ultimately higher revenue and profit margins than competitors (Mendes, 2011). Fuller et al. (1993) were early on to advocate the need to develop such market-specific supply strategies as they argued that logistics was increasingly becoming a competitive advantage. A number of frameworks have since then been presented to guide managers that are attempting to match differing customer needs with tailored production and distribution strategies (Fuller et al. 1993; Fisher, 1997; Pagh & Cooper, 1998; Christopher et al. 2002). One of those, and perhaps the most acknowledged (Lamming et al., 2000; Pagh & Cooper, 1998; Childerhouse et al., 2002; Jüttner et al., 2007; Rainbird, 2004; Heikkilä 2002), is Fisher’s (1997) supply chain selection model for functional and innovative products.

ATLAS COPCO INDUSTRIAL TECHNIQUE

The Industrial Technique Business Area (ITBA) is one of four business areas within the Atlas Copco Group. ITBA develop, manufacture and market assembly equipment and material removal tools for industrial use under several brands. The main flow of physical goods goes by the distribution centre, Power Tools Distribution (PTD), in Belgium. PTD is replenished from the ITBA production sites located in Sweden, Hungary, France, Italy, Japan and China as well as from sub-suppliers of products, spares and accessories. Components and raw materials are sourced from a global supplier base located in Europe and Asia.

The current supply strategy, in terms of production planning and stock policies, used by ITBA was designed in the late 1980s and fully implemented as the distribution centre in Belgium was finalised in 1992. The main difference from the former setup is the centralization of inventory. Earlier the complete assortment was kept in stock at the local sales companies close to the market. The local stock was replenished from national warehouses that in turn were replenished from two central warehouses (Abrahamsson, 1993). The key element of the strategy is the concept of daily direct distribution (DDD) whereby customer orders for the majority of the product portfolio is to be filled from stock at one central warehouse. This strategy implies a shift from being geographically close to the market, to being close to the market in terms of short
delivery lead-time. Establishing PTD and implementing DDD decreased the average delivery lead-time from 2 weeks to 24-72 hours for the European market (Abrahamsson, 1993). Forecast based Material Requirements Planning (MRP) is used to replenish inventory of finished goods at PTD as well as of components from ITBA factories. Reorder-point (ROP) planning is used to replenish products and components scoured from suppliers. The stock policy determining whether a certain article should be a stock-keeping unit or made-to-order is based on order frequency and annual volume solely. Thus, the decision to hold inventory is not linked to the responsiveness that the customer require in terms of delivery lead-time. The basic principles of the ITBA supply strategy, briefly mentioned above, have remained essentially unchanged since the beginning of the 1990s. At that time 80% of annual sales originated from the European markets, thus the current strategy was designed accordingly (Abrahamsson, 1993). Besides the shift of sales to Asia and North America (Annual Report 2011), the nature and scope of the assortment has evolved extensively the last 20-25 years. Hence, there is a notion amongst managers that ITBA has outgrown its supply strategy.

1.2 Purpose & Aim

In the light of the notion that the ITBA product portfolio has outgrown its supply strategy, the following assignment was formulated:

*Investigate how to go about developing tailored supply chain strategies for the ITBA product portfolio.*

Thus, the research topic of this study is *market-specific supply chain strategies*. The essence of the frameworks referred to earlier is to classify the product portfolio using a set of criteria or aspects that capture relevant product and demand characteristics. The available frameworks for classifying a company’s products emphasizes different product and demand characteristics and vary in level of detail and applicability. The DWV\(^3\) classification system, originally proposed by Christopher and Towill (2000), seems to be an emerging methodological approach to define and design market-specific supply chains (Wong et al., 2006; Jüttner et al., 2007; Mendes, 2011; Godsell et al., 2011). However, what has been written about the DWV\(^3\) classification system is somewhat general in its nature and the practitioner is left without detailed instructions on how to proceed with the analysis. Hence, the purpose of this thesis is to make the DWV\(^3\) classification system more available to practitioners, and thus the aim is to illustrate how to tackle the key elements of the framework by applying it on the ITBA product portfolio.

1.3 Delimitations

The study is delimited to the Atlas Copco brand within the ITBA brand portfolio. To further narrow the scope of the study two assortments were selected from the entire ITBA product portfolio of industrial tools and assembly systems. These were the electrical tools and the air assembly tools. This selection was based on preparatory discussions with the Logistics Manager. The main reason behind the choice of these assortments in particular was that electrical tools and air assembly tools differ with respect to product line characteristics such as average product life cycle length, product technology and number of products per product line as well market price. Within the two selected assortments articles classified as spare parts or accessories is excluded to focus the scope of the study on the electric and pneumatic nutrunners and screwdrivers.

1.4 Readers’ guide

The thesis is divided in five chapters. In Chapter 2 previous research relevant to the topic of this study is reviewed, and in Chapter 3 the methodological considerations as well as the selected research methodology is presented and motivated. Chapter 4 presents the research data and analysis, and Chapter 5 where the conclusions are made is the closing chapter of the report.
2 Literature review

This chapter begins with brief review of the Supply Chain Management and Demand Chain Management concepts. The chapter continues with a description of production philosophy principles and concepts. This is followed by a review of previous research within the area of market-specific supply chain strategies. Four different frameworks for classifying products in order to develop market-specific supply chain strategies are presented and compared.

2.1 From Supply Chain Management to Demand Chain Management

Supply Chain Management (SCM) was used in academic literature for the first time in the early 1980’s (Cooper et al., 1997) by Oliver and Webber (1982). They emphasize the need for a new approach to logistics that consider the whole chain of supply as one entity, and that should be about strategic decision making with supply as the guiding objective in every link of the chain. Stock should only be used when there is a need to balance between production capacity and customer demand, and they emphasize the need for integration along the chain. They continue by saying that SCM require that whenever a functional strategy affect the outcome of some other functional strategy, the trade-off between conflicting objectives needs to be addressed and resolved (Oliver & Webber, 1982). Bechtel and Jayaram (1997) provide a review of the literature on SCM as it was in the mid and late 1990’s. They describe how the concept has evolved along four tracks that each view SCM differently. They conclude that there is a move from the pure transactional focus of moving physical goods between supply chain actors in the most efficient way, towards a focus on customer satisfaction as the starting-point for all supply chain activities. Furthermore, Bechtel and Jayaram (1997) critique the concept of SCM for placing too much emphasis on “supply” when instead, they argue, the customer demand should drive the flow in the supply chain. Christopher (1998) proposes that the term Supply Chain Management should be rephrased as Demand Chain Management (DCM) to emphasise that it is the market that should drive the chain and not the supplier. However, Rainbird (2004) concludes, in contrast to some researchers, that neither SCM nor DCM is superior to the other. Instead he proposes that SCM and DCM are seen as equal elements of the firm’s value chain representing the supply capabilities and demand requirements. Juttner et al. (2007) define DCM as the “...concept which aims to integrate demand and supply oriented processes. Demand processes are all processes at the customer or market interface, aimed at responding to customer demand through value creation. Traditionally, these processes are allied to the marketing discipline. Supply processes comprise the tasks necessary for fulfilling demand.”.

2.2 Being demand-driven

This section will describe production philosophy principles and concepts. First the fundamental principles of push and pull will be explained. After this the lean and agile concepts are described and compared. Lastly Material Resource Planning and kanban is described as two methods of implementing push and pull principles in a supply chain.

PUSH VS. PULL

Push and Pull are fundamental concepts for describing the nature of a flow of items or, as in this case, the character of a supply chain. In a pull flow the succeeding actor A₁ (e.g. operation/process) trigger activity at the preceding actor A₂ e.g. to send a batch of components forward and start to manufacture a new batch. At the same time A₂ will in turn trigger activity at the preceding actor A₃ and so forth throughout the whole flow. In a push flow the situation is
reversed as A3 pushes the finished batch of components to A2 irrespective of if A2 can start to process this batch as it arrives. If A2 is busy with another batch of components the result is that a queue will start to build up in front of A2. (Slack et al., 2007) A supply chain is demand-driven if manufacturing and distribution activities are initiated by actual customer demand and not based on forecast (Ayers & Malmberg, 2002). Thus, a forecast driven supply chain corresponds to a push flow whereas a demand driven supply chain corresponds to a pull flow (Harrison, 2003). Harrison (2003) describes a supply chain strategy that combines both push and pull principles where the first steps in the chain (e.g. raw material sourcing and component manufacturing) are based on push and the last steps are initiated by customer pull (e.g. final assembly). He argues that a mix strategy is suitable when the products have a high demand uncertainty, i.e. it is difficult to forecast future demand accurately, and there is a need to reduce cost through economies of scale. The point in the supply chain where the push flow meets the pull flow is called the push-pull boundary. This interface should be positioned so that the steps in the chain where the demand uncertainty is high are based on customer pull. Ways of implementing push and pull flows will be examined in a coming section but first the lean and agile concepts will be described.

LEAN VS. AGILE

Lean and Just-in-time (JIT) are two closely related concepts, and JIT is sometimes used as a synonym for lean as the line between the two concepts is vague. The main element of lean is to eliminate all kind of waste in every step of the production system to shape a low cost, fast and reliable production system that secure high quality in products (Slack et al., 2007). Slack et al. (2007) distinguishes lean as a philosophy of operations management and JIT as the various techniques used to implement lean in a production system. Some of these techniques are: elimination of waste through value stream mapping, ensuring visibility to reveal potential for improvements, reducing set-up times, and continuously improving the current system (Slack et al., 2007). Agility is the ability of a production system to adapt to new conditions as the market change i.e. a key characteristic of an agile supply chain is market sensitiveness. This ability enables the production system to cope with changes in demand variability i.e. how much is requested, and demand variety i.e. variations in which products are requested. (Christopher, 2000) The ability of being agile is reflected in the flexibility and speed of the production system (Slack et al., 2007), which in turn depends on the information system and logistics processes as well as organizational structures and the mind-set of employees (Christopher, 2000). Naylor et al. (1999) compare and discuss lean and agile strategies. They use eight different characteristics to describe and distinguish these both strategies. Three of the characteristics are common and equally important for both a lean and an agile supply chain. These are the use of market knowledge, integration between actors throughout the supply chain, and lead-time compression. Two of the eight characteristics are not equally important to the strategies but still important to both. Elimination of waste is of higher importance for a lean than for an agile supply chain. The reason for this is that to achieve agility some non-value adding activities will be necessary otherwise the responsiveness of the supply chain will suffer. For lean, however, elimination of waste is essential to achieve low cost products. Rapid reconfiguration is another characteristic that Naylor et al. (1999) emphasise. The ability to swiftly reconfigure production processes is essential for an agile supply chain since this ability improves the responsiveness of the chain. To reducing set-up times is one way to eliminate waste, thus a lean supply chain should embrace this. However, rapid configuration is of less importance for a lean than for an agile supply chain. Two characteristics that distinctly distinguish lean and agile supply chains are robustness and smooth demand. An agile supply chain needs to be robust to successfully respond to volatile demand. A lean supply chain, however, presupposes smooth demand as a prerequisite. Christopher (2000) argues that an agile strategy is suitable when the volume that customers demand is unpredictable, and there are numerous product variants that result in many low-volume products. In a reverse situation the volume is predictable and the product variety is low.
Under such conditions, Christopher (2000) argues, companies should adopt a lean strategy. Naylor et al. (1999) propose that companies should combine lean and agile strategies within the same supply chain. The two strategies should be used according to their characteristics. Thus, the part of the chain that experiences high variability in volume and high product variety should adopt an agile strategy. At the interface between the agile and lean part of the supply chain there will be a de-coupling point. At this point in the chain stock will be kept to absorb the volatility in demand (Naylor et al., 1999). Thus, upstream of the de-coupling point the chain will produce according to forecast i.e. the stock is replenished based on a push mechanism. Downstream of this point the actual customer demand will pull the products through the remaining steps of the chain. Thus, the part of the supply chain downstream of the de-coupling point is demand-driven. The location of the de-coupling point is based on what order-to-delivery time the customers can accept, and the production lead-times that the manufacturer can achieve. Naylor et al. (1999) argue that independently of where in the supply chain the de-coupling point is positioned, a lean design is preferable upstream this point and an agile design is preferable downstream this point.

