

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

LUT School of Energy Systems

LUT Mechanical Engineering

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**COST EFFICIENT SUPPLY PROCESSES FOR THE COMPACT SLIM  
ELEVATOR DOOR**

Examiner: Professor Juha Varis

D. Sc. Mika Lohtander

## **ABSTRACT**

Lappeenranta University of Technology  
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LUT Mechanical Engineering

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### **Cost efficient supply processes for the Compact Slim Elevator Door**

Master`s Thesis

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Keywords: Manufacturing, manufacturing strategies, sheet metal, outsourcing, VSM, product offering, variability, lead time, pricing, cost accounting, EOQ, elevator doors

The aim of this thesis was to observe possibilities to enhance the development of manufacturing costs savings and competitiveness related to the compact KONE Renova Slim elevator door. Compact slim doors are especially designed for EMEA markets. EMEA market area is characterized by highly competitive pricing and lead times which are manifested as pressures to decrease manufacturing costs and lead times of the compact elevator door. The new elevator safety code EN81-20 coming live during the spring 2016 will also have a negative impact on the cost and competitiveness development making the situation more acute.

As a sheet metal product the KONE Renova slim is highly variable. Manufacturing methods utilized in the production are common and robust methods. Due to the low volumes, high variability and tight lead times the manufacturing of the doors is facing difficulties. Manufacturing of the doors is outsourced to two individual suppliers Stera and Wittur. This thesis was implemented in collaboration with Stera. KONE and Stera pursue a long term and close partnership where the benefits reached by the collaboration are shared equally. Despite the aims, the collaboration between companies is not totally visible and various barriers are hampering the development towards more efficient ways of working.

Based on the empirical studies related to this thesis, an efficient standardized (A+) process was developed for the main variations of the compact elevator door. Using the standardized process KONE is able to order the most important AMDS door variations from Stera with increased quality, lower manufacturing costs and manufacturing lead time compared to the current situation. In addition to all the benefits, the standardized (A+) process also includes risks in practice. KONE and the door supplier need to consider these practical risks together before decisions are made.

## TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto  
LUT School of Energy Systems  
LUT Kone

Oskari Leppänen

### **Cost efficient supply processes for the Compact Slim Elevator Door**

Diplomityö

2016

114 sivua, 42 kuvaa, 9 taulukkoa and 2 liitettä

Tarkastaja: Prof. Juha Varis  
TkT Mika Lohtander

Ohjaaja: Insinööri Harri Anttila

Hakusanat: Valmistus, valmistusstrategiat, ohutlevy, toimituksen ulkoistaminen, VSM, tuotetarjonta, varioituvuus, toimitusaika, hinnoittelu, kustannuslaskenta, EOQ, hissien ovet

Diplomityön tarkoituksena oli tutkia mahdollisuuksia tehostaa kompaktin KONE Renova slim hissien oven valmistuskustannuksia ja kilpailukykyä liittyen ovien tilaus-toimitusprosessiin. Kompaktit hissiovet ovat suunnattu erityisesti EMEA markkina-alueelle, jolle tyypillinen kova kilpailu asettaa paineita niin tuotteen valmistuskustannusten pienentämiselle kuin toimitusaikojen lyhentämiselle. Asian tekee KONEen kannalta radikaalimmaksi keväällä 2016 kokonaisuudessaan voimaan astuva uusi hissistandardi EN81-20, joka osaltaan nostaa KONE Renova slim oviin liittyviä kustannuksia.

Kompaktien slim ovien valmistukseen sisältyvät menetelmät voidaan katsoa perinteisiksi ja koetelluiksi ohutlevyjen valmistusmenetelmiksi. Pienen voluumin, varioituvuuden ja tiukkojen toimitusaikojen johdosta oven valmistamistukseen liittyy monia haasteita. Tuotteen valmistus on ulkoistettu kahdelle toimittajalle Stera ja Wittur, joista diplomityö toteutettiin yhteistyönä toimittajan Stera kanssa. KONE ja Stera tähtäävät yhteistyössään todelliseen pitkäaikaiseen kumppanuuteen ja yhdessä kehittymiseen. Yhteistyöstä saadut edut pyritään jakamaan toimijoiden kesken tasaisesti. Näistä päämääristä huolimatta yritysten välinen yhteistyö ei ole läpinäkyvää, ja moninaiset esteet häiritsevät toiminnan kehittämistä kohti adaptiivisempaa yhteistyötä.

Työhön sisältyviin tutkimuksiin perustuen kehitettiin tehokas (A+) prosessi kompaktien hissien ovien tärkeimmille variaatioille. Kehitetyn prosessin kautta KONEen olisi mahdollista saada kompaktin oven tärkeimmät variaatiot alemmilla kustannuksilla ja lyhyemmällä toimitusajalla verrattuna nykyiseen tilanteeseen. Lisäksi tärkeimpien ovi variaatioiden laadun voidaan katsoa parantuvan uuden prosessin myötä. Saavutettavien etujen lisäksi prosessiin sisältyy käytännössä kuitenkin myös riskejä, jotka vaativat KONEen ja ovitoimittajan huomiota ennen implementointi päätösten tekemistä.

## ALKUSANAT

Diplomityön tekeminen voi olla mielenkiintoista ja jopa mukavaa, mikäli olet saanut juuri itsellesi sopivan aihealueen ja oikeat ihmiset ympärillesi tukemaan prosessia. Tilanteeni tämän diplomityön kanssa oli edellä kuvatun lainen. Näin ollen haluaisinkin ensiksi kiittää KONEen TRB and Service Repairs tiimiä luottamuksesta ja aiheen esille tuomisesta. Eritoten haluan kiittää myös ohjaajaani Harri Anttilaa, sekä tuoteomistajaa Jyrki Nurmivaaraa loputtomasta tuesta ja ajasta projektini aikana. Diplomityöni toteutus ei olisi kuitenkaan onnistunut ilman avoimesti suhtautuvaa toimittajaa. Täten haluan kiittää myös Stera:n Antero Laaksoa lukuisista neuvoista, avoimuudesta ja rattoisista palavereista liittyen työhöni.

Vilpittömät kiitokset myös kaikille opiskelukavereille riehakkaista, hämyisistä ja ennen kaikkea ikimuistoisista teekkarivuosista Lappeenrannassa!

Viimeisimpänä, mutta ei suinkaan vähäisimpänä, haluan osoittaa syvimmat kiitokset vanhemmilleni. Teidän opastuksen ansioista aikanaan luovuin haaveistani rekkamiehen ammattiin ja päädyin lukioon, sekä sieltä edelleen yliopistoon. Viittä vaille valmiina diplomi-insinöörinä asiaa puntaroidessani, on onni, että katsoitte perääni. En olisi tässä tilanteessa ilman teidän kannustusta ja tukea, jota sain koko opiskelujeni ajan.

Oskari Leppänen

Helsingissä 10.5.2016

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APPENDIX I: Current state map of AMDS value stream.

APPENDIX II: Future state map of limited AMDS main variations.

## LIST OF SYMBOLS AND ABBREVIATIONS

AMD	Advanced Modular Door
AMDS	Advanced Modular Door Slim
AMDSL	Advanced Modular Door Slim Landing
AMDSC	Advanced Modular Door Slim Car
ATO	Assemble-to-Order
BTO	Build-to-Order
CODP	Customer Order Decoupling Point
D	Annual Demand [PCS/Year]
EBULI	Existing Building
EMEA	Europe, the Middle East and Africa
EOQ	Economic Order Quantity
ETO	Engineered-to-Order
FURE	Full Replacement
H	Yearly Warehousing Costs
HA	Height of Door Lintel [mm]
HH	Clear Opening Height of the Entrance [mm]
LAL	Width of Left Sideposts [mm]
LAR	Width of Right Sideposts [mm]
LL	Clear Opening Width of the Entrance [mm]
MTO	Make-to-Order
MTS	Make-to-Stock
NEB	New Equipment Business
NVA	Non-value Adding
R&D	Research & Development
RSW	Resistance Spot Welding
S	Cost of Ordering or Setting Up One Batch [€/Batch]
SEB	Service Equipment Business
SOF	KONE Supply Operations Finland
TRB	KONE Tendered Repairs Business
VA	Value Adding

VOC	Volatile Organic Compounds
VSM	Value Stream Mapping
WIP	Work in Progress

## 1 INTRODUCTION

KONE Corporation is often regarded as a very innovative high-flyer in the field of elevators and escalators. Development of the business and the markets is driving the company forward, as it tries to pursue the position of market leader. However the number one spot is not easy to reach. As former chief executive officer Pekka Herlin used to say: “to be able to stay still, we have to run as fast as we can.” The phrase still holds true and one of the company’s main focus points during the years 2014-2016 is to offer the most competitive people flow solutions. Needless to say competitiveness is a corporate-wide and never ending target of development. (Simon, 2010.)

KONE Oyj offers a wide range of advanced modular doors (AMD) for different market segments. This thesis focuses particularly on the Advanced Modular Door Slim (AMDS) also known as KONE Renova slim. It is the most compact advanced elevator door available for both car and landing doors. These compact elevator doors are designed for residential buildings and small office blocks with a low duty range. Slim doors are popular in the EMEA (Europe, the Middle East and Africa) market area for existing car-door-less elevators and elevators with manual doors. As a sheet metal product, slim doors are characterized by very high dimensional variability, high amounts of decorative materials, small batch sizes and many safety standards affecting the design. The production of the doors is decentralized and outsourced.