IMPLEMENTING PUSH AND PULL PRINCIPLES

Material Resource Planning (MRP) is characterised as a push mechanism for production planning and control. The MRP strive to match the produced volume and timing of the finalized goods with forecasted demand as well as actual customer orders. At the heart of the MRP lies the master production schedule (MPS). In short, the MPS is a time-phased plan that based on demand and current available stock projects the future available stock. Depending on the initial stock level and demand in each period the available stock will eventually not be able to satisfy demand in coming periods. For these periods order quantities are created that match the demand. The MPS is then used to plan when different operations need to start in order to replenish the stock in time. There are several prerequisites for successful MRP. The calculations made to determine when different operations must start in order to deliver the finished product on time, assume that production lead-times are constant. When this is not the case the plan will not be valid anymore. Other calculations are made to specify the necessary quantity to be produced and rely on accurate stock records and correct bill-of-materials. Thus, inventory deviations result in disturbances or that unnecessary stock is produced. The main advantage of the MRP is the ability to create plans for future activities even though the product is made up of many components that need to go through several operations each. Thus, the MRP is a good choice for complex products that are infrequently requested i.e. the strangers. (Slack et al., 2007)

JIT control is, in contrast to MRP, characterised as a pull mechanism for production planning and control. JIT control aims to link all activities, internal as well as external, and assure that these activities react in response to market demand. Kanban, i.e. a card, is one way of implementing JIT control and can be set-up in several ways. Regardless of the exact implementation this is a highly visual and transparent way of controlling when a certain operation starts and how much it produces. The visual aspect of kanban is one of its main advantages. The simplest way of implementing kanban is a single-card system. In this setup a move kanban is sent from the succeeding operation to the preceding operation to request a standard amount of components. When the succeeding operation has consumed all components the move kanban is again sent to the preceding operation requesting more components. At the same time the empty box is returned to the preceding operation, which will trigger this operation to produce a standard amount of components. To secure a satisfactory outcome of JIT control resource flexibility and minimized lead-times are prerequisites. Other conditions that need to be fulfilled are that independent demand is levelled and dependent demand is synchronized. Operations that are exposed to independent demand need to be planned and controlled based on forecasted demand. The demand is then said to be levelled if the forecasted mix and volume of products is evenly distributed over a period of time. For operations that are exposed to dependent demand the required mix and volume is easier to predict since this demand depends on a known
factor. When each operation in the production system produces at the same pace the demand is said to be *synchronised*. JIT control is a good choice for simple products with high components commonality, and that are frequently requested (weekly or monthly) i.e. the runners and repeaters. Although MRP and kanban are principally different planning and control methods, the two can be combined. MRP can be used to make sure that enough materials (raw material, components, subassemblies) are available throughout the production system or whole supply chain to be requested by means of kanban when actual demand arises (Slack et al., 2007)

### 2.3 Becoming demand-driven

A number of frameworks have been presented to guide the activity of matching customers’ needs and the nature of the products with tailored production and distribution strategies. This section will review and compare four such frameworks, and one of these will be selected for further investigation. These four frameworks were selected in light of the research question and because they are presented in such detail that it would be feasible for practitioners to define a market-specific supply chain strategy by applying them.

#### LOGISTICALLY DISTINCT BUSINESS METHODS

Fuller et al. (1993) were early on to advocate the need to develop market-specific supply strategies as they argued that logistics was increasingly becoming a competitive advantage. They proposed a framework, *logistically distinct business methods* (LDB methods), where a cross-functional team is assigned the task of developing tailored logistics pipelines that meet specific customer needs. This framework starts with segmenting the customers with respect to characterising needs related to logistics. To achieve this the team needs to translate customers’ needs in a way that is relevant for the design activity. This can be more or less challenging depending on how explicit the customers can express their actual service requirements. After settling the distinct customer segments that should be targeted the team will design a logistics service offering that matches the need of each customer segment. The rearranging of physical assets and redesigning of processes according to the newly defined logistics service offerings follow this step. Finally the team tries to gain synergies between different logistics pipelines as long as these are still differentiated with respect to the customer segments’ specific needs. To support the team in defining the target customer segments, Fuller et al. (1993) propose a number of questions. The aim of these questions is to express the nature of a company’s products. Some of the aspects that these questions concern are the products’ sales volume per year, margin, required delivery lead-time and frequency, demand variability, and substitutability as well as handling aspects. The intelligence gained from answering these questions are used to cluster products to shape new pipelines that can meet the needs of the target customer segments.

#### FISHER’S MODEL

Fisher (1997) argues that products are characterised as either functional or innovative, and that the nature of the two requires completely different supply approaches. The functional products typically have a long life cycle, low contribution margin, low variety i.e. few product variants in each assortment, long expected delivery time and a rather low average stock-out rate. For this kind of products the focus should be to decrease the production cost and increase efficiency due to high pressure on prices i.e. a physically efficient supply chain. The innovative products, on the other hand, typically have a short life cycle, high contribution margin and high product variety i.e. numerous of product variants in each assortment. Furthermore the market expects fast delivery upon order and the average stock-out rate is rather high. To handle these kinds of products successfully, he argues, the manufacturer needs to be able to meet early sales and respond quickly to uncertain demand. He argues that the innovative products should be matched with a market-responsive supply chain characterised by sufficient stock of components or
finished goods, and excess capacity to buffer for uncertain demand. Other aspects that will increase the responsiveness are investments in short production lead-time, flexible suppliers and postponed product differentiation through modular design. Fisher’s (1997) framework for classifying products as either functional or innovative and then designing the supply chain according to the nature of the products is one of the most acknowledged frameworks in its genre.

**THE PROFILE ANALYSIS**

Pagh and Cooper (1998) presented a framework, the Profile Analysis, to support managers in selecting a suitable supply chain strategy among four postponement and speculation strategies. Before reviewing the Profile Analysis the four postponement and speculation strategies will be described. Pagh and Cooper (1998) defined manufacturing postponement as the act of differentiating products as late as possible in the manufacturing process. They defined logistics postponement as the act of keeping the stock of finished goods as far upstream the logistics chain as possible. The opposite of postponement is speculation i.e. building complete products based on forecast and keep these products in decentralized inventories. By mixing the manufacturing and logistics postponement they defined four generic postponement and speculation strategies. The first strategy is the full speculation strategy i.e. manufacturing speculation combined with logistics speculation. All manufacturing and logistics activities are based on forecast. The main advantage of this strategy is that economies of scale can be achieved and the main disadvantages are that inventory costs will be high and the need to scrap stock due to obsolescence and transferring stock between markets will increase. The second strategy is the manufacturing postponement strategy i.e. manufacturing postponement combined with logistics speculation. Products are completed when there is an actual customer need, not before that. However, at this point the products have already been differentiated from a logistics perspective i.e. inventory is decentralised and kept close to the market. The main advantage of this strategy is that the numbers of product variants that are stocked prior to customer orders decrease which ease inventory planning. The main disadvantage is that economies of scale are lost for the finalizing manufacturing operations. The third strategy is the logistics postponement strategy i.e. logistics postponement combined with manufacturing speculation. All manufacturing activities are based on forecast and carried out before any logistics activity. As a customer places an order the finished goods are shipped directly from a central warehouse or even from the factory to the customer. The advantages of this strategy are shorter and more reliable lead-times, decreased inventory costs while securing a high availability. However, the cost for distribution can increase due to smaller shipments and the use of faster modes of transport. The fourth strategy is the full postponement strategy i.e. combining manufacturing postponement with logistics postponement. In its most extreme form this strategy implies that all manufacturing and logistics activities are performed upon customer order. The main advantage of this strategy is that inventory levels through out the chain can be decreased. However, to keep the delivery lead-times low the first manufacturing steps will probably need to be based on forecast.

The first step when applying the Profile Analysis is to define which aspects of the assortment, the customer needs and the production set-up that should be used. These aspects should express the level of postponement and speculation needed in the supply chain. Pagh and Cooper (1998) suggest a number of aspects that should be considered to evaluate which strategy is the most preferable. These are product life cycle, monetary density, value profile, product design characteristics, delivery time, frequency of delivery, demand uncertainty, economies of scale, and special knowledge. They emphasize that these are just some of the possible aspects that could be included, and stress the need to choose a sufficient number of aspects that are relevant for the choice of postponement and speculation strategy. The Profile Analysis is prepared by matching the four strategies with each aspect i.e. for each aspect specify when a certain strategy should be used. The aspect of product life cycle and delivery lead-time is used as an example. During its life cycle a product goes through four phases: introduction, growth, maturation, and
decline. During the introduction phase of a product’s life cycle the full speculation strategy is most preferable. This is also the most suitable strategy to secure a short delivery lead-time. In its growth phase the manufacturing postponement strategy should be applied and as the product matures and declines the strategy will shift from logistics postponement towards full postponement. If customers can accept a long delivery lead-time the full postponement strategy is feasible otherwise there will be a need for speculation i.e. the logistics postponement strategy might be a better option. When this is repeated for all aspects a matrix is created. The next step of the Profile Analysis is to profile or evaluate the need of postponement and speculation using the matrix. This is carried out by assessing the current requirements on the supply chain posed by the market, the assortment or other circumstances with respect to each aspect. For example, if the majority of the assortment is in its growth phase and customers require short delivery lead-time, then the manufacturing postponement strategy seems feasible.

THE DWV3 CLASSIFICATION SYSTEM

The DWV$^3$ classification system was originally created by Christopher and Towill (2000). This classification system was later presented by Childerhouse et al. (2002) as a part of a framework aimed for the development of focused demand chains according to lean and agile principles. The scope of this framework included the initial formulation of the overall demand chain strategy, classification of the product portfolio – and related design of manufacturing and distribution operations – and finally implementation of the resulting focused demand chains. Building on this work Christopher et al. (2009) reworked the framework into a business process improvement tool, which they called value stream classification, by removing the strategy formulation step as the starting point of the analysis. They also emphasized the importance of utilizing the competence of a cross-functional team through out the whole process of identifying; designing and implementing focused demand chains. However, the core of the framework – the DWV$^3$ classification system itself – remained essentially unchanged.