KONE’s R&D department (Research & Development) has identified a problem with costs and competitiveness related to KONE Renova slim elevator doors. Poor cost efficiency and competitiveness is leading to a decreasing order volume. This issue is essentially occurring due to high price competition in the EMEA market area. Additionally a remarkable proportion of the modernization business is conducted with short lead times. The new elevator standard EN81-20 coming live during the spring 2016 will also have a negative impact on the cost development of KONE Renova slim doors. Due to these problems this thesis was launched in order to find cost saving possibilities and ways to improve competitiveness of compact elevator doors.

### 1.1 Objectives and limitations

This thesis has two main objectives. The first of the main objectives is cost reduction. This thesis will study possibilities to gain cost reductions in the AMDS order-delivery process and point out the possible “hot spots” in the entire supply line related to AMDS. As the costs of the product do not tell the whole truth, the second main goal of the study is increased competitiveness of the final product. The more accurately the second main objective is related to shorter lead times and more efficient processes. Accordingly the objectives of the research focuses on ways to decrease manufacturing costs, decrease lead times and propose new more efficient solutions for process principles.

The objectives of this thesis are very clear but at the same time very extensive. This leads to the limitations of the study. Firstly, the design of AMDS and related possibilities of cost cutting and competitiveness have been recently carefully studied. In this thesis the design of the product is not considered, shifting the focus to other aspects of the product, namely its supply line and product offering. The research will study AMDS related A-process while more complicated C-process is excluded. In the empirical part NanoSpace elevator platform will have the highest priority. Secondly due to basic elevator technology the order volume of KONE Renova slim landing doors is significantly higher than slim car doors. Considering this, the study will concentrate on landing doors and car doors are considered only as a second priority. Additionally, as slim doors have a multi-level product structure, the doors also have numerous lower level assemblies with varying manufacturing processes. The door railing, along with door operator and drive are assemblies left out of the empirical part. The focus of the study, from the assembly point of view is on the sill, door panels and door frame.

### 1.2 Research problems and questions

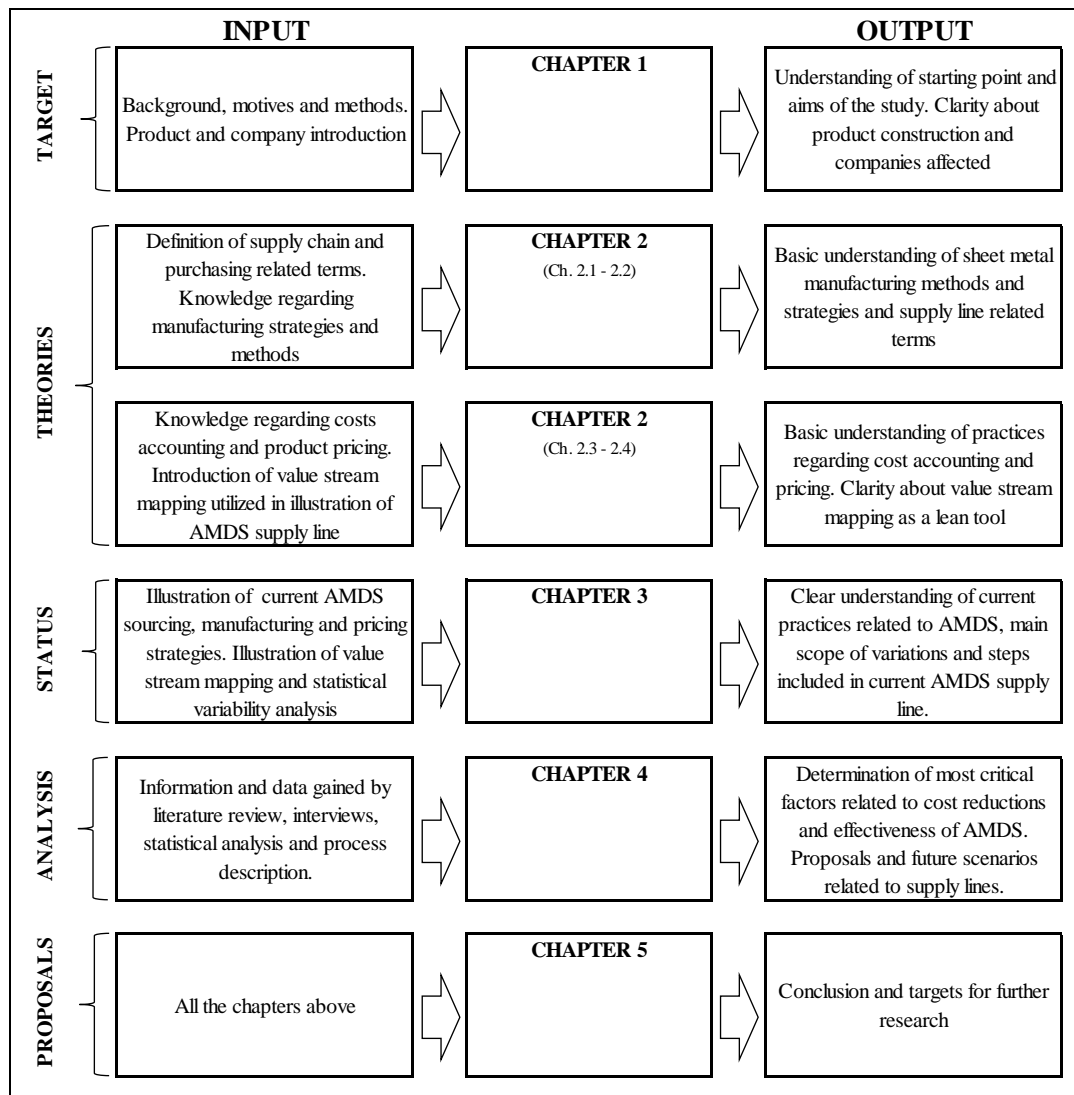
This thesis is executed in order to answer two main research problems identified in KONE's R&D department: (1) KONE Renova slim doors could be cheaper but the design is totally fixed: Can the cost reductions related to KONE Renova slim doors be achieved on the supply line side? (2) The competitiveness of the KONE Renova slim doors could be higher: Are there possibilities on the supply line side to increase overall competitiveness of the end product? The main research problems were analyzed and six diverse research questions were formed: (1) What are the characteristics of the KONE Renova slim door as

a sheet metal product? (2) How to define and illustrate the entire supply line and related manufacturing process steps (3) What are the sourcing principles related to AMDS and the role of Stera as a KONE supplier (4) How are the doors are manufactured currently? (5) Is the range of main product variables defined? Can it be determined? (6) How is the door related cost accounting executed and how is the price of the product formed? The above listed research questions are then used as guidelines for the study and goals of the research are pursued accordingly.

### 1.3 Structure of the study

This thesis consists of a theoretical part, which is later followed by an empirical part. KONE and its door supplier Stera are introduced at the beginning of the theoretical part and the basic principles of slim elevator door construction are clarified at the end of Chapter 1. The major portion of theoretical knowledge is presented in Chapter 2, which consists of four sub sections. The theory in Chapter 2 provides essential knowledge of the most important thematic entities related to the order-delivery process observed in this study. Knowledge presented in the theoretical section will ensure an understanding of the analyses executed in the empirical section. The theoretical section is also utilized when development proposals are generated and introduced.

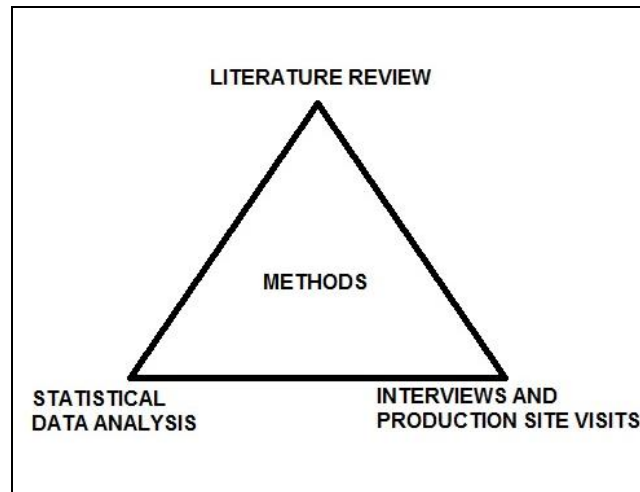
The empirical part consists of Chapters 3 and 4. Chapter 3 introduces the completed analyses and illustrates the current practices related to AMDS. Chapter 4 focuses on analysing the data produced in the analyses, introduces the proposals and defines the targets for further research. Finally Chapter 5 concludes the thesis. Figure 1 below illustrates the full structure of the thesis with inputs and hypothetical outputs per chapter.



**Figure 1.** Structure of the thesis.

#### 1.4 Methods

In this thesis three varying and independent research methods are utilized in order to find answers for the research problems and questions posed earlier. All the methods are introduced in figure 2. The literature review forms the theoretic base for the following more empirical related methods. Empirical analyses gathering the practical information are then implemented by interviews and site visits. In addition an investigation of product offering and sales volume development is done using by statistical data analyses.



**Figure 2.** Independent research methods utilized in this thesis.

### 1.5 Introduction of companies

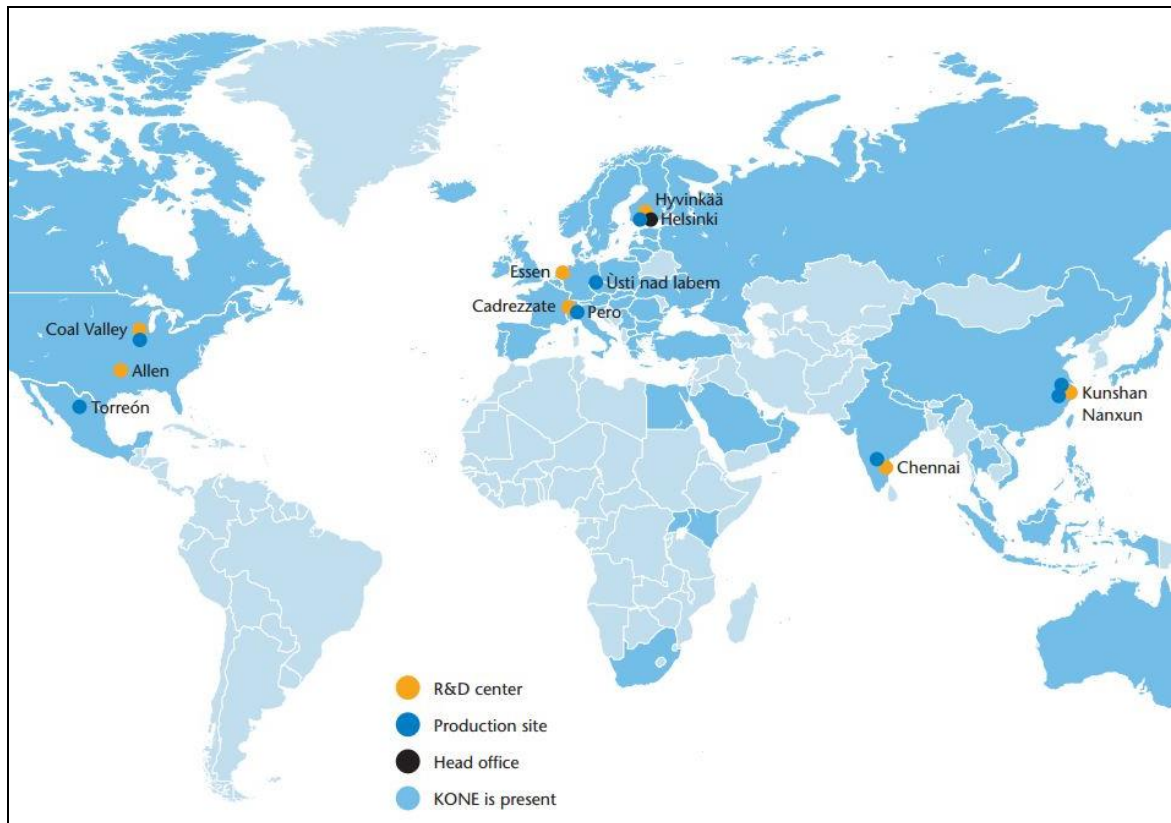
As stated in Chapter 1.1 the production and delivery of the KONE Renova slim door is outsourced. To be able to study the manufacturing sections of the supply line, this thesis collaborates with the supplier, Stera. In general there is a significant difference between business models of the companies. This chapter introduces the financial numbers and business areas of KONE and its supplier, Stera

#### 1.5.1 KONE Corporation

KONE founded in 1910, is one of the global leaders in the field of elevator and escalator business. The company provides elevators, escalators, automatic building doors and integrated people flow solutions. KONE services cover the whole lifetime of a building. The current offering consists of new equipment, maintenance and modernization businesses. The general vision of KONE is to deliver the best people flow experience with the best people flow solutions. The company has listed four cornerstones, which are urbanization, demographic change, safety and environment. These are the triggers that impact the business environment and drive KONE's business. (KONE, 2014a, p. 1–5.)

During the history of KONE that has lasted more than a century, the corporation has grown from a small Finnish machine job shop to an innovation-driven global company. In 2014, KONE serviced over million elevators and escalators and its products were available in almost 60 countires. The company had over 47,000 employees and 400,000 customers worldwide. The key customer groups were: Building owners, builders, developers and

facility managers. As figure 3 shows, KONE operations have spread all over the globe. The corporation's head office is located in Helsinki, Finland and Class B shares are listed on the NASDAQ OMX Helsinki stockmarket. (KONE, 2014b, p. 1–3.)



**Figure 3.** KONE presence and operations across the world (KONE, 2016c, p. 2).

In 2015, KONE's net sales increased by 8.3% compared to the previous year 2014 and totaled 8,647 MEUR. The new equipment business (NEB) composed the largest share at 57% and its accounted net sales was 4,935 MEUR. In 2015 the amount of new KONE elevators and escalators delivered was approximately 137,000 units. In 2015 the operating income grew and reached 14.4% of net sales. The financial position and cashflow of KONE were very sound at the end of December 2015. (KONE, 2016c, p. 4–5.)

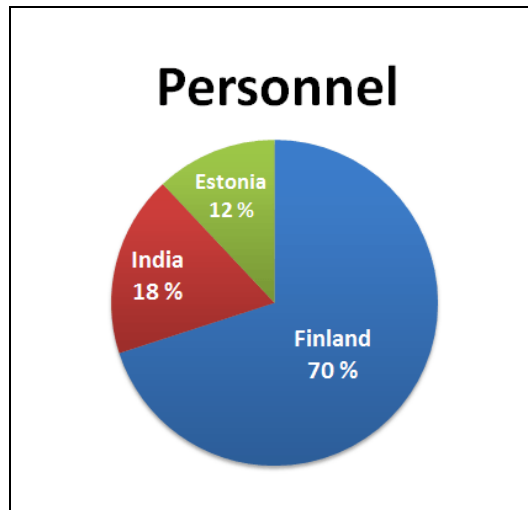
The Slim doors are mainly targeted at the service equipment business (SEB) in the EMEA market area. SEB consists of the maintenance and modernization businesses. Because of the changing industry dynamics the importance of SEB is increasing. As the installed elevator base ages modernization requirements increase. This leads to growing opportunities for the modernization business in all markets. The importance of the

modernization business is increasing within the total market in emerging markets as a result of the dynamics of a changing market. (KONE; 2015d, p. 24.)

Service business provides maintenance and performance monitoring solutions for existing equipment. It covers 31% of total net sales and totaled 2,642 MEUR in 2015. Modernization's business idea is to provide modernization solutions for ageing equipment. The modernization offering ranges from full replacement solutions where the entire elevator is modernized to the replacement of a single part. The modernization business covered 12% of KONE's total net sales in 2015 and totaled 1,071 MEUR. Modernization and service business together covered 43% of KONE's total net sales in 2015. In the maintenance and modernization business in the EMEA area the pricing environment is characterized by strong competition, especially in the markets of South Europe and also in some parts of the Central and North European markets. Another characteristic increasing the competition in the SEB business in EMEA is the short lead time. (KONE, 2016c, p. 4–5.)

#### 1.5.2 Stera

Stera is a privately owned global company group specialized in contract manufacturing of mechanical and electronical components. The company has over 60 years' experience in the field of engineering and its head office is located in Finland. Stera was established in 2007, when Levyosa Oy, Elektromet Yhtiöt Oy, Hihra Oy, Aumec Systems Oy and Beertekno Oy combined their business operations. Stera has close to 750 employees working in seven different factories around the world. Figure 4 shows where Stera's personnel are located. Overall the company has more than 55,000 m<sup>2</sup> of manufacturing area. In 2014, Company's turnover was 63 MEUR and assumed growth for 2015 is approximately 3%. (Stera, 2015.)



**Figure 4.** Distribution of Stera personnel (Stera Technologies, 2015).

Stera provides a wide range of solutions from designing and prototyping to mass production. The company has state-of-the-art machinery and in-house tool production. Stera produces high quality, competitive and customized products. Long-term partnerships and strict environmental requirements are key values of the company. (Stera, 2015.)

#### 1.6 Background of the study and history of KONE Renova slim doors

The first designs of AMDS doors were released at the beginning of twenty-first century. The car door was released in the year 2000, when KONE's TRB (KONE tendered repairs business) R&D department was still located in France. After TRB R&D department was moved to Finland, the slim landing door was released two years later in 2002. KONE Renova slim doors were an answer to the need for a compact mass produced door in the market. KONE AMDS technology was new and the width and thickness of the AMDS package were very space-efficient. KONE was the market leader in terms of the technology of slim series doors and was ahead of the competition. Since the beginning of 21<sup>st</sup> century until 2008 only minor improvements were made to the designs and competitiveness of slim doors.

In February 2008 AMDS landing door went through more significant changes when improvements to pass the EN81-58 fire rating (E60, E120, EW60, EI30 and EI60) test were implemented. Back then the landing door panel thickness was harmonized between fire rated and non fire rated panels and the construction of panel itself was improved to be

simpler and stronger. More specifically thickness of sill the profile “nose” was increased from 2 mm to 4 mm and an eccentric anti tip roller was added to the fast hanger plate. Also double bending was removed from the front uprights. Alongside the fire rating issue this R&D project targeted a reduction of costs related to AMDS, but when the new landing door version was released, it was more expensive to produce than the old model. During the following months the manufacturing costs of the revised door were decreased to the level of the old model.

In 2009 the next R&D project called “KONE Renova Ultra slim” started. The project was meant to focus purely on cost cutting, but it extended dramatically and finally the project included the aim to decrease the door package thickness. As a result, a totally new slim door was developed; including railing, sill, landing/car door panels, frame and operator. After five years of researching, development and testing the ultra slim “blue project” was terminated in 2014 due to technical challenges related to the new railing. A lot of information and knowledge was learned, but the project’s main goals were not reached.