The basic idea of the DWV$^3$ system is to classify the product portfolio in a way that products with similar demand characteristics are grouped together. Applying the DWV$^3$ system, this is achieved using five classification variables: duration of life cycle, time window for delivery, volume, variety, and variability. (Childerhouse et al., 2002) These classification variables were selected from a pool of variables that previous research on segmentation had proposed. Childerhouse et al. (2002) motivate why these five demand characteristics in particular were chosen as classification variables. Their reasoning is briefly summarized below as well as relevant contribution by other researchers. Duration of life cycle is included due to at least two reasons: (1) to capture the expected life cycle length of a product and (2) the current life cycle phase of a product (Childerhouse et al., 2002). Fisher (1997) refers to innovative products with short life cycle and functional products with long life. He argues that production and distribution of an innovative product, unlike a functional product, will need to be ramped up quickly and maintained at a high volume during the product’s short life. Aitken et al., (2003) emphasize that as a product move from one life cycle phase to the next the demand characteristics as well as the customer needs and requirements on that product is likely to change. This implies that a supply chain strategy that was suitable during the introductory phase might not be suitable as the maturity level peak and the product start to decline. Hence, the manufacturer needs to revise the supply chain strategy at regular interval through out a product’s life cycle. The time window for delivery is included to express the customers’ responsiveness requirements upon the manufacturer in terms of desired delivery lead-time. Based on this knowledge and the internal lead-times the need of stock and positioning of this stock – at component level, as subassemblies or as finished goods – can be evaluated. Volume is a key attribute of demand that can be used to divide a product range a long a spectrum from high to low running products – i.e. distinguishing the runners, repeaters and strangers from each other. This differentiation of products is, among others, useful when deciding which planning and control method that should be used (Slack et
al., 2007). Variability captures the aspect of demand fluctuations. This is the main driver of the need for stock and extra capacity to cope with sudden increases in demand. (Childerhouse et al., 2002) The last classification variable, variety, expresses the extent of variants within a product range. This is an important aspect to capture since an increased number of variants tends to increase the complexity of planning and the number of changeovers needed.

For each classification variable one or more codification levels i.e. limits need to be defined. A single codification level allows a product to be classified as less than or higher than the chosen level i.e. HIGH/LOW. Using two codification levels allows a product to be classified into one of three possible categories i.e. HIGH/MEDIUM/LOW. The activity of grouping products with similar demand characteristics is referred to as cluster analysis, and is an iterative process where the number of codification levels to be used as well as the limits need analytic experimentation to be defined. The first run of the cluster analysis will most likely scatter the product portfolio over far too many clusters to be feasible for supply chain design. By adjusting the limits and number of codification levels as well as grouping adjacent clusters together a realistic number of distinct market-specific supply chains may be defined. (Christopher et al., 2009)

Childerhouse et al. (2002) used an industry case to verify the DWV classification system, and in this section the highlights of what they found is presented. The company that they studied was a lighting company that went through a two-step re-engineering programme. Before this programme the company used a traditional push approach with MRP to plan and control the internal flow of products. Productivity was low since products were not differentiated on volume or on the frequency by which they were requested. There was also a lot of waste through out the company’s production system. To improve the situation the company decided to develop tailored demand chains that matched each category of the product portfolio. In this first step, volume and the customer’s responsiveness requirements were given the greatest impact on the product classification. The final result was two focused demand chains: one for the low volume and low responsiveness products operated by MRP and one for the high volume and high responsiveness products operated by kanban. The development of two separate demand chains was followed by a reduction of the supplier base with more than 50%. The combined result of the first step was lowered costs, shorter order-cycle, shorter product development and increased sales. There were mainly two challenges that led the company to revise its demand chain strategy. The products had become commoditized and the company had a hard time competing on prize with low labour cost countries. The other challenge was to meet the need of customized products. The solution to these challenges was to further segment the product portfolio by creating four segments instead of two. The main differences were that duration of life cycle was used as a first differentiator to filter out all the new products that needed a separate design and build flow. The low volume and low responsiveness segment from the first re-engineering step, excluding the new products, was kept and still operated by MRP. The high volume and high responsiveness segment from earlier was divided into two new segments. For the high volume and low variant products a strategy based on kanban control and finished goods stock was selected to achieve short delivery times and as low cost as possible. For the high volume and high variant products a postponement strategy was selected to achieve high availability of a broad assortment. The decoupling point was located at the subassembly level, and upstream this point a lean strategy was used. With the resulting demand chain strategy, made up of four separate flows, products were now treated according to their demand characteristics. (Childerhouse et al., 2002)

**DISCUSSION OF THE FOUR FRAMEWORKS**

The four frameworks presented above all aim to support the activity of developing differentiated supply chain strategies. The main focus in these frameworks is the classification of a company’s product portfolio. This classification is made with respect to a number of product and demand characteristics, and aim to group similar products together. The four frameworks propose different sets of characteristics to capture the nature of the product portfolio. The level of detail
used to describe the preferred supply chain strategies, and explain how companies should go about matching these strategies with a characteristic group of products also differ among the frameworks.

Fuller et al. (1993) proposed a number of questions that capture a wide variety of product and demand characteristics. They provide a step-by-step methodology, the LDB methods, and emphasize that a cross functional team should be involved. However, they don’t describe a distinct supply chain strategy that they link to the characteristics used to classify the products. Although their contribution is important it is not as neatly presented as the framework presented by Fisher (1997). He proposes seven aspects of demand that can be used to characterise a product as either functional or innovative. Fisher (1997) also describes two fundamentally different supply chain strategies: the physically efficient and the market-responsive supply chain. He visualizes his model with a matrix, and argues that functional products should be matched with an efficient supply chain and innovative products with a responsive supply chain. Fisher’s Model is concise and establishes a fundamental principle regarding the nature of a product and its associated supply chain. However, the supply chain strategies proposed by Fisher lack detailed descriptions. Pagh and Cooper (1998) propose nine determinants that capture the characteristics of the product, the demand and the market as well as the manufacturing and logistics system. They present, rather detailed, four supply chain strategies based on postponement and speculation principles. To support the activity of matching a company’s product portfolio with these strategies they present an analytic tool, the Profile Analysis. This framework provides a clear link between possible supply chain strategies and the product and demand characteristics used to classify the product portfolio. However, to classify products with respect to nine characteristics create an extensive framework, which decrease its applicability. Childerhouse et al. (2002) present an analytic tool, the DWV$^3$ classification system, to support the activity of grouping similar products with respect to five classification variables. The DWV$^3$ system is based on lean and agile principles, and the authors illustrate how clusters of similar products are linked to suitable manufacturing and distribution strategies based on these principles. The DWV$^3$ system seems to be an emerging methodological approach to define and design market-specific supply chains as several researchers (Wong et al., 2006; Jüttner et al., 2007; Mendes, 2011; Godsell et al., 2011) has referred to or built on the work of Christopher and Towill (2000) and Childerhouse et al. (2002). Wong et al. (2006) studied a toy manufacturer to investigate what classification determinants are suitable for a supply chain that is characterised by products with seasonal and volatile demand. They developed a new differentiation model, building on the DWV$^3$ system, to support the toy manufacturer in defining a responsive supply chain for its products. The original classification variables were evaluated amongst others and four determinants were selected: demand variability, forecast uncertainty, time window of delivery, and contribution margin. Godsell et al. (2011) applied a revised version of the DWV$^3$ system on a global producer of fast moving consumer goods that sought to develop a segmented supply chain strategy. They decided to base the segmentation on volume and variability only since the other three classification variables were not that relevant for the studied supply chain. After running the analysis they conclude that a lean strategy matched 70% of the manufacturer’s product portfolio as these products had relatively high volume and low variability. Among the four frameworks the DWV$^3$ system is found to have the highest applicability for developing market-specific strategies due to a combination of factors:

Few product and demand characteristics are used to classify the products.

Since rather few and well-grounded classification variables are used the complexity of the analysis is reduced without losing essential information.
The use of lean and agile principles, independently and combined, is advocated. The DWV³ system was developed in the light of lean and agile principles. This provides a solid foundation that supports the design of differentiated supply chain strategies without dictating the ultimate strategies.

The DWV³ system is adaptable to company specific conditions. The sequencing of the classification variables and codification of each variable is not predefined. The fact that these two aspects is part of the analysis makes the DWV³ system adaptable to company specific conditions. Although the five classification variables are generic and the authors argue that they hold for many industries (Childerhouse et al., 2002), there will be occasions when other aspects are more relevant. In that case one or several of the original variables will need to be substituted. Wong et al. (2006) and Godsell et al. (2011) show that it is fully possible to customize the DWV³ system in this way, which increases its adaptability.

The above stated characteristics are the reason why the DWV³ system was chosen for further investigation based on the assignment presented in Chapter 1.

2.4 Research problem & questions

Christopher et al. (2009) emphasize the need for more industry cases that apply and evaluate the DWV³ classification system; especially they highlight the relative importance of the five classification variables i.e. the sequencing of the classification variables as an area for future research. After reviewing what has been written about the DWV³ classification system it is clear that the practitioner is left without detailed instructions on how to complete the cluster analysis. Thus, the assignment presented in Chapter 1 is reformulated into the research problem of this thesis, and defined in the following way:

How can manufacturing companies use the DWV³ classification system to evaluate the opportunity for a market-specific supply chain strategy?

As stated in Chapter 1, the aim of this thesis is to illustrate how to tackle the key elements of the framework by applying it on the ITBA product portfolio. The key elements of the DWV³ classification system that is not explicitly described in the literature is (1) how to measure each classification variable, (2) how to define a suitable limit for each measure in order to classify the products and (3) how to reason when sequencing the classification variables in the clustering analysis. Hence, the research questions of the study is:

1. What measures should be used to express each classification variable?

2. What limit should be used for each measure?

3. What sequencing of the classification variables should be applied?

The production philosophy concepts reviewed in this chapter will be used as the basis for investigating and exploring the DWV³ system, and constitute the basis for answering the research questions.

2.5 Chapter summary

Chapter 2 has provided a brief review of SCM and DCM as the underlying concepts of the theory of market-specific chain supply strategies. Evolution of the SCM concept has lead to a situation, where it is considered favourable that the market demand for products should control the supply chain flow rather than the supply chain itself pushing goods to the market. Previous research within the area of market-specific supply chain strategies has been reviewed. Several
researchers emphasize that there is a possibility for companies to achieve customer satisfaction as well as securing efficient operations by arranging its supply chain according to the demand characteristics of the products. Four different frameworks for classifying products in order to develop market-specific supply chain strategies have been presented and compared. Among these four frameworks the DWV\(^3\) system was found to have the highest applicability, and thus chosen for further investigation based on the assignment presented in Chapter 1. The evolution of the DWV\(^3\) system as a methodological approach for designing market-specific supply chains has been described, and the different elements of the framework have been explored. However, the literature concerning the DWV\(^3\) system leave the practitioner without detailed instructions on how to proceed with the analysis. Thus, the assignment presented in Chapter 1 was reformulated into the research problem of this thesis, and defined in the following way: \textit{How manufacturing companies can use the DWV}\(^3\) classification system to evaluate the opportunity for a market-specific supply chain strategy}. It was recognised that there are three key elements in the DWV\(^3\) system that are critical for its applicability. Based on these key elements the research problem was further specified into three research questions. What has been written about production philosophy concepts in this chapter will be used as the basis for analysing the case study findings and answering the research questions in Chapter 4. Before that, the selected research methodology and research design as well as the methodological considerations is presented in Chapter 3.
3 Research methodology

This chapter describes and adapts the selected research methodology and research design. The phenomenon under investigation is specified and the research activities of the study are outlined. The methods used to collect and process data are described, and the methodological considerations made concerning the reliability and validity of the findings are presented.