Today the KONE Renova slim door’s design principles are basically the same as they were after the last modifications. The slim car door design is from the year 2002 and the landing door from 2008 with only improvements needed to pass the new EN81-20 safety code for elevators. Competitors are starting to overtake of KONE Renova slim technology and the new safety code will increase costs, which is not helping the situation with regards to competitiveness. Due to these facts, there is an acute need for cost cutting and increasing competitiveness. KONE has not planned a new R&D project to seek cost savings or a new design for slim doors after the Ultra slim project. As a result of the situation described above this master’s thesis project was launched.

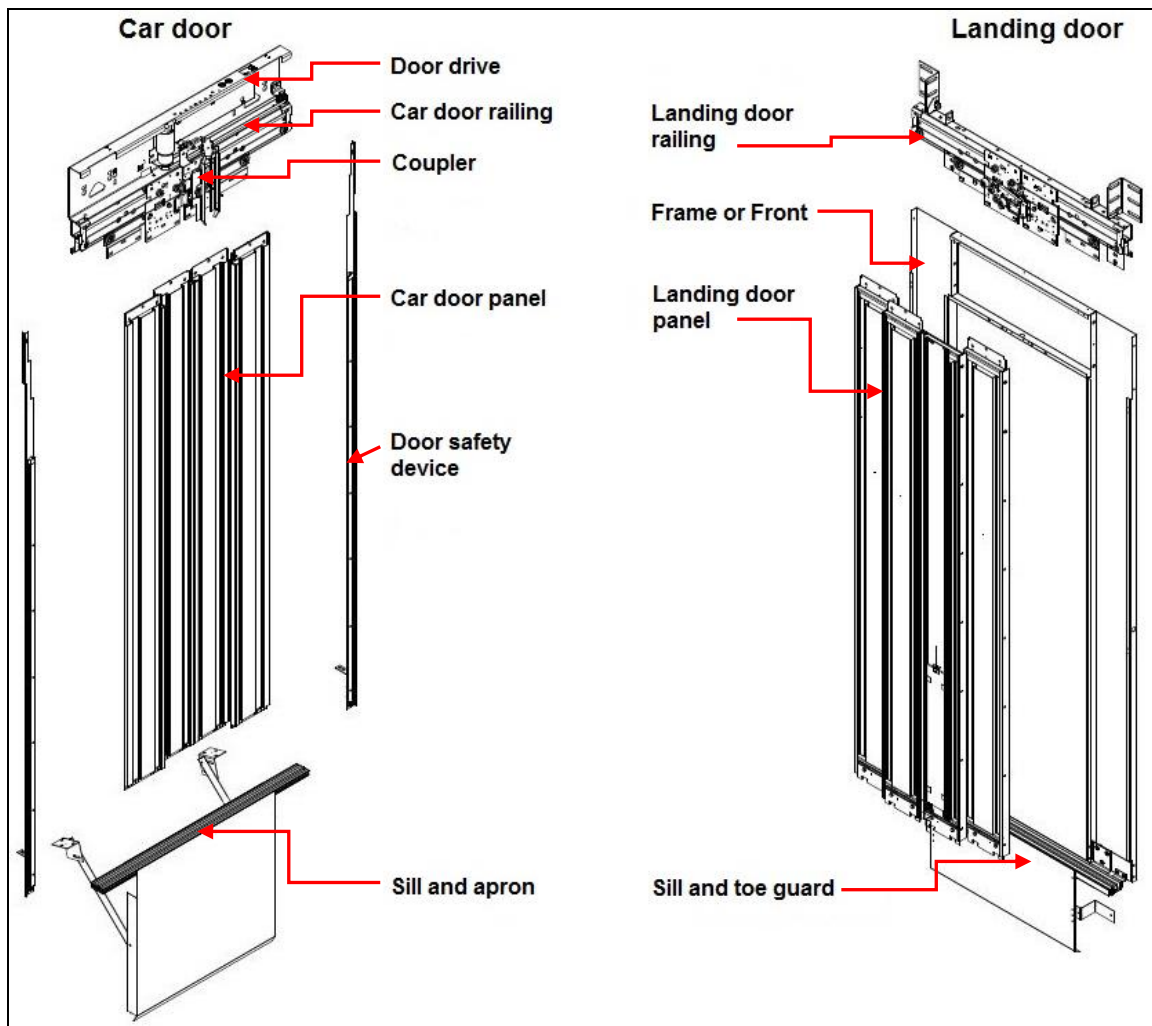
### 1.7 A general introduction of KONE Renova slim doors and their main assemblies

If we consider the entire elevator as a product, the role of doors is very important. Door functionality is critical simply because doors operate on every floor and car entrance. Doors consisting of large sheet metal surfaces also form a large part of the cost of an elevator in general. The importance of doors is further increased because their appearance is integral to the customer’s impression of the elevator. Doors can be categorized into car and landing doors. Landing doors are located in every landing entrance and car doors in the

elevator car entrance. The main function of the doors is to keep passengers safely inside the car or outside of the shaft, in other words, to prevent passengers falling into shaft. In cases of fire, landing doors also act as isolating barriers and prevent fire from spreading through the elevator shaft.

KONE Renova slim doors are automatic doors with the most compact outer dimensions. KONE uses the term AMDS for slim doors which means Advanced Modular Door Slim. More accurately the term AMDSC means a slim car door and AMDSL, a slim landing door. The usage areas of AMDS are base duty elevators located in small hotel, office and residential buildings. Slim doors are designed especially to replace manual doors, old swing doors and conventional automatic modular doors if tight space requirements are demanded. AMDS doors are also meant for cases where a passenger elevator has no car door or when an elevator is added to an existing building. Slim doors are a low volume but highly variable product. All the slim doors are safety standard EN81-20 approved. Slim landing doors are also available with fire classification, which is rare in the automatic slim door markets. The slim door complies with the following fire classifications: E60, E120, EW60, EI30 and EI60 as defined in the code EN81-58.

The slim car and landing door can be divided into major assemblies illustrated in figure 5. Most important assemblies are railing, panels, frame and sill. Assemblies included in car and landing doors differ as the figure 5 below shows. The car door has an operator (drive + railing) and a safety device, but the frame structure included only in the landing door. The frame assembly can be replaced with a front wall in the case of a car door. Every main assembly has its own location and a critical function in the door operation.



**Figure 5.** AMDSC3 and AMDSL3 major assemblies.

The drive is located on the car door railing. Assembly is the “brains” of the door and provides motive for the doors. The railing holds the door panels and guides their movement. The coupler is fixed to the car door railing and acts as the linkage between landing and car door railings. The frame is located on the landing side where it covers the gaps between the clear opening and the shaft. The door panels are the visible, horizontally moving parts fixed to the railing and sill. While the sill is the lowest module of the door; it also guides the movement of the door panels. The apron and toe guard are fixed to the sill and are required for safety reasons. The main assemblies and their subassemblies are introduced more specifically in Chapters 1.7.1–1.7.6.

The main types of slim doors are AMDS3, AMDS4 and AMDS6. AMDS doors can be further subcategorised into a six different door types depending on the location of a door,

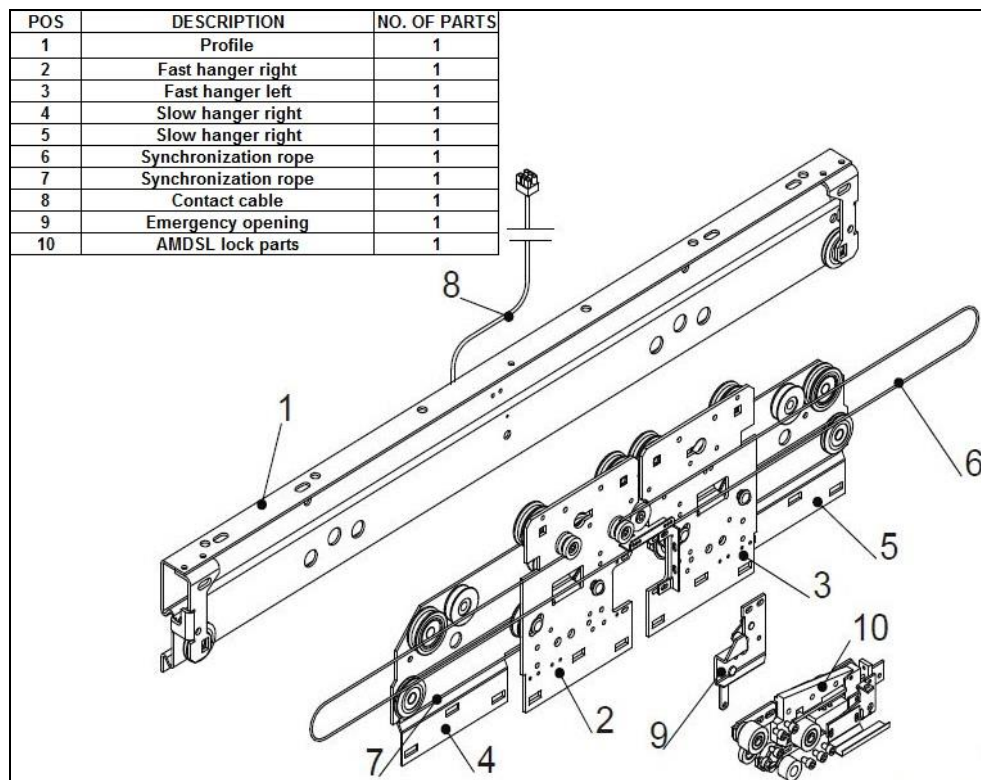
the amount of door panels and opening strategy. Type AMDS6 is not available with a fire classification. The amount of panels opening in the same direction increases the depth of the whole door package. The more panels there are the higher material consumption, and less space is available in the shaft for other components. All the different slim door types with their opening directions are presented in figure 6. The most common slim door type ordered during years 2008–2015 was four-panel centre opening door AMDS3.