3.1 Introduction

Throughout history two main research paradigms of different origins have evolved, positivism and interpretivism. Those paradigms differ in their fundamental assumptions and ultimately which methodologies they are associated with. Thus, the paradigm that the researcher chooses to conform to will restrict how the study will be carried out and provide guidance on what methodology and methods to apply (Collis & Hussey, 1997). Collis and Hussey (1997) describe three philosophical assumptions that distinguish the two paradigms from each other. One by one those assumptions will be briefly mentioned here. The first differing assumption relates to the view of the nature of reality, the ontological assumption. Interpretivists argue that reality is subjective and that there are multiple realities because different people have their own view of reality. Positivists argue the opposite and say that reality is objective and thus there is only one reality. The second differing assumption is about whether the researcher’s values affect the study of a certain phenomena, the axiological assumption. Positivists consider the research object being studied completely distanced from the person doing the research and therefore the results will not be affected by the researcher’s values and actions. Interpretivists argue the opposite and say that the researcher’s values will influence the result since the researcher is not separated from the objects being studied. What is considered as valid knowledge, the epistemological assumption, is the third differing assumption. Positivists, unlike interpretivists, argue that a phenomenon has to be measurable for a researcher to be able to conclude valid knowledge about that phenomenon. Collis and Hussey (1997) argue that the positivistic and interpretivistic research paradigm should be viewed as extremes on a spectrum and that any specific research approach is likely to have elements of both paradigms. They also state, that in addition to the basic assumptions the dominating paradigm within the specific area of research as well as the nature of the research question will affect what paradigm will be guiding a specific study. There are a number of common research methodologies associated with the main paradigms that are briefly described in figure 3.1 and figure 3.2.

Figure 3.1. Common research methodologies under the positivistic paradigm (Collis & Hussey, 1997).

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental studies</td>
<td>Investigate how the independent variable influences the dependent variable in order to describe the relationship between these variables.</td>
</tr>
<tr>
<td>Surveys</td>
<td>Collect data from a sample with the aim to generalize the results to a population.</td>
</tr>
<tr>
<td>Cross-sectional studies</td>
<td>Collect data about a certain phenomena in different contexts under the same period of time in order to investigate similarities between the different contexts.</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>Observe and analyse a phenomena over a long period of time.</td>
</tr>
</tbody>
</table>
Table 3.2. Common research methodologies under the interpretivistic paradigm (Collis & Hussey, 1997).

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermeneutics</td>
<td>Interpret and understand text with respect to a historic context.</td>
</tr>
<tr>
<td>Ethnography</td>
<td>Observe and understand human activity through participant observation.</td>
</tr>
<tr>
<td>Participative enquiry</td>
<td>Participants act as co-researchers to the researcher and are involved in data collection as well as analysis.</td>
</tr>
<tr>
<td>Action research</td>
<td>The researcher initiates change and study the results.</td>
</tr>
<tr>
<td>Case studies</td>
<td>The researcher uses several methods to gain a thorough understanding of a single phenomenon (case).</td>
</tr>
<tr>
<td>Grounded theory</td>
<td>A theory is created inductively from collected data.</td>
</tr>
<tr>
<td>Feminist, gender and ethnicity studies</td>
<td>The researcher investigates a phenomenon from a feminist, gender or ethnicity perspective.</td>
</tr>
</tbody>
</table>

### 3.2 Selected research methodology

A single-case study design was chosen as a suitable research approach for this thesis. The following reasoning is the basis for this decision. First of all, a case study is a suitable research methodology for gaining in-depth understanding of a delimited area of interest (Collis & Hussey, 1997) which was the ambition in this thesis. Furthermore, Scapens (1990) emphasizes five types of case studies intended for different research purposes: descriptive, illustrative, experimental, exploratory, and explanatory. These types of case studies are not mutually exclusive but may be combined. Scapens (1990) proposes that an illustrative case study should be used when the researcher wants to demonstrate new practices, and that an experimental case study should be used to evaluate the benefits and investigate the difficulties of new practices and techniques. The purpose of this thesis had an evaluative and demonstrative nature, which matches an experimental and illustrative case study as defined by Scapens (1990). Secondly, Yin (2008) argues that a single-case study design is appropriate when the objective is to understand and explain an entity that may be considered representative amongst similar entities. Ultimately this enables generalizable results and that knowledge about the studied case can be transferred to similar cases. Given the nature of the purpose of this thesis a single-case study design seemed reasonable. Finally, a case study design is a frequently used method within the area of research concerning market-specific supply chain strategies as well as within the broader area of research related to DCM, e.g., Childerhouse et al., 2002; Wong et al., 2006; and Heikkinen, 2002.

### 3.3 Case study design

The application of the DWV³ system to the ITBA product portfolio was considered as the phenomenon under investigation, the case, of this study. The case study was divided into four steps:

1. Collect data and establish a database to be used in the study.
2. Propose a preliminary set of measures linked to the classification variables.
3. Evaluate the preliminary measures to define the final set of measures and propose limits for each measure.
4. Perform cluster analysis to define a suitable sequencing of the classification variables.
3.4 Data collection and processing

QUANTITATIVE AND QUALITATIVE DATA

Collis and Hussey (1997) define *quantitative* data as research data in a numerical form and *qualitative* data as research data in a nominal form such as words. These two types of data may be collected irrespective to which research paradigm the study is performed under. However, in an interpretive study research data need to be rich in detail to support a thorough understanding of the phenomena under study, whereas in a positivistic study the data need to be very precise to ensure that the subsequent analysis is accurate. Because of this, qualitative data collected in a positivistic study, unlike an interpretive study; need to be quantified to enable statistical analysis. There are two key aspects of research data that the researcher needs to be aware of. These are *data integrity* and *results currency*. High results currency increases the level of generalizability of the results whereas high level of data integrity decreases the risk of error and bias in the results. An interpretivistic study tends to produce results with high level of data currency while the methodologies used in a positivistic study will provide results with high level of data integrity. (Collis & Hussey, 1997)

DATA COLLECTION

*Quantitative data*

Two sets of quantitative data were collected, (1) demand data and (2) product master data. The demand data needed for the analysis was retrieved from three different sources, figure 3.4.

**Figure 3.4. Demand data was collected from three different sources.**

<table>
<thead>
<tr>
<th>Data source</th>
<th>Key data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sales data at Customer Centre level</strong></td>
<td>Sales data for 2011 were retrieved from a business intelligence application used by the Marketing Departments. Invoiced amount and quantity, product number and customer code at order number level.</td>
</tr>
<tr>
<td><strong>Customer segment data</strong></td>
<td>An enquiry was sent to the Customer Centres to collect segment information for each customer. Customer Centre code, segment code and segment description at customer code level.</td>
</tr>
<tr>
<td><strong>Sales data at Distribution Centre level</strong></td>
<td>Sales data for 2011 were retrieved from the data warehouse originating from the ERP system. Ordered quantity, product number and order date at order line level.</td>
</tr>
</tbody>
</table>

Product master data such as name, description, article type, assortment and range information, date of creation, and date of deactivation was retrieved from the data warehouse originating from the ERP system.

*Qualitative data*

Two sets of qualitative data were collected, (1) descriptive information concerning the ITBA supply chain set-up, and (2) descriptive information about the products as well as the customers’ responsiveness requirements for each assortment included in the study.

All qualitative data was collected through interviews. The interviewees were presented with the purpose and aim of the study, and asked to share their understandings and opinions related to various aspects of the study. Some interviewees were also presented with initial findings and facts as well as open-ended questions prepared beforehand see appendix 1.
DATA PROCESSING

Product master data

For each assortment included in the study the product numbers of interest were filtered out and product range categories were formed. The resulting product master data were analysed as well as used in preparation of the sales data.

Sales data at Customer Centre level & Customer segment data

To prepare the collected sales data at Customer Centre level for analysis the irrelevant data was cleared out in accordance with the scope and interest of the study using the product master data lists. The remaining data was combined with the customer segment data to get customer segment information for every order in the sales data.

Sales data at Distribution Centre level

The sales data at Distribution Centre level was prepared for analysis using the product master data lists to clear out the irrelevant data.

3.5 Reliability and validity

Research findings can be characterised with respect to its credibility by two key concepts. Those are the reliability and the validity of the findings. Collis and Hussey (1997) have defined reliability in the following way:

“Reliability refers to the absence of differences in the results if the research were repeated”. (p. 64)

Thus, reliability is about the repeatability of the research and that the same result is obtained every time the study is repeated. The reliability of this thesis has been assured by providing detailed descriptions on what and how quantitative data was collected. In addition, statements and opinions made by interviewees have been reproduced to avoid inaccurate interpretation. Collis and Hussey (1997) have defined validity in the following way:

“Validity is the extent to which the research findings accurately reflect the phenomena under study”. (p. 65)

Thus, if the researcher is able to actually capture the entity that the study aims to investigate the study will have high validity. Yin (2008) proposes a number of tactics to secure high validity of the research findings, some of which will be used in this thesis. To assure high validity of this thesis several employees with various assignments and responsibilities within the company has been interviewed. The interviewees has also been asked to review and comment on text based on their response. The validity has been further strengthened by explicit justification of choices made throughout the thesis to eliminate unfounded conclusions.

3.6 Chapter summary

Chapter 3 has provided a short review of available research methodologies and underlying concepts, followed by a presentation and motivation of the selected research methodology and design. A single-case study design was found to be the most preferable research methodology. The application of the DWV system to the ITBA product portfolio was considered as the case, and the study was arranged in four separate steps, (1) collect data, (2) define preliminary measures, (3) evaluate measures and define limits, and finally (4) perform the cluster analysis and define sequencing. Finally, the collection and processing of research data was described as well as considerations made to reassure reliability and validity of the findings. In Chapter 4 the case study findings will be presented and analysed.
4 Case study

This chapter begins with a presentation of the preliminary set of measures proposed for each classification variable. An evaluation of the preliminary measures to define the final set of measures follows this as well as a proposal of preliminary limits. In the last section the final set of measures are used in the cluster analysis and the preliminary limits and sequencing of the classification variables are evaluated.

4.1 Preliminary set of measures

The findings presented in this section are related to the first research question:

(1) What measures should be used to express each classification variable?

Based on the literature review and initial exploration of product master data and demand data, one or more preliminary measures for each classification variable are proposed and motivated.

THE TIME WINDOW FOR DELIVERY

To express the responsiveness requirements placed on the manufacturer by the customer the desired delivery lead-time is proposed as a measure. In combination with the production lead-time of components and final products the wanted delivery lead-time will determine at what point inventory should be kept in order to meet customers expectations on delivery performance. Hence, customer preferences on delivery lead-time are crucial knowledge as the manufacturer designs its supply chain. The study was delimited to focus on the Atlas Copco branded electrical tools and air assembly tools assortments. The ITBA product offering for electric tools and air assembly tools include a large number of screwdrivers and nutrunners for industrial tightening. Several product lines are offered to meet the divers needs of the customer base regarding tool performance in terms of precision, mobility and torque etc. The majority of these product lines are within the scope of this study. It is clear, from the initial investigation, that it is hard to specify a desired delivery lead-time for each and every product. Thus, the lead-time requirement on a single product might need to be derived from the general lead-time requirement for the range or assortment that the product belongs to.

VOLUME

Demand volume expressed as the annual volume per product is a measure that distinguishes the high running from the medium and low running products and ultimately the volume needed at component level. Aggregated annual volume per product range or assortment will provide the manufacturer with important information about long term capacity needs in the final assembly and component manufacturing as well as at suppliers. Thus annual volume per product is proposed as a measure of demand volume.

DURATION OF LIFE CYCLE

Since the demand volume, variability and variety characteristics are likely to change throughout the product’s life cycle (Aitken et al., 2003); it is useful to differentiate the products with respect to which life cycle phase they are currently in. Therefore the current life cycle phase as in introduction, growth, mature and decline phase is proposed as a measure to classify products with respect to duration of life cycle.
VARIABILITY

The quantity on each order line (OL), the number of OLs, and the date of request of these OLs define the demand pattern for a product. The OL quantity define how much of the product is needed, the number of OLs define how many times there is a demand for the product during a period and the OLs’ date of request define how often there is a demand for the product during this period, figure 4.1.

Figure 4.1. Three aspects characterise a product’s demand pattern, the quantity on each OL, the number of OLs and the date of request of these OLs.