TYPE	FIGURE	DESCRIPTION
ReNova Slim L3 R		Four-panel centre opening door, lock on the right
ReNova Slim L3 L		Four-panel centre opening door, lock on the left
ReNova Slim L4 R		Three-panel to the right side opening door
ReNova Slim L4 L		Three-panel to the left side opening door
ReNova Slim L6 R		Three-panel asymmetrical opening door, lock on the left
ReNova Slim L6 L		Three-panel asymmetrical opening door, lock on the left

**Figure 6.** Different types of KONE Renova slim door. = Drive motor position, = coupler position.

### 1.7.1 Railing

The railing is the functional mechanism locating above the door panels. The main duty of railing is to enable horizontal movement of the door panels. Car- and landing door railings, along with sills and the car door drive carry out and allow the opening and closing operations of slim doors. The upper part of the car door railing is attached to the drive and the underside to the car door panels with fixings. The upper part of the landing door railing is fixed to the shaft wall with two fixing brackets and the bottom part to the landing door panels with fixings. Slim railings vary based on the ADMS door types, namely 3, 4 and 6. Every door type has its own railings for car and landing door side. Slim railings for the car door and landing doors have the same basic structure but also differences can be found between the assemblies. The emergency opening devices differ between AMDSC and AMDSL railings. A coupler is attached only to the car door railing and a closing device only to the landing door railing and door panels. Also the railing profile design varies between AMDSL and AMDSC. Figure 7 below illustrates the centre opening slim railing of a landing door. The landing door railing assembly consists of a railing profile (top track body), hanger rollers, fast hanger plates, slow hanger plates, synchronization ropes, emergency opening device, AMDSL lock parts, contact cable and other smaller parts.



**Figure 7.** Parts of AMDS railing type 3; centre opening.

The railing profile also known as the top track body is made of roll molded zinc coated sheet metal. In order to ensure the smooth operation of the railing, the top track body must withstand horizontal and vertical bending stresses. Hangers are subassemblies of the railing that are also made of zinc coated steel. Door panels are attached to the hanger plates. Multi panel railings always contain slow and fast hangers which are synchronised together. Four panel centre opening doors (AMDS3, AMDS6) include two fast panels and two slow panels. Three panel side opening doors (AMDS4) include three speed doors, fast, middle and slow panels. Rollers and bearings of slim hangers are chosen according to the light-duty class. The main synchronization of railings is used to improve railing functionality, to remove the need for a second coupler and to allow increased LL dimensions to be used in narrower shafts. Synchronization consists of rollers, steel ropes and fixings. All hangers opening in the same direction are synchronized. During operation the speed of fast hangers is two times higher than the speed of the slow hangers. The middle hanger's opening speed is between the fast and slow hanger's speed.

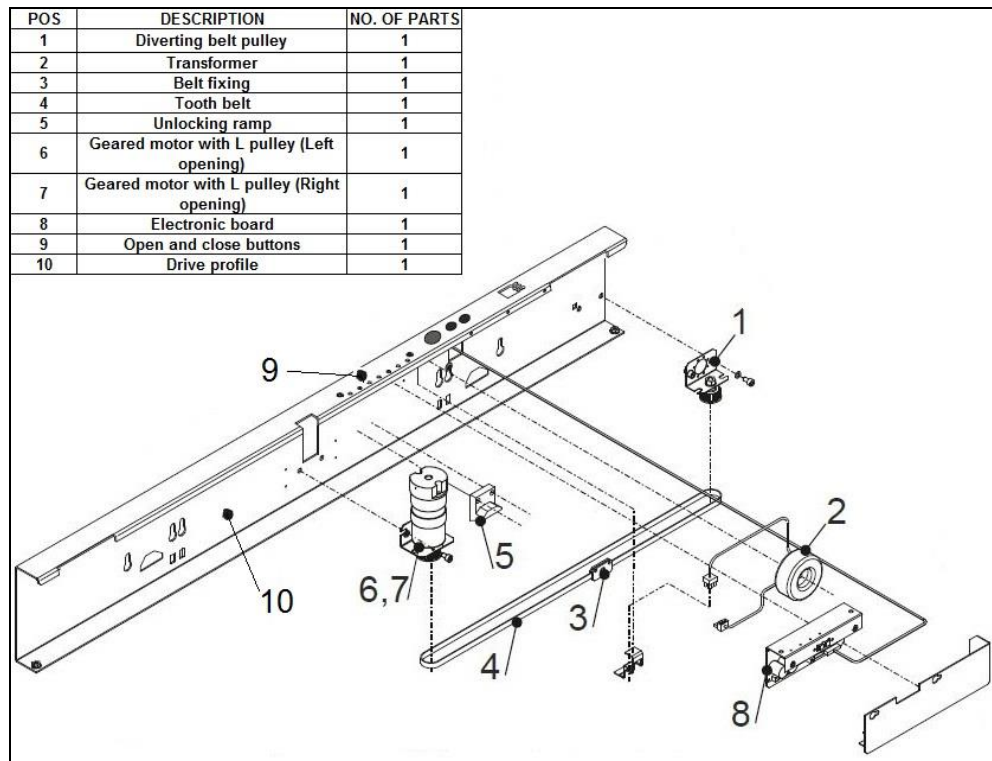
The current safety code EN81-1 and the new EN81-20 defines the emergency opening and closing device as obligatory assemblies for AMDS. The emergency opening device is fixed to the top track bodies of landing and car door railings. The design of the mechanism needs to be according to the given safety code regulations, but still no universal design exists for KONE AMD products. In case of emergency the emergency opening device ensures that doors can be opened manually from the outside and passengers are able to leave the elevator car. The second obligatory mechanism is the closing device, which is fixed to AMDSL hangers and door panels. The slim closing device operates with a closing weight. The purpose of the mechanism is to close the landing doors automatically when the elevator car with its coupler is not present. This function is needed for example during maintenance services. The closing device also helps the car door operator to close the doors during normal operations.

### 1.7.2 Drive

Every KONE elevator with advanced modular doors has a drive assembly located above the car door railing. It is the unit which controls the operations of the doors. Together with car door railing it forms a door operator. The drive is fixed to the elevator car with an operator fixing set. KONE AMD Drive 10 is used with slim doors. It provides the noiseless and

smooth opening and closing operations of the doors. Drive 10 is suitable for low range elevators with up to 200,000 door cycles per year (1 cycle = open + close). KONE AMD Drive 10 is an evolution of the older KONE AMD drive 1 with improved eco-efficiency, reliability and ride comfort (drive curve can be selected automatically). Maximum movable masses with the drive 10 are limited to 130 kg and its estimated lifetime is 5 million cycles if maintained according to instructions.

As figure 8 below shows, the main parts of the drive 10 are motor and gear, door control board, open and close buttons, power supply connections, transformer and tooth belt. These components are fixed to a drive profile made of sheet metal. The AMD Drive 10 can be used with side and centre opening door types. Because the slim door types have different amounts of door panels and varying opening strategies, the AMDSC types 3, 4 and 6 have their own designs of drive profile. Therefore, all the slim car door types also have different codes for the drive assembly. However the general functionality of the varying assemblies is still the same. The only significant exception is AMDSC4 side opening 3-panel door, which has an alternative of low headroom operator. The low operator is lower and deeper than the regular operator with the same functionality.



**Figure 8.** AMDSC3 drive 10, centre opening.

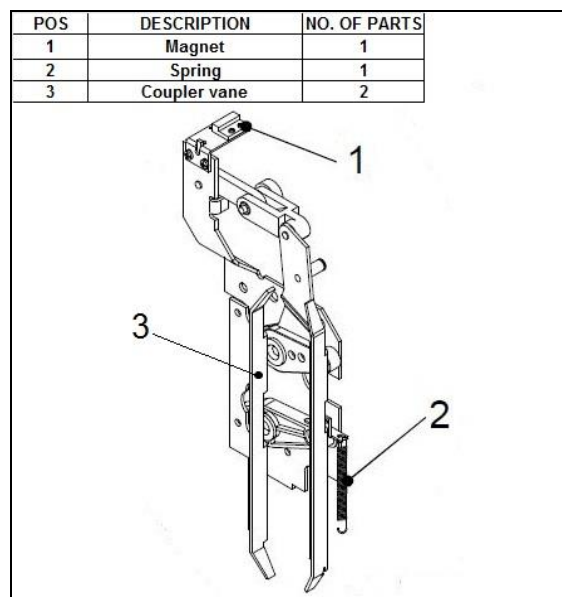
The drive 10 motor is a brushless permanent magnet motor, with gear ratio of 13:1 and VF3 control. AMD 10 drive control board receives input signals from KCECPU / LCECPU elevator control unit and manages the operations of the drive motor accordingly. If the doors need to be operated, the drive control board starts the motor and the toothed belt + pulleys transmit the power to the railing. Drive control system also gives output signals to the elevator control system about door positions and safety devices.

### 1.7.3 Coupler

The coupler is an assembly integrated into car door railing, whose main purpose is to act as a link between car and landing doors. The coupler opens the locks of landing door and enables the transmission of car door's horizontal movement to the landing doors. Two lock rollers attached to the landing door railing make this operation possible. KONE couplers are pressing couplers or strut couplers depending on how the coupler vanes are bevelled. When the car door arrives at the landing the landing door lock rollers pass between coupler vanes in case of a pressing coupler or the outer sides of the vanes if a strut coupler is used. With a pressing coupler the lock rollers are pressed together and the dynamic lock roller moves and opens the door lock. With a strut coupler the coupler vanes are normally pressed together. When the coupler vanes spread out the dynamic lock roller moves and opens the lock. The static roller never moves, it is only present to activate the car door lock. After horizontal opening movement of the car door begins, interlocking ensures simultaneous sliding of car and landing doors. Due to the main synchronization of the door railings, only one coupler is needed. A Magnet is also attached to the coupler to act as a close end switch. It indicates to the door control board when doors are fully closed. The magnet is further required when the operation program is taught to the doors.

For slim doors there are various couplers available. Slim couplers are strut couplers with the same basic principle but varying design depending on the vane length, installation side (right or left side hanger), and lock type which can be either car door lock or emergency opening device or both. Strut coupler requires less space - is more compact than pressing coupler and therefore used with slim doors. Lock and emergency opening device for the couplers are obligatory according to the code EN81-20, but couplers are still offered without these mechanisms. Vane lengths for slim couplers without a lock are 300 mm (symmetric) and 400 mm (asymmetric). Lock couplers have vane lengths of 360 mm

(symmetric) and 440 mm (asymmetric). Optimal position of the landing door lock roller is at the middle position of the coupler vanes. Coupler vanes are designed for an asymmetrical lock roller position also but the expected lifetime is not as long as with the symmetrical version. Different vane lengths are needed because the height of landing doors can vary within the building. Slim coupler manufacturing is outsourced to supplier Wittur. A Symmetric version of slim coupler without a lock is shown in below figure 9.



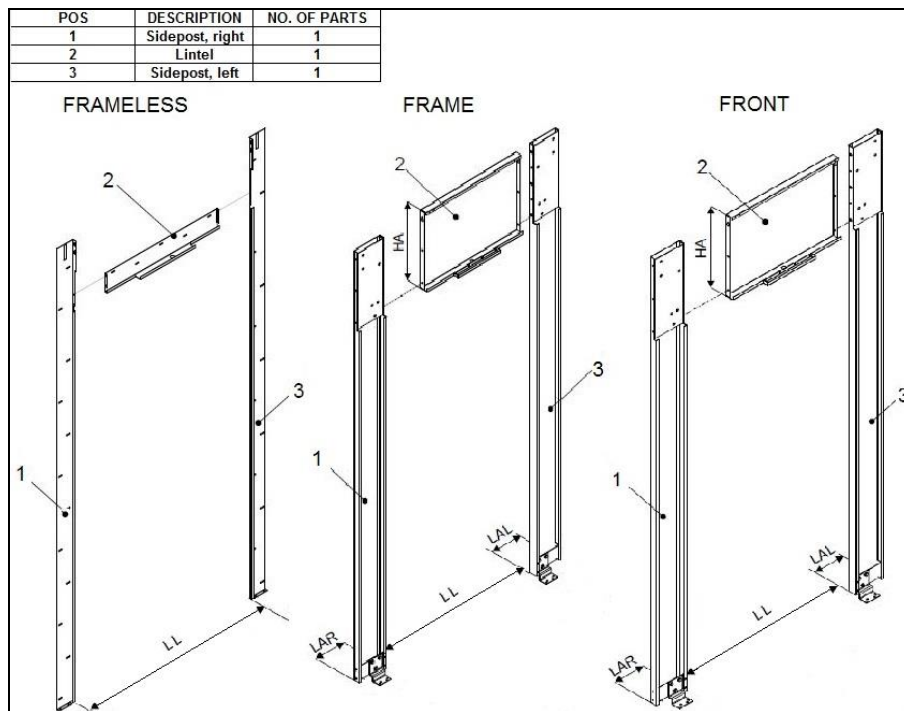
**Figure 9.** Symmetric slim coupler 602782G03 without a lock. The Vane length of the coupler is 300 mm. In symmetric couplers the vanes are equal length.

#### 1.7.4 Frame

The frame is the visible assembly in front of the elevator door landing. It covers the edges of the opening to the shaft and has therefore a very important visual factor. In case of side opening doors the side part of a frame also acts as a stopping buffer for the door panel's leading edge. The frame consists of three pressed sheet metal profiles and other smaller subassemblies. Slim frames have a "single skin" structure. It means there are no separate body- and decoration plates. The lintel is the upper part of the frame, locating above the landing door clear opening. Sideposts, also known as slamposts in case of side opening doors are the side parts of the frame locating on the each side of landing door clear opening. The bottom sides of sideposts are fixed to the sill while the top sides are attached to the lintel and the landing door railing.

The main types of slim frames are Frameless, Frame and Front. Frame types Frame and Front are available with a maintenance access panel and certificated fire insulation. In addition the three slim frame types vary from each other by the height of door lintel (HA) and width of right and left sideposts (LAR) and (LAL). The fourth significant variable is the the clear opening width of the entrance (LL) which varies depending on the AMDS door type. The above mentioned dimensions are defined in figure 10 along with the slim frame types.

Due to the LL dimension, all the slim door types 3, 4 and 6 have their own models of Frameless, Frame and Front. For slim frame type Frameless HA, LAL and LAR dimensions are 0, for type Frame HA, LAL; LAR dimensions are 99.5 mm and for type Front the dimensions are the following: HA = 120–800 mm, LAL = 120–430 mm and LAR = 120–270 mm. Slim frame types Frameless and Front have a material thickness of 1.5 mm while type Frame is made of 1 mm thick sheet metal. As the frame has an important visual function, the slim frame offering consists of a wide range of different materials and painting possibilities. The most common slim frame materials during the years 2008–2015 were brushed stainless steel and zinc coated steel. The strength requirements are given in the standard EN81-20 (pendulum impact test) for sideposts wider than 150 mm. Manufacturing methods used for the slim frames are punching, bending and welding.



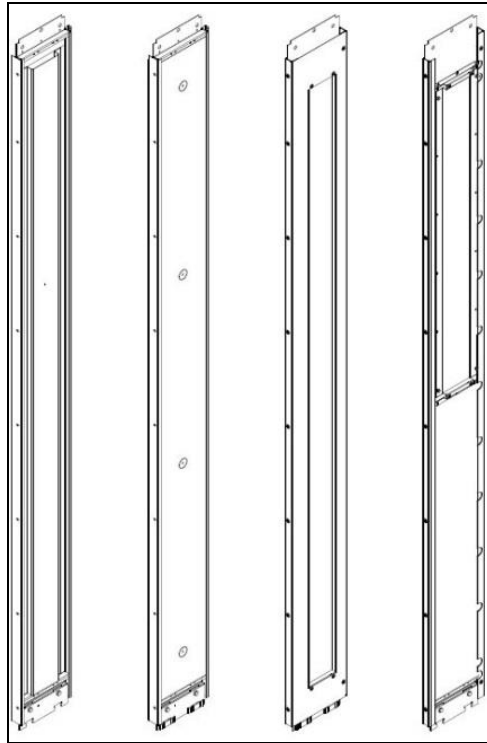
**Figure 10.** AMDSL3 frames and fronts. Where LL = Clear opening width of the entrance, HA = Height of door lintel, LAR = Width of right sidepost and LAL = Width of left sidepost.

#### 1.7.5 Panels

The door panels are the main visible element of AMDS. Door panels are located in front of every landing and car entrances. The main purpose of the door panels is to cover car and landing entrances when the doors are closed. The panels are fixed to railing hangers with panel fixing set. A sliding shoe assembly consisting of steel plates and plastic sliders is attached to the bottom side of every door panel and panels are then allowed to run in the sill grooves.

For AMDSC and AMDSL there are three main types of door panels available: Steel panel, partial height window panel and full height window panel. Figure 11 below illustrates all the different slim panels. AMDSL steel panels are fire classified according to fire classes presented in Chapter 1.7. For the full and partial height window panels there are several restrictions; window panels are not fire rated and not available with frameless door types 3 and 4. Also some general panel materials and LL dimensions are excluded from the window panel offering. The door panel width and height are calculated regarding the given LL and HH (clear opening height of the entrance) dimension of the opening. For different

slim door types the calculation formulas differ. Slim panels are offered with wide range of materials. During the years 2008–2015 the most common panel material was brushed stainless steel.



**Figure 11.** The panels of slim landing door type 3. From left to right: Steel panel, steel panel with fire classification, full height window panel and partial height window panel.