<table>
<thead>
<tr>
<th>Aspect of demand pattern</th>
<th>Key data</th>
<th>Measure of demand variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much</td>
<td>Quantity on OLs</td>
<td>CV Qty</td>
</tr>
<tr>
<td>How often</td>
<td>Date of request for OLs</td>
<td>CV Req</td>
</tr>
<tr>
<td>How many times</td>
<td>Number of OLs</td>
<td>OL frequency</td>
</tr>
</tbody>
</table>

The aspect of “how much” can be characterised by the average OL quantity and the standard deviation from the average OL quantity. However, the standard deviation is only meaningful in the light of the average. To achieve this the standard deviation is divided by the average to calculate the coefficient of variation (CV), which is a relative measure of the variability in OL quantity. The CV in OL quantity (CV Qty) can be used to compare products with respect to variability in OL quantity although the products have disparate average OL quantity. Thus, the CV Qty is proposed as a measure of demand variability since it can be used to differentiate products that have steady OL quantity from the products that have fluctuating OL quantity, figure 4.1. The aspect of “how often” can be characterised by the average time between requests and the standard deviation from this average. The variability of the time between requests ought to be expressed with the coefficient of variation according to the reasoning above. Hence, the CV in time between requests (CV Req) can be used to compare products with respect to variability in the time between requests although the products have disparate average time between requests. Thus, the CV Req is proposed as a measure of demand variability since it can be used to differentiate products that have steady inflow of OLs from products that have irregular inflow of OLs, figure 4.1. The aspect of “how many times” can be characterised by the OL frequency i.e. the number of OLs during one year. Defined in this way there is no meaningful measure of variability in OL frequency on single product level. However, the OL frequency is a useful measure of the demand variability since it can be used to differentiate the frequently ordered products from the infrequently ordered.

VARIETY

Demand variety expressed as the number of products per assortment and/or product range is a measure that captures the challenge that the final assembly faces. As the number of products increase so does the demand variety and the associated complexities. One of the associated complexities of high product variety is the increased number of components that are needed to create this product variety. Thus, it is important to develop a measure that captures the variety at the component level. Any component is used according to one of the following three cases:

1. Used in multiple products across several product ranges and/or assortments
2. Used in multiple products but limited to a specific product range and/or assortment
3. Used in a single product

Components from the first group will inherit demands from multiple products and are therefore likely to be high running components. Components from the second group are also likely to be high running components since demand is inherited from multiple products. However, since the use of those components are limited to a specific range the demand at the component level is
likely to decrease as the product range age and products are deactivated. A component from the third group will inherit demands from a single product, which results in low annual volume for the component if the product is a low runner. Based on this understanding of how components are used the variety index per product is proposed as a measure of demand variety.

\[
\text{Variety index} = \frac{\text{the number of components in product } A}{\text{sum}(\text{the number of products sharing component } X_i)} \times 1000
\]

for all components \(X_1\) to \(X_n\) in product \(A\)

As the number of components used to build the product increase and the number of other products sharing each of the used components decrease the variety index will increase. High product variety is reflected in a high variety index i.e. the product is built from many components that each is shared with few other products.

**SUMMARY: PRELIMINARY MEASURES**

In total 8 preliminary measures are proposed in above sections, figure 4.1. Two measures of demand variety and three measures of demand variability are proposed for further evaluation in order to define a single measure for each classification variable. For duration of life cycle, time window for delivery and demand volume one measure each is proposed, figure 4.2. These measures will be further explored and motivated in the coming sections, and suitable limits for each classification variable will be proposed based on the electric tool and air assembly tool assortments.

**Figure 4.2. Preliminary measures for each classification variable based on the literature review and initial analysis of product master data and sales data.**

<table>
<thead>
<tr>
<th>Classification variable*</th>
<th>Measure</th>
<th>Level of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of life cycle</td>
<td>Current life cycle phase</td>
<td>Product number</td>
</tr>
<tr>
<td>Time window for delivery</td>
<td>Desired delivery lead-time</td>
<td>Product assortment/range/number</td>
</tr>
<tr>
<td>Volume</td>
<td>Annual volume per product</td>
<td>Product number</td>
</tr>
<tr>
<td>CV** in OL quantity (CV_{OL})</td>
<td></td>
<td>Product number</td>
</tr>
<tr>
<td>CV** in time between requests (CV_{Req})</td>
<td></td>
<td>Product number</td>
</tr>
<tr>
<td>OL frequency</td>
<td></td>
<td>Product number</td>
</tr>
<tr>
<td>Variety</td>
<td>No. of products</td>
<td>Product assortment/range</td>
</tr>
<tr>
<td>Variety index</td>
<td>Product number</td>
<td></td>
</tr>
</tbody>
</table>

* According to the DWV3 system (Childerhouse et al., 2009)

** Coefficient of variation = standard deviation / average
4.2 Evaluation of preliminary measures

The findings presented in this section are related to research question 1 and 2:

1. **What measures should be used to express each classification variable?**
2. **What limit should be used for each measure?**

The first research question is addressed as the preliminary measures for each of the five classification variables are evaluated and a final set of measures is proposed. The second research question is addressed as preliminary limits for each measure are proposed based on the product and demand data for the studied assortments.

**INTRODUCTION**

Based on the initial exploration of the research data there seems to be two ways of reasoning to codify a product with respect to any of the classification variables. The first approach is to use a measure at the product level to assign the status of a product directly. The second approach is to use a measure at the range (or assortment) level and have all products in that range inherit the status of the range. The disadvantage of the second approach is that the resolution of the cluster analysis will decrease when products are codified at an aggregate level. Hence, the first approach is preferable. The aim of the DWV$^3$ system is to group products with similar demand characteristics in order to match these with tailored supply chain strategies. Thus, each classification variable needs to be expressed by a measure that capture the product’s demand characteristics in a way that is relevant to the choice of supply chain strategy. The above arguments can be summarized in two guiding principles for evaluating and defining the final set of measures:

1. **As far as possible use measures at the single product level.**
2. **Use measures that express each classification variable in a way that is relevant to the matching of demand characteristics and supply chain strategy.**

Throughout the analysis it is assumed that the factories (workshop and assembly units) and the distribution centre are operating 250 days a year with five-day weeks.
TIME WINDOW OF DELIVERY

There are three criteria to rely on when determining the desired delivery lead-time, two criteria on product level and one criterion on order level, figure 4.3. These criteria will be discussed more in the following section. In general there is a link between what delivery lead-time the customer expect and the level of customization. The more customized a product is the longer is the customer prepared to wait, at least to a certain limit. The pneumatic tool ranges LUM, LMS, EP and LTV are positioned at the “Standard tool” end of the spectrum whereas the LTC and LTO ranges as well as some LUM models have a higher level of customization that position them towards the “Customized tool” end of the spectrum. The LTP, LMP and EPP ranges are positioned towards “Standard tool” but the customer can accept a longer delivery lead-time compared to the previously mentioned pneumatic tool ranges, especially for the models with higher torque. (interview Mathieu Legars)

Figure 4.3. There are two criteria to determine the desired delivery lead-time at product level and one criterion at OL level.

<table>
<thead>
<tr>
<th>Delivery lead-time criterion</th>
<th>Standard tool (0-4 w)</th>
<th>Customized tool (8 w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard vs. customized tool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torque performance</td>
<td>Low torque tool (0-4 w)</td>
<td>High torque tool (6-8 w)</td>
</tr>
<tr>
<td>Order type</td>
<td>Break down order (0 w)</td>
<td>Daily business order (use torque criterion)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Project order (8-12 w)</td>
</tr>
</tbody>
</table>

For the electric tool assortment the torque performance of the tool can be used to differentiate the delivery lead-time requirement on product level. For low torque tools, 30-50 Nm up to 200 Nm, the customers (in general) expect delivery in 0-4 weeks. For high torque tools, above 200 Nm, the customers (in general) can accept a delivery lead-time of 6-8 weeks. The customer segments Final Assembly, Aerospace and Appliance all use low and medium torque tools to cover their basic needs whereas Offroad use high torque tools in their every day operations. The result is that one and the same tool is expected to have short delivery lead-time from Offroad point of view whereas other customer segments can accept a longer delivery lead-time. Hence, the torque criterion is not always a clean-cut way of differentiating products regarding desired delivery lead-time. Based on this insight the delivery lead-time requirement on product level could be approached from a customer segment perspective. Referring to the “typical” customer for each customer segment, there are known differences between segments on how and what product the typical customer uses in its operation. Based on this, one could decide to meet the requirements of the most dominating segment for each product number, range or assortment. With thousands of products and numerous customers the task of defining and maintaining the desired delivery lead-time on product level is simply not feasible. Although it is possible to describe the general responsiveness requirements on product range or assortment level this information may not be specific enough to be used when for example deciding whether a certain product should made-to-stock or assembled-to-order.

In many cases, especially for the electric tools, the delivery lead-time requirement for a specific tool is not static but instead it depends on the nature of the order i.e. the reason why the order was placed. There seem to be at least three kinds of different order types. These are the “break-down orders”, the “daily business orders” and the “project orders”. The break-down order has the highest level of urgency i.e. the customer needs immediate delivery in order to minimize down-time. The daily business order is a “regular” order i.e. the customer places an order and expects delivery as soon as possible but there is no crisis. In this case the torque criterion is a good indicator of which delivery lead-time the customer expects. A project order is an order
where the actual tool is sold as an element of a system (including e.g. torque arms and other accessories). In this situation the customer can accept a longer delivery lead-time, approx. 8-12 weeks. Unfortunately it is not possible to say what type of order a specific order is based on the sales data; furthermore, in the cluster analysis it is necessary to specify the desired delivery lead-time on product level. Thus, the “Order type” criterion is not possible to use to differentiate products with respect to desired delivery lead-time. Instead this is achieved using the “Standard vs. customized tool” and “Torque performance” criteria as far as possible. When necessary the product is assigned its level of required responsiveness based on the responsiveness requirements of the range it belongs to or the current delivery lead-time. HIGH responsiveness requirement corresponds to a desired delivery lead-time of 0 weeks, MEDIUM corresponds to 0-4 weeks and LOW corresponds to 6-8 weeks, figure 4.4.

**Desired delivery lead-time**

![Graph showing desired delivery lead-time](image)

Figure 4.4 The desired delivery lead-time.
The annual volume at product level range from 1 to 1988 pcs during 2011. It is clear that the Pareto principle applies to the sales data as 80% of the total volume of 2011 originates from 20% of the product numbers sold during this period, figure 4.5.

![Annual volume per product](image)

Figure 4.5. Annual volume per product and accumulated annual volume as share of total annual volume. It is clear that the Pareto principle applies to the sales data as 20% of the products cause 80% of the sold volume.

The annual volume per product for the high running 20% of the products ranges from 71 to 1988 pcs, figure 4.6. Given the assumption of the number of working days per year a 71-pcs/year product will be assembled 1-2 times per week in average. The remaining 80% of the products can be divided in two groups. The 30% of the products that cause 16% of the sales and the 50% of the products that cause 4% of the sales, figure 4.6. The annual volume per product dividing these two groups is 12 pcs/year. A 12-pcs/year product will need to be assembled every forth week, i.e. once a month, in average.

![Share of total number of products and corresponding share of total sales as well as the corresponding annual volume per product](image)

Figure 4.6. Share of total number of products and corresponding share of total sales as well as the corresponding annual volume per product.

<table>
<thead>
<tr>
<th>Share of products</th>
<th>Share of total sales</th>
<th>Annual volume per product (pcs)</th>
<th>Average assembly frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>80%</td>
<td>71 - 1988</td>
<td>Daily – weekly</td>
</tr>
<tr>
<td>30%</td>
<td>16%</td>
<td>13 - 70</td>
<td>Weekly – once a month</td>
</tr>
<tr>
<td>50%</td>
<td>4%</td>
<td>1 - 12</td>
<td>Once a month – once a year</td>
</tr>
</tbody>
</table>

The demand for the studied products is strongly characterised by the great number of low running products that shape the long tail of low volume sales, figure 4.5. The consequence of differentiating between high and low volume products using 71 pcs/year as the limit, i.e. HIGH/LOW, is that the products classified as LOW will be very heterogeneous. This group will comprise products that have an average assembly frequency ranging from weekly to once a year. Products that are assembled only once a year has to be treated differently than those that are assembled weekly. For example the components for infrequent products will not be stored at or
close to the assembly line. They will be picked from a remote inventory or even manufactured or sourced when needed (interview, Tomas Andersson). Thus, two codification levels are needed to further differentiate the low volume products. This is achieved by coding all products that has an annual volume between 13 and 70 pcs as MEDIUM and the products with an annual volume less than or equal to 12 pcs as LOW, figure 4.7.

Figure 4.7. Proposed limits for classification on annual volume.

<table>
<thead>
<tr>
<th>Limit (pcs/year)</th>
<th>Codification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual volume</td>
<td></td>
</tr>
<tr>
<td>&gt;= 71</td>
<td>HIGH</td>
</tr>
<tr>
<td>&lt;= 70</td>
<td>LOW</td>
</tr>
<tr>
<td>&gt;= 71</td>
<td>HIGH</td>
</tr>
<tr>
<td>(13,70)</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>&lt;= 12</td>
<td>LOW</td>
</tr>
</tbody>
</table>

**DURATION OF LIFE CYCLE**

To differentiate products with respect to which life cycle phase they are currently in, a set of limits that specify these phases need to be determined. By investigating how the annual volume changes throughout the life cycle, suitable age limits could be determined to separate the introduction, growth, maturation and decline phase. Based on sales data for the last 10-year period these phases may be observed for some high running products. However, for the vast majority of the products it was not possible to observe any distinct life cycle phases at product level. Consequently, it is not possible to use current life cycle phase to differentiate products in introduction, growth, maturation and decline phase. Thus, the use of the duration of life cycle is reduced to distinguish newly launched products from old products. In other words current life cycle phase is still the preferred measure but products will only be classified as either new or old. “New” will correspond to the introduction phase whereas “old” will comprise the growth, maturation and decline phase. There is one more reason to define the measure in this way besides the fact that it is not possible to clearly distinguish several life cycle phases. The extent to which a product’s demand characteristics change throughout its life cycle will be captured by the other four classification variables as the cluster analysis is repeated during the life cycle. Thus, the volume, variability, variety and time window for delivery characteristics will be guiding the choice of supply strategy for the old products.

To define an appropriate upper limit for new products the average age of deactivation may provide an initial guidance. The average age of deactivation for the studied assortments is approx. 6 years. However there is a clear difference between the electric and the pneumatic tools. The electric tools have an average life cycle length of approx. 4,5 years and a range between 0 and 16 years, figure 4.8. The pneumatic tools are deactivated at an age of approx. 7 years in average, with a range between 0 and 31 years, figure 4.9.
Figure 4.8. The average age of deactivation for electric tools is approx. 4.5 years and range between 0 and 16 years.

Figure 4.9. The average age of deactivation for pneumatic tools is approx. 7 years and range between 0 and 31 years.

The year of creation is likely not the same year as the product is launched. Since the launch date is not available it is assumed that a product number is created at least one year before the actual launch (interview Petra Grandinson). Thus, none of the products that were deactivated at the age of 0 year were released for sale. This is probably also the case for a portion of the products that were deactivated at the age of 1 year and 2 years. ITBA uses a vitality index to monitor the contribution of each age class of products to the total sales. Products that have an age of 0-3
years are distinguished as new products in the vitality index follow up. Thus, 3 years is defined as the upper limit to differentiate new products from old products.

VARIABILITY

OL frequency

The number of OLs per product during 2011 ranged from 1 up to 458 for the most frequently requested product. The reason to differentiate the low volume from the medium volume products was to enable special treatment of infrequent products. To make this distinction the limit for annual volume was set to 12 pcs/year. This annual volume corresponds to a product being ordered once a month in average. Thus, a product that have 12 OLs/year or less is considered as infrequent since the need to assemble will be monthly or less often in average. This limit naturally means that all low volume products are infrequent, figure 4.10. Also a number of medium volume and high volume products will be classified as infrequent products, figure 4.10. In total 61% of all products are considered as being infrequently requested i.e. ordered once a month or as infrequently as once a year. Besides revealing how many times a product is requested, the OL frequency can also indicate how often the product is requested in average and how much is requested each time in average (given that the annual volume is known). However, the OL frequency can only indicate these aspects of the demand pattern and is not a sufficient measure of the demand variability.

![OL frequency per product 2011](image)

Figure 4.10. Share of total number of products per OL frequency category. A product that has less than or 12 OLs/year is considered as infrequently requested.

$CV_{Req} – the variability in time between requests$

Products with high annual volume and that are frequently requested ($\geq 12$ OL/year) have an average time between requests that range from 1 to 27 days, figure 4.11. Frequent products with medium annual volume have an average time between requests that range from 6 to 28 days, figure 4.11. As expected from the analysis of annual volume a majority of the high volume products are ordered at least once a week in average and the medium volume products are ordered from once a week to once a month. The deviation from the average time between requests is quantified with the $CV_{Req}$. The frequent high volume products have an average $CV_{Req}$
of 115% and the corresponding figure for the frequent medium volume products is 103%. This indicates that the actual time between requests differ quite much from the average time between requests. The low volume products and the infrequent high and medium volume products have such low OL frequencies that there is no real flow of OLs to study. Thus there is no relevance in measuring the variability in time between requests for these products. Since it is difficult to influence when customers place their orders, in order to smooth the incoming flow of OLs, there is no good reason to differentiate the products with respect to variability in the time between requests. The knowledge that the CV_{Req} would provide to the cluster analysis if it was used as a measure of demand variability is simply not that useful for the activity of matching demand characteristics and supply chain strategy.

The low volume products and the infrequent high and medium volume products have such low OL frequencies that there is no real flow of OLs to study. Thus there is no relevance in measuring the variability in time between requests for these products. Since it is difficult to influence when customers place their orders, in order to smooth the incoming flow of OLs, there is no good reason to differentiate the products with respect to variability in the time between requests. The knowledge that the CV_{Req} would provide to the cluster analysis if it was used as a measure of demand variability is simply not that useful for the activity of matching demand characteristics and supply chain strategy.

Figure 4.11. The average time between requests for frequent high and medium volume products.

CV_{Qty} – variability in OL quantity

The peaks in the demand pattern pose great challenges through out the ITBA internal supply chain. The challenges can be observed on three levels, at the distribution centre (DC), at the final assembly unit and at the component manufacturing and sourcing level. Since the peaks cannot be forecasted accurately the forecast errors will increase which in turn result in increased safety stock levels in the finished goods inventory at the DC. At the final assembly unit a highly flexible assembly staff is required to cope with the sudden increases in demand in certain models or product ranges (interview Henrik Nyström). At the component manufacturing and sourcing level the peaks in demand will increase the needed safety stock since stock outs will result in delayed delivery when the production lead-time exceed the delivery lead-time. While a non stock-keeping unit will face challenges at the assembly unit and at the component manufacturing and sourcing level, a stock-keeping unit (SKU) will face challenges at all three levels.

To further evaluate the CV_{Qty} as a measure of demand variability it is assumed that all frequently requested high and medium volume products are considered as candidates for being SKUs. This group of products will face increased safety stock levels in the DC due to variability in the OL quantity. Figure 4.12 show the demand pattern during 2011 for one of the products in this group. Each black bar represent an OL and the height of the bar define the OL quantity. The green line shows how the average OL quantity changes though out the year as new OLs are placed. The red crosshatched line shows how the standard deviation of the OL quantity evolves throughout the year as new OLs are placed. Finally, the blue line shows how the CV_{Qty} changes as new OLs
with varying quantity are placed. The OL frequency for this product is 164 OL/year i.e. one of the more frequent high volume products.

One way to tackle the challenge at the DC caused by variability in OL quantity for SKUs is to catch and treat the OLs that differ too much from the “normal” flow of OLs separately. These OLs are referred to as *bulk* OLs. The aim in this study is not to develop suitable criteria for filtering out bulk OLs. However, it is necessary to define some kind of bulk criteria in order to continue the evaluation of $CV_{Qty}$. The most common OL quantity for frequent high and medium volume products is 1 pcs/OL, figure 4.13. As much as 80% of all OLs for frequent high and medium volume products are for 1 or 2 pcs. OL quantities from 1 up to 5 pcs may be considered as “normal” since only 6% of the OLs have a higher OL quantity. Furthermore, the average OL quantity for the frequently requested high and medium volume products is approx. 2,2 pcs and the corresponding standard deviation is approx. 3,7 pcs. Thus, if the quantity of $OL_X$ is greater than or equal to the average OL quantity plus two standard deviations, $2,2 + 2 \times 3,7 \approx 10$ pcs, then $OL_X$ is considered to be a *bulk OL*. This criterion for filtering out bulk OL results in approx. 4 bulk OLs a day in average.

![Figure 4.12. The demand pattern of a high volume and frequently requested product.](image_url)
Figure 4.13. The share of OLs per OL quantity for the high and medium volume products.

By excluding the bulk OLs from the demand pattern the $CV_{Qty}$ is decreased significantly, figure 4.14. Thus, excluding the bulk OL from the forecast calculation will decrease the forecast errors; mean average deviation (MAD). A decreased MAD value will in turn decrease the safety stock level and ultimately the working capital at the DC. To filter out and treat the bulk OLs separately can also ease the challenges at the final assembly unit and at component manufacturing and sourcing level. A possible way to handle a “bulky” OL would be to give the customer a delivery time based on the assembly lead-time. This is feasible when there are sufficient supplies of components, otherwise the confirmed delivery time will have to include the longest manufacturing or sourcing lead-time. In this way at least two advantages are gained. From assembly and component supply point of view the demand can be somewhat levelled and from a customer point of view a more accurate delivery time will be communicated.

Figure 4.14. By excluding all OLs with an OL quantity greater than or equal to 12 a more smooth demand pattern is created. The $CV_{Qty}$ for new demand pattern is significantly lower compared to the original demand pattern.
The CV\textsubscript{Qty} seems to be the most relevant measure of demand variability. It captures a challenging aspect of the demand pattern, and by differentiating on variability in OL quantity the problematic products can be focused and targeted with specific strategies. Thus, CV\textsubscript{Qty} is chosen as the final measure of demand variability to be used in the cluster analyse. To use the CV\textsubscript{Qty} as a measure of demand variability in the cluster analysis a limit that differentiates the products with low variability in OL quantity from the products with high variability needs to be defined. By filtering out the bulk OLs a more acceptable demand pattern is shaped. Thus, by studying the effect of excluding bulk OLs for the SKU candidates a suitable limit for CV\textsubscript{Qty} can be defined. The CV\textsubscript{Qty} was decreased for 35\% of the SKU candidates, figure 4.15. This group of products had an average CV\textsubscript{Qty} of 134\% calculated for the original demand pattern. After excluding the bulk OLs the average CV\textsubscript{Qty} was decreased to 79\%, figure 4.16. Thus, products that have a CV\textsubscript{Qty} greater than or equal to 80\% are considered to have HIGH variability in OL quantity and those that have a CV\textsubscript{Qty} less than 80\% are considered to have LOW variability in OL quantity.