AMDSL panel designs are different compared to AMDSC panels. Generally the AMDSL panel has a “double skin” construction, which means the door panel structure has two different layers. The Panel consists of an inner body plate with material thickness of 2 mm and an outer 0.8 mm thick decoration plate. The body plate material is Rautaruukkis` zinc coated Z100 MAC sheet metal. The mass of the zinc coating for this type sheet metal is  $100 \text{ g/m}^2$  and the thickness of the coating  $7 \text{ }\mu\text{m}$ . The decoration material can differ according the client`s needs. The maximum single panel weight is limited to 35 kg. In order to meet the EN81-20 requirements a separate stiffener is needed for the body plate. The door panel stiffener is a hat profile and connected to door body part by spot welding. Fire rated landing door panels structures differ compared to regular panels. The fire classified panels have additional features such as insulation material or fire labyrinths. Fire rated landing door panels are wider than non fire rated car door panels. This causes the

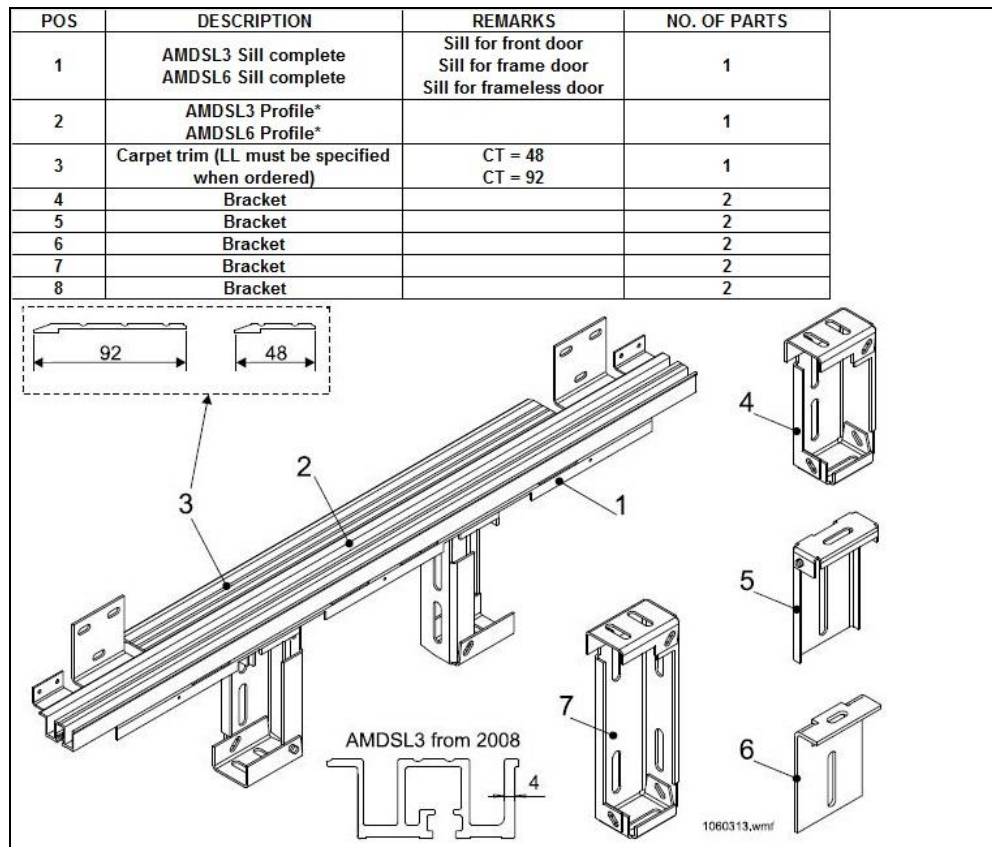
need for extended opening of AMDSC panels. To be able to fully open the landing door, the car doors need to over extend during the opening operation. For the centre opening doors the needed extra opening distances are 7.5 mm per side and 15 mm in case of side opening doors. With certain fireclasses no separate body plate stiffener is needed for AMDSL because the fire insulation structure itself makes the panel stiff enough. If stiffeners or fire insulation structure is taken into account, AMDSL panel structure can be defined as “triple skin”. The main manufacturing phases for the slim door panels are puching, bending, welding, gluing and assembling.

#### 1.7.6 Sill, toe guard & apron

The sill is the lowest assembly of slim car and landing doors. Sill designs for AMDSL and AMDSC vary but the functionality is the same. The sill guides the sliding movement of door panels from the bottom. The door panel sliding guides which include plastic sliders prevent the door from dropping out of the sill groove. The main parts of the sill are toe guard, the profile itself and fixing brackets. The slim landing door sill profile is located inside the elevator shaft. The sill assembly can be connected either to the entrance wall or to the shaft wall. The shaft wall connection is the most typical. The sill fixed on the floor is used when the whole landing entrance must be installed on the floor. The reason for its use is if there's not enough space inside the elevator shaft. Then the entance must be located on to the floor. This is typical with through type elevators. The AMDSC sill is fixed to the elevator car.

When AMDSL and AMDSC are fitted in the same elevator the gap between sills is 25 mm. The four-panel center opening door AMDS3 and three-panel asymmetrical opening door AMDS6 need only a two groove profile, but the four panel side opening door AMDS4 uses a three groove profile. Due to this the sill profile of slim door type 4 differs from sill designs of door types 3 and 6. For all the door types several different sill fixing brackets are available which increases the variety of sills. Figure 12 illustrates the AMDSL3 and AMDSL6 slim sill profile with different fixing brackets. The optional carpet profiles detailed in the figure are profiles covering the gap between sills and landing finishing. For the sill of AMDSC the optional carpet profile covers gap between sill and car floor finishing. The slim sills are required to carry 4,000 N when applied onto 2 points. This imitates the normal passenger use of elevator. The load limit also allows the use of light

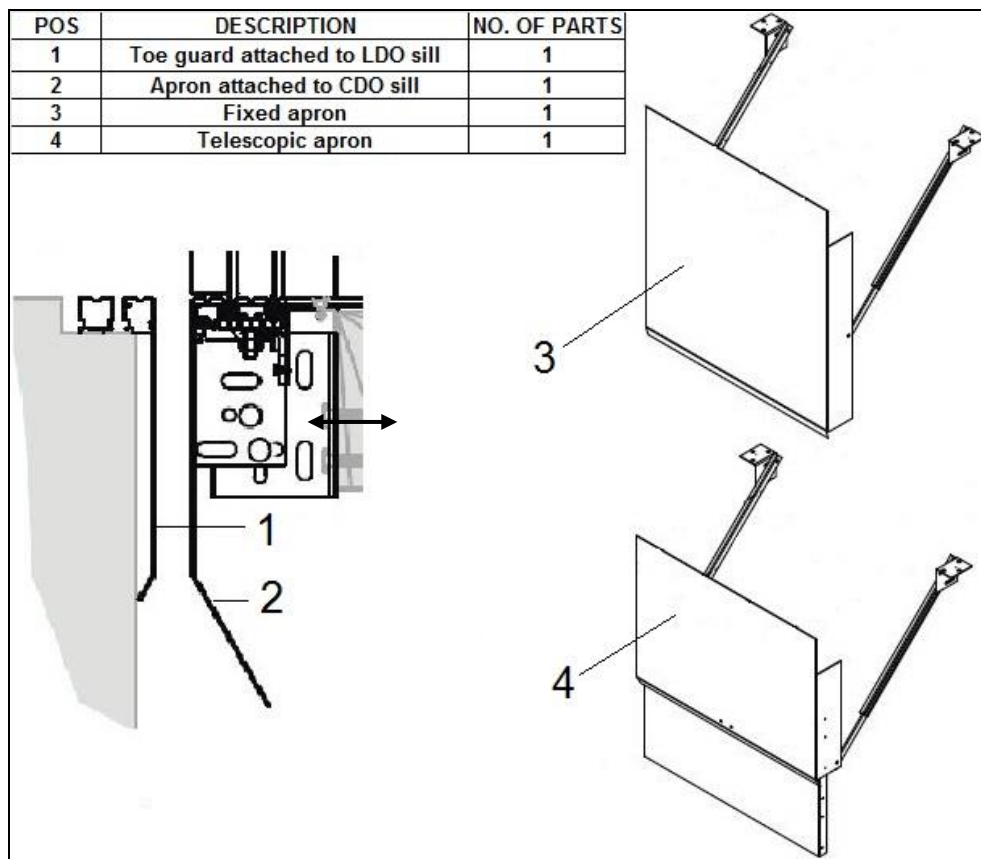
trolleys. The stiffness of the construction is verified with a shock pendulum test. During the test the sill must be able to hold the door panels in their place. Currently there are no standards concerning sill durability. AMDS sill profile materials are aluminum or stainless steel.



**Figure 12.** AMDSL3 and AMDSL6 sill.

The toe guard attached to landing and car door sills are obligatory components according to the standard EN81-20. The AMDSC toe guard is known more specifically as an apron. The Apron height is 750 mm and its design can be fixed or telescopic. A telescopic apron is required if the pit depth is 650-1,100 mm. AMDSL standard toe guard is always fixed and has a height of 350 mm. As an exception an AMDSL lower toe guard with height of 240 mm is available for KONE MaxiSpace elevators. The toe guard is fixed to the AMDSL sill and the apron to the sill of the AMDSC. The toe guard protects toes or fingers against crushing if the elevator moves when the doors are open. This should never happen but can happen accidentally during, for example in rescue situations when the elevator break is released by a serviceman and a minor movement might happen when landing and

car entrance are not at the same level. The toe guard's height equals the height of coupler vanes. The apron's main duty is to prevent passengers falling into the shaft. Exempli gratia in emergency situations apron blocks the gap between car floor and landing entrance when the car is stuck above the landing floor and doors are the opened by a serviceman. The telescopic apron also has a safety switch function. The different function of each explain why apron height is greater than toe guard's. If a door's LL dimension is greater than 1,200 mm two aprons / toe guards are needed in parallel. Apron and toe guard material options are zinc coated steel or brushed stainless steel. Figure 13 below shows how the apron and toe guard are placed and illustrates fixed and telescopic aprons more accurately.



**Figure 13.** Location of toe guard and apron and different apron types.

#### 1.7.7 Opening and closing operation

KONE AMDS doors with drive 10 are configured with two different opening-closing curves that define the speeds related to operations and adjust the door times. The standard curve focuses on maximizing the performance and Asia curve improves the ride comfort of closing-opening operations. A microcontroller located in the car door operator

automatically selects the curve type depending on the door width and no specific activity is needed by the serviceman or installer. As a rule of thumb, most of the centre opening slim door types AMDS3 and AMDS6 are opening-closing using the Asia curve and most of the side opening AMDS4 doors operate using the standard curve. More accurately the door microcontroller selects the speed curve depending on the panel movement distance: If the panel movement distance is 695 mm or lower the Asia curve is selected. In cases when the panel movement distance is greater than 695 mm, the standard curve is chosen.