![The effect of excluding bulk OL on CV\textsubscript{Qty} for SKU candidates](image)

Figure 4.15. CV\textsubscript{Qty} calculated on the original demand pattern and CV\textsubscript{Qty} calculated on the demand pattern excluding bulk OLs. Excluding the bulk OLs has a lowering effect on the CV\textsubscript{Qty} for SKU candidates.

Figure 4.16. By excluding the bulk OLs the CV\textsubscript{Qty} was decreased for 35\% of the SKU candidates. The CV\textsubscript{Qty} was decreased from an average of 135\% to an average of 79\%.

<table>
<thead>
<tr>
<th></th>
<th>Average CV\textsubscript{Qty}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original demand pattern</td>
</tr>
<tr>
<td><strong>Products with decreased CV\textsubscript{Qty}</strong></td>
<td>134%</td>
</tr>
<tr>
<td><strong>Products with unaffected CV\textsubscript{Qty}</strong></td>
<td>65%</td>
</tr>
</tbody>
</table>
VARIETY

No. of products & variety index

The majority of the studied product variants are found within the electric tools assortment where the ST and DS range make up 33% of the total number of studied products, figure 4.17. The pneumatic tool ranges LTV and LUM follow these ranges with a 19% share of products.

It is clear that the studied tools do not have identical performance characteristics. However, suppose that the features making each different product variant unique is so small from a customer point of view that products within each range compete for the same demand. The result would be that a range carrying many variants also has high numbers of low volume products. This reasoning implies that the products within the previously mentioned ranges have the highest variety. On the other hand the average variety index per product range point in another direction. The ST, DS, LTV and LUM ranges all have low average variety index whereas ranges with few product variants, LMS, EPP and DL, have high average variety index, figure 4.18. Not all ranges with few product variants have a high average variety index. LTO carries few variants, only about twice as many as EPP, but has much lower average variety index than EPP. The reason for this is that the components needed to build the LTO range are reused in many other products whereas the component base for EPP is reused to a much lower degree. The demand for ST tools is spread on many product variants, which result in a large share of low and medium volume products. However the demand is focused towards a component base that is frequently reused. This decreases the average variety index for the ST range. The variety index is selected as the preferred measure of demand variety for two reasons. The first reason is that the variety index is a measure at product level and secondly; the variety index captures the important aspect of component reusability. The average variety index per product across all the studied ranges is 11,6 and the standard deviation is 5,8. Thus, it is proposed that if a product has a variety index greater than or equal to the average variety index plus one standard deviation, 11,6 + 5,8 = 17,4, it is considered to have HIGH variety.
SUMMARY: FINAL MEASURES AND PRELIMINARY LIMITS

In the above sections the preliminary measures have been evaluated and a single measure for each classification variable has been defined and motivated, figure 4.19. To indicate customers’ responsiveness requirement, time window for delivery, the desired delivery lead-time was set as the measure. The annual volume per product was defined as the measure of demand volume to be able to differentiate high running products from medium and low running products. As a measure of duration of life cycle the current life cycle length was selected to distinguish new products from mature products. As a measure of demand variability the CV in OL quantity (CV_{OL}) was selected in order to differentiate the products with respect to variability in OL quantity. Finally, the variety index was chosen as the measure of demand variety to emphasize the challenge of a numerous component base due to many product variants. Based on product master data and demand data for the electric tool and air assembly tool assortments, suitable limits for each measure have been specified, figure 4.19, which will be applied in the cluster analysis in the next section.

Figure 4.19. The final set of measures and corresponding limits to be used in the cluster analysis to differentiate the studied products.

<table>
<thead>
<tr>
<th>Classification variable*</th>
<th>Measure</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of life cycle</td>
<td>Current life cycle phase</td>
<td>NEW &lt;= 3 years &gt; OLD</td>
</tr>
<tr>
<td>Time window for delivery</td>
<td>Desired delivery lead-time</td>
<td>LOW, MEDIUM, HIGH based on mix of criteria and guideline</td>
</tr>
<tr>
<td>Volume</td>
<td>Annual volume per product</td>
<td>LOW &lt;= 12 &lt; MEDIUM &lt;17 &gt;= HIGH</td>
</tr>
<tr>
<td>Variability</td>
<td>CV** in OL quantity (CV_{OL})</td>
<td>LOW &lt; 80% &gt;= HIGH</td>
</tr>
<tr>
<td>Variety</td>
<td>Variety index</td>
<td>LOW &lt; 17,4 &gt;= HIGH</td>
</tr>
</tbody>
</table>

* According to the DWV3 system (Childerhouse et al., 2009)
** Coefficient of variation = standard deviation / average
4.3 Cluster analysis

The findings in this section are related to research questions 2 and 3:

(2) *What limit should be used for each measure?*

(3) *What sequencing of the classification variables should be applied?*

The cluster analysis is performed twice. After the initial run the sequencing and preliminary limits are evaluated. By altering the sequencing of the classification variables and adjusting the limits a feasible classification is achieved.

**FIRST RUN OF THE CLUSTER ANALYSIS**

In the first run of the cluster analysis, figure 4.20, the preliminary limits specified in Chapter 4.3 are used, and the following sequencing is applied:

(1) *Time Window for delivery*
   In the first run the customers’ requirements on delivery lead-time is considered as the most important differentiator. These requirements will determine at what point in the internal supply chain that the manufacturer needs to keep stock to balance the required delivery lead-time and the production lead-time. Thus, the time window for delivery will separate the make-to-order products from the make-to-stock products.

(2) *Volume*
   The second most important variable is considered to be the volume aspect. In this way the high running, medium and low running products are isolated at an early stage.

(3) *Variety*
   By keeping volume and variety close together products that are likely to have many low running components are highlighted.

(4) *Variability*
   In the first run variability is not considered to be very important and thus sequenced as the forth differentiator.

(5) *Duration of life cycle*
   A product’s demand characteristics are likely to change throughout its life cycle. By reviewing the supply strategy during the product’s life cycle this will be captured by the volume, variety and variability classification variables. Thus, duration of life cycle is considered as the least important variable and therefore sequenced as the last differentiator.
The first iteration of the cluster analysis is performed using the preliminary limits specified in Chapter 4.3.

Cluster analysis, first run

Volume
Variety
Variability
Duration of life cycle

Time window for delivery

% of total product No.

% of product No.

% of product No.
SECOND RUN OF THE CLUSTER ANALYSIS

The first run of the cluster analysis resulted in 48 different segments out of 72 possible. Such large number of segments makes it hard to draw any conclusion as the product portfolio is far too scattered. To simplify the analysis i.e. to decrease the number of clusters some of the limits are adjusted. The preliminary limits for the time window for delivery differentiated the products into three groups. The MEDIUM level is removed and these products are considered to have LOW requirements on responsibility. In this way time window for delivery still differentiates the make-to-stock from make-to-order products. The preliminary limits for volume classified products as high, medium or low running. To further decrease the number of segments the high and medium running products are combined into one group. Although this decreases the level of detail, this is an acceptable trade-off as the cluster analysis becomes easier. Before the second run of the cluster analysis the sequencing is adjusted to enhance the final classification. The overall reason to adjust the sequencing is to find clusters that are relevant for the production philosophy concepts that one aims to establish the supply chain strategy based on. The redefined sequencing is listed below and the reason to reprioritise is motivated.

(1) Duration of life cycle
   To be able to filter out and treat the prototype and newly launched products separately the duration of life cycle variable is reprioritised to be the first differentiator.

(2) Time Window for delivery
   Down-prioritised in favour for duration of life cycle.

(3) Volume
   Down-prioritised in favour for duration of life cycle.

(4) Variability
   In the second run of the cluster analysis variability is considered to be more important than variety. The reason for this is that smoothness of demand is a key differentiator between the lean and agile concepts. Thus, variability has a greater impact on the choice of supply chain strategy than variety.

(5) Variety
   Down-prioritised in favour for variability.

The changes described above decrease the number of possible segments from 72 to 32; figure 4.21. Out of the possible 32 segments 26 is populated. The old products make up 69% of all studied products. These are scattered on four main segments with different demand characteristics. The remaining 31% of the studied products are classified as new products. The aim of this study is not to propose a detailed supply chain strategy based on the cluster analysis, as this would need further extensive research. However, to further elaborate on research question 3 it is appropriate to propose a possible clustering of the 26 segments. This is done with respect to the production philosophy principles and concepts reviewed in Chapter 2. One way to group the segments together into clusters is shown in figure 4.21 and described below.

(1) New products, not in respect to desired delivery lead-time and volume.
   Products in this cluster get special treatment during industrialization and are shifted into one of three possible tracks when ready.

(2) Old products, short desired delivery lead-time, high or medium volume.
   Products in this cluster are made-to-stock, thus the de-coupling point is placed far downstream to secure the shortest possible delivery lead-time.
(3) **Old products, short desired delivery lead-time, low volume.**

Products in this cluster are made-to-order and the de-coupling point is placed at component/sub-assembly level to secure a short delivery lead-time.

(4) **Old products, customer can accept a longer delivery lead-time, no respect to volume.**

Products in this cluster are made-to-order and the de-coupling point is placed at raw material/component level depending on the production and sourcing lead-times.

In order to design a market-specific supply chain strategy the next step would be to evaluate the proposed clustering in detail and if necessary adjust the sequencing and limits, and repeat the cluster analysis. A closer analysis might for example find that it is feasible to use the variability variable to further differentiate cluster 2 into one lean (low variability) and one agile (high variability) track. However, this kind of in-depth analysis falls outside the scope of this thesis.

### 4.4 Chapter summary

The aim of this thesis was to illustrate how to tackle the key elements of the framework by applying it on the ITBA product portfolio. These key elements were specified in Chapter 2 as the research questions of this study. Chapter 4 has in a systematic way presented the analysis and findings related to one and each of these questions. In section 4.1 the first question was addressed as the preliminary set of measures for each classification variable was proposed. This was based on the literature review and initial exploration of product master data and demand data. After this section 4.2 presented how the ITBA product portfolio was used to evaluate the preliminary measures in order to select one measure for each classification variable. Thus, the first question had been fully addressed. In the same section the second question was addressed as the preliminary limits for each measure were specified. In section 4.3 the cluster analysis was performed using the previously defined measures and the preliminary limits. After the first run the sequencing had to be reprioritised and the limits slightly redefined. The reason to change the sequencing was to create a classification of the products that was relevant for the production philosophy principles and concepts reviewed in Chapter 2. The reason to adjust the limits was to decrease the number of segments in order to ease the grouping of segments into clusters. Thus, section 4.3 addressed and fully covered the second and third question.
Fig. 4.21. After the initial run of the cluster analysis, the order of the classification variables are re-prioritized and the limits are adjusted. The number of populated segments decreases from 48 to 26.
5 Conclusion and future research

This chapter presents the conclusions that can be drawn from the findings of this study and explains its contribution to the body of knowledge related to market-specific supply chain strategies. The limitations of the study are discussed and possible areas for future research are identified.

5.1 Conclusion

Before presenting the conclusions it is appropriate to briefly recapitulate the assignment given by ITBA, as well as the purpose statement and aim of this study that were derived from the assignment. The assignment given by ITBA reads as follows:

Investigate how to go about to develop tailored supply chain strategies for the ITBA product portfolio.

After reviewing the literature within the area of market-specific supply chain strategies it was decided that this research focus should be on the DWV³ classification system. It was found that the available literature regarding applying the DWV³ system is somewhat general in its nature and that the practitioner is left without detailed instructions on how to proceed with the analysis. Consequently, the purpose of this research has been to make the DWV³ system more available to practitioners, and thus the aim is to illustrate how to tackle the key elements of the framework by applying it on the ITBA product portfolio. Based on the purpose statement and the aim of this study the assignment was reformulated into the research problem, which reads as follows:

How manufacturing companies can use the DWV³ classification system to evaluate the opportunity for a market-specific supply chain strategy.

By reviewing available literature about the DWV³ system three key elements of the system were identified. These are (1) the measures to express each classification variable, (2) the limits for each measure used to classify the products, and (3) the sequencing of the classification variables in the cluster analysis. The key elements were used to further break down the research problem into three research questions. In the following sections the findings related to each research question will be summarized and the conclusions extracted.

WHAT MEASURES SHOULD BE USED TO EXPRESS EACH CLASSIFICATION VARIABLE?

The activity of defining one measure for each classification variable was made in two steps. First a preliminary set of measures was developed based on initial exploration of the research and the literature review. These measures were then evaluated against the ITBA product portfolio to select a single measure for each variable in the DWV³ system. As the preliminary measures were developed it was found that there are two basic ways of reasoning to classify a product with respect to any of the classification variables. Either a measure at product level is used or a measure at the product assortment is used. In the latter case the product will inherit the same status as all other products have within the assortment. This approach decreases the level of detail in the cluster analysis, and thus the first approach is preferred. It was also discovered that the selected measures have to express aspects of a product’s demand characteristics that are relevant to the matching of demand characteristics and supply chain strategy. The findings related to each classification variable are presented below and at the end of the section the conclusions related to research question 1 are presented.
Time window for delivery

The preferred measure of this variable is the customers’ desired delivery lead-time. This is key knowledge for the manufacturer since the need to keep stock depends on what delivery lead-time the customers’ expect and on the internal lead-times (e.g. production, sourcing).

Volume

The preferred measure of the volume characteristic is annual volume as this measure makes it possible to distinguish between high, medium and low running products.

Duration of life cycle

The preferred measure of this classification variable is current life cycle phase where a product may be classified as either new or old. The preliminary definition of this measure was revised as the measure was evaluated against the ITBA product portfolio. Since it was not possible to distinguish several life cycle phases the measure was reduced to differentiate newly launched products from old products.

Variability

It was found that three aspects describe the demand pattern of a product. These aspects are (1) how much of the product is needed, (2) how many times there is a demand for the product during a period and (3) how often there is a demand for the product during this period. To define a measure of demand variability a preliminary measure for one and each of these aspects was first developed. The first aspect was measured by the coefficient of variation (CV) in order line quantity (CV_{Oy}). The second aspect was measured by the CV in time between requests (CV_{Req}). Finally, the number of order lines during one year (order line frequency) was defined as the measure of the third aspect. When the preliminary measures were evaluated against ITBA product portfolio the CV_{Oy} was found to be the most relevant measure of demand variability. The CV_{Oy} captures a challenging aspect of the demand pattern, and by differentiating on variability in order line quantity the problematic products can be focused and targeted with specific strategies.

Variety

Two preliminary measures were proposed for the demand variety characteristics. These were the number of products per assortment and/or product range and the variety index. It was found that the variety index nuanced the understanding of demand variety as it effectively emphasized the component level of the product variety aspect. Thus, the variety index was selected as the preferred measure of demand variety. The first reason to do so was that the variety index is a measure at product level and secondly, the variety index capture the important aspect of component reusability.

Conclusions

(1) As far as possible use measures at the single product level.
(2) Use measures that express each classification variable in a way that is relevant to the matching of demand characteristics and supply chain strategy.
(3) Be prepared to redefine initial measures in order to describe the studied products’ characteristics in the best possible way.
WHAT LIMIT SHOULD BE USED FOR EACH MEASURE?

The limits related to each measure were developed in two steps. First a preliminary set of limits was developed based on demand and master data for the studied ITBA products. These limits were then used and evaluated in the cluster analysis. The preferred limits were defined as the preliminary limits were adjusted to attain a feasible classification of the products. The findings related to each measure are presented below and at the end of the section the conclusions related to research question 2 is presented.

Desired delivery lead-time

A set of criteria was proposed to guide the specification of desired delivery lead-time. One of these criteria, the “Order type” criterion was not possible to use for two reasons. Firstly, this criterion requires that the order type (break-down orders, daily business orders, and project orders) is known which is not the case today. Secondly, in the cluster analysis the desired delivery lead-time need to be specified at product level (not order level). The remaining two criteria, the “Standard vs. customized tool” and “Torque performance” criteria were used to specify the desired delivery lead-time for the studied products. Initially two codification levels were used but since this resulted in too many segments in the cluster analysis the limits were revised. The final limits made it possible to distinguish the make-to-stock products from the make-to-order.

Annual volume

It was found, as the Pareto principle predicts, that 80% of the total volume of 2011 originated from 20% of the product numbers sold during this period. The next 30% of the products caused 16% of the sales and the last 4% of the sales was caused by 50% of the products. Since such large share of the products have very low annual volume it was necessary to distinguish between high, medium and low volume products. Among the products that caused 80% of the total volume, the product with the lowest annual volume had a volume of 71 pcs. Among the products that caused 16% of the total volume, the lowest annual volume was 12 pcs. The preliminary limits for annual volume were set so that products with more than or equal to 71 pcs in annual volume were classified as high running and those with less than or equal to 12 pcs were classified as low running products. The remaining products i.e. they that had an annual volume between 13 and 70 were classified as medium running. This preliminary set of limits were used and evaluated in the first run of the cluster analysis. It was found that two codification levels caused too many segments. The product portfolio was so scattered it was hard to find feasible clusters. In order to decrease the number of segments the high and medium running products were combined i.e. one instead of two codification levels were used.

Current life cycle phase

The measure of duration of life cycle, current life cycle phase, was defined to differentiate new products from old. Thus, the limit should specify the age when a product is no longer considered to be new. This limit was set to three years, based on the vitality index that ITBA uses to monitor the total sales based on age.

The CV_{Qy}

To specify a suitable limit for the CV_{Qy} the impact of sudden increase in demand for the frequently requested high and medium volume products was studied. To do this the CV_{Qy} was first calculated while including the bulk order lines. Then an arbitrary criterion to filter out the bulk order lines was applied and the CV_{Qy} was calculated again. By excluding the bulk order lines the CV_{Qy} was decreased for 35% of the studied products. The average CV_{Qy} for this group of products was lowered to 79%. By removing the bulk order lines a more acceptable demand pattern was shaped. Thus, products that have a CV_{Qy} that is greater than or equal to 80% were said to have high demand variability.
Variety index
A product is considered to have high demand variety if the variety index differ more than 1 standard deviation from the average variety index of the studied products.

Conclusions

(4) Develop measures that are based on available data or data that is feasible to attain.
(5) Adjust the number of codification levels to find the best trade-off between the level of detail in the cluster analysis and the number of populated segments.

WHAT SEQUENCING OF THE CLASSIFICATION VARIABLES SHOULD BE APPLIED?

The cluster analysis was performed twice to illustrate how the sequencing affects the final clustering of the products. The initial sequencing of the classification variables had to be revised to better support the matching of each product cluster with a suitable supply chain strategy. Although the first run did not result in any feasible product clusters it gave a good insight to the nature of the studied products. In the second run of the cluster analysis demand variability was moved from the 5th to 4th level and demand variety was down-prioritised one level. The reason for this was that smoothness of demand is the main differentiating aspect between a lean and an agile supply chain. Thus, by moving demand variability upwards it is easier to find product clusters that can be targeted with either a lean or an agile strategy. This was not the only reprioritisation. Duration of life cycle was moved from being the last differentiator to becoming the first. In this way new products was singled out at the 1st level in the cluster analysis, which enabled a tailored strategy for this group of products. Based on the classification from the second run, four potential product clusters were formed. Each of these clusters was assigned an initial supply chain strategy and the next step of designing a market-specific supply chain strategy was pointed out. The next step would be to evaluate the initial strategy in detail and if necessary adjust the sequencing and repeat the cluster analysis. However, this kind of in-depth analysis falls outside the scope of this thesis.

Conclusions

(6) Alter the sequencing and repeat the cluster analysis to gain insight into the demand characteristics of the product portfolio.
(7) The final sequencing of the classification variables must produce clusters that are relevant for the chosen production philosophy concepts.

In summary, the conclusions drawn from the findings related to the research questions form a set of guidelines on how to tackle the key elements of the DWV³ system. Thus, the aim of this thesis, which was to illustrate how to tackle the key elements of the framework, has been achieved. Furthermore, by presenting the systematic analysis and discussion of the key elements this study is a useful support for others that are about to apply the DWV³ system. The purpose of this thesis, which was to make the DWV³ system more available to practitioners, has therefore been fulfilled. This study also contributes with yet another industry case of applying the DWV³ system, which have been requested by Christopher et al. (2009). Furthermore, the measures outlined in this study, for example the variety index, will be used by the Logistics Department at ITBA for various analyses.
5.2 Limitations and future research

There are a number of limitations worth mentioning. First two aspects that affect the entire study will be commented. In section 1.3 the scope of this study was defined to exclude a number of the ITBA product assortments as well as all spare parts and accessories. The choice of classification limits depends on the nature of the studied articles, thus it is obvious that the limits would have been defined differently if the scope had included the entire ITBA product portfolio. Whether a different scope would have affected the choice of measure or not is not as obvious. Perhaps articles with a complete different demand characteristic would have required the measures to be defined in another way. Here lies one of the overall limitations of this study. Another general limitation is related to the cluster analysis and the extent of supply chain strategy design-activity. To shape a manageable thesis it was necessary to exclude an in-depth cluster analysis and the development of detailed market-specific supply chain strategies for the studied products. However, to fully evaluate the suitability of the measures, limits and sequencing such detailed and extensive investigation is necessary.

Second, the limitations related to specific parts of the study will be discussed. The limit set to differentiate between new and old products was based on a currently used Key Performance Indicator (KPI) related to R&D efforts and sales contribution. This KPI is not clearly linked to the processes related to industrialization, manufacturing and distribution. Thus, the limit for current life cycle phase is an area for future investigation. The variety index was developed as a measure of demand variety in this study. Since component commonality is a way to tackle the challenge of great product variety it would be interesting to explore and develop the variety index further. One possible improvement to investigate is to rate different types of components according to their feasibility of being sourced. The customers’ responsiveness requirements are naturally a key in designing market-specific supply chain strategies. However, within this study it was not possible to carry out an extensive investigation regarding the customers’ buying pattern and expectations on delivery service. Thus, an important area for future research is to investigate the desired delivery lead-time for each relevant customer segment and product combination.
References

Articles


**Books**


**Interviews**

Petra Grandinson, Logistics Manager, interview was conducted 2012-01-27, 2012-03-09, 2012-04-20.

Henrik Nyström, Assembly Manager, interview was conducted 2012-04-11.

Mathieu Legars, Business Manager Assembly Products, interview was conducted 2012-05-15.

Tomas Andersson, Production technician, interview was conducted 2012-04-11.

**Other**

Appendix 1 – Interview questions

Open-ended questions related to *time window for delivery*, one of five classification variables within the DWV³ system.

The following questions apply to the electric or pneumatic nutrunners and screwdrivers in the electric tools or air assembly tools product lines.

- What are the customers’ responsiveness requirements in terms of delivery lead-time?
- Is there any significant difference between different customer segments regarding the requirement on delivery lead-time?
- Is there a way to divide the products, a cross range/assortment, to form groups of products with similar lead-time requirement?
- From a marketing perspective, what should be the criteria for a non-stock kept product to have short lead-time?