Sliding door components have a lot of kinetic energy when the doors are moving. The safety code EN81-1 limits the maximum allowed kinetic energy with normal operation speed to 10 joules and with nudging speed to 4 joules. This rule defines the allowed operation speeds for elevator doors. For both Asia and Standard curves there are four different opening and closing speeds available. In general opening speeds are higher than closing speeds and the Standard curve's speeds are greater than speeds available with the Asia curve. In addition to the main closing and opening speeds acceleration speeds and jerk speeds are also listed in the following figure 14 along with nudging and coupler speeds. Acceleration speed describes how fast the door reaches the operating speed or nudging speed. Jerk speed illustrates the rate of acceleration or deceleration change and nudging speed is a reduced operation speed to be used in situations where extra caution is demanded. For example if the door safety device (curtain of light) is interrupted during the door closing motion, the door operator opens the doors immediately and after a timeout the doors start to close with nudging speed. Also if the doors are staying open longer than the predefined opening time; the doors will close with nudging speed even if the curtain of light is interrupted. The following figure 14 shows the opening and closing speeds of the standard curve.

Opening speed with standard curve

Parameters	Speed 1	Speed 2	Speed 3	Speed 4
Speed [m/s]	0.23	0.31	0.38	0.46
Acceleration [m/s <sup>2</sup> ]	0.43	0.57	0.71	0.85
Jerk [m/s <sup>3</sup> ]	0.75	1	1.25	1.5
Nudging speed [m/s]	0.08	0.10	0.13	0.15
Coupler speed [m/s]	0.15			

Closing speed with standard curve

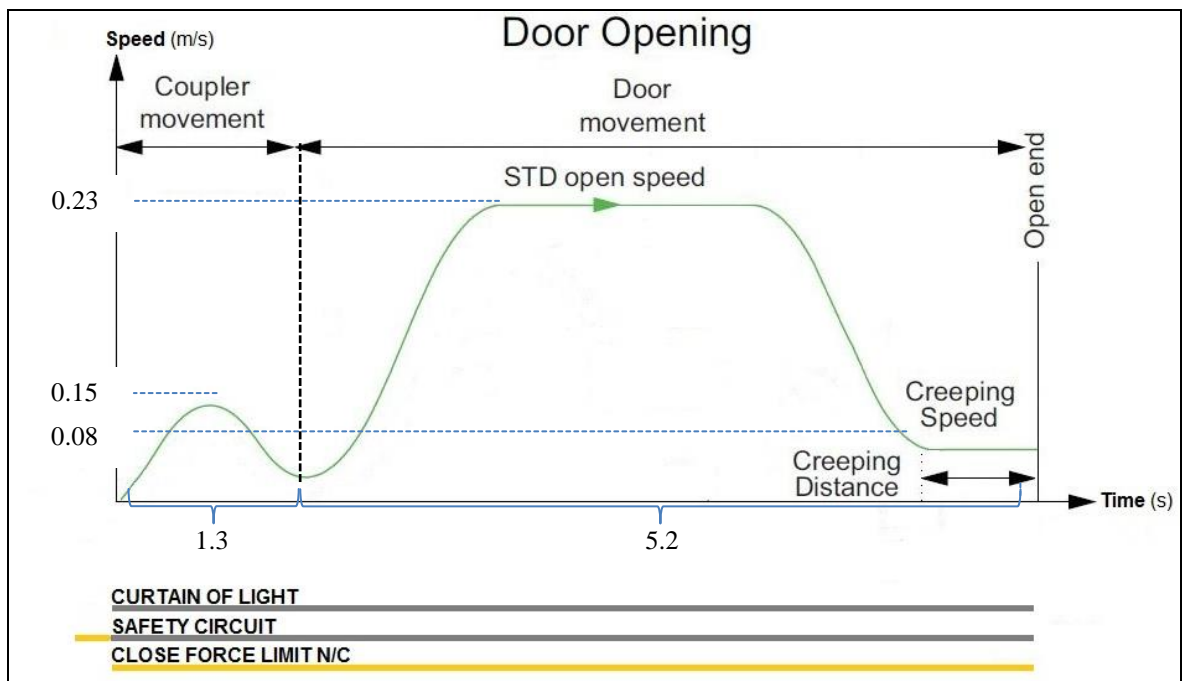
Parameters	Speed 1	Speed 2	Speed 3	Speed 4
Speed [m/s]	0.17	0.22	0.28	0.33
Acceleration [m/s <sup>2</sup> ]	0.43	0.57	0.71	0.85
Jerk [m/s <sup>3</sup> ]	0.75	1	1.25	1.5
Nudging speed [m/s]	0.08	0.10	0.13	0.15
Coupler speed [m/s]	0.15			

**Figure 14.** Four different opening and closing speeds of standard curve.

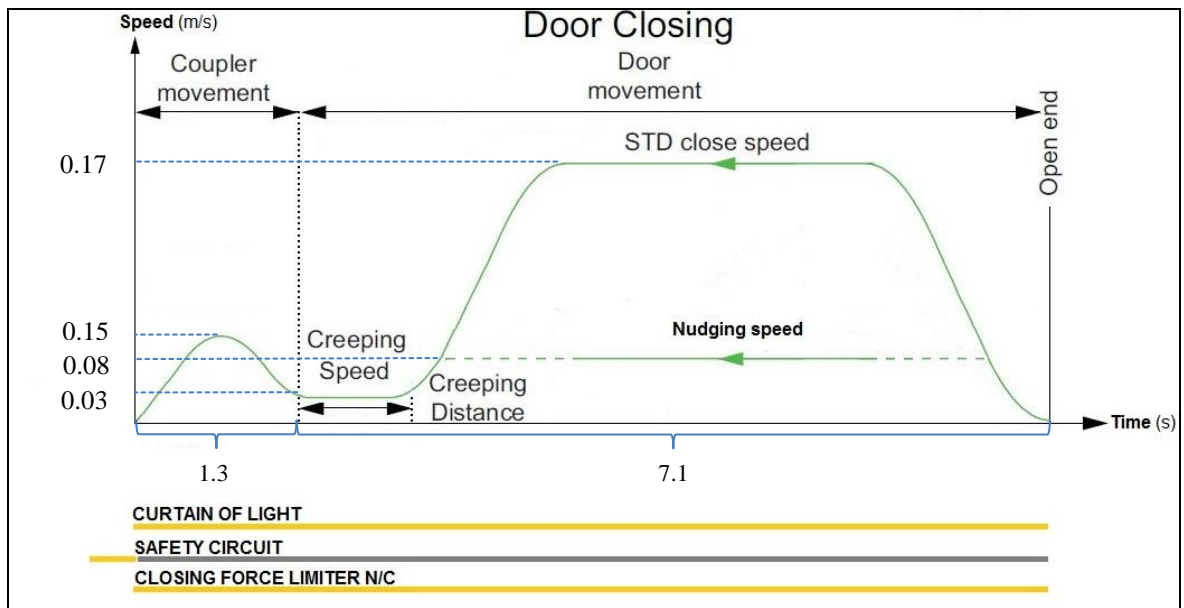
Along with operation speeds, the second important variable related to the door function is the operating time. Door operation times depend on the selected speed, door masses, friction, mechanical adjustment and the alignment of landing doors. The wider the door width, the longer the door opening-closing times are. In general the door opening times are shorter than the closing times. Another point to note is that, centre opening slim door types 3 and 6 operate significantly faster than side the opening slim door type 4. For example AMDS opening times for side opening doors vary between 2.3–6.3 s and closing times from 2.9 s to 8.9 s. Center opening AMDS opening times vary from 1.7 s to 4.9 s and closing times between 2.1–6.4 s. Coupler operation time in closing-opening operations with the Asian curve is 2.0 s and with Standard curve 1.3 s.

When curve type, operating speeds and times are defined the door opening and closing curves can be illustrated. Curves show for instance which component is moving, how the operative speed varies in different sections of opening and closing operation, how much time has elapsed and when safety components are activated. Standard open and closing curves for AMDS3 are shown in figures 15 and 16. The door opening time is 5.2 s and closing time 7.1 s for the side opening door type with speed class 1 and door width of

1,000 mm. Before opening operation begins a safety circuit monitors the doors. This circuit is disabled when the opening operation begins. At the beginning of the opening process the closing force limiter is activated and door coupler opens with speed of 0.15 m/s. Then the door accelerates ( $0.43 \text{ m/s}^2$ ) to the defined operation speed of 0.23 m/s. This operation speed is maintained until the door panel reaches the offset position of the reference switch. After the offset position is passed, doors are nearly fully opened. The distance between the door fully open and offset positions is known as creeping distance. For AMDS with Standard curve the creeping distance is 10 mm. In the creeping distance the door operating speed is decreased to 0.03 m/s and the opening process is finished carefully. The closing operation is generally the reversed opening operation with a lower operation speed. The curtain of light is activated and nudging speed can be triggered if unexpected actions occur. After door panels are fully closed, the door coupler closes and door is fully closed.



**Figure15.** AMDS3 standard opening curve with speed values and operation times. Safety component activity: ■ = Enabled, ■ = Disabled.



**Figure 16.** AMDS3 standard closing curve with speed values and operation times. Safety component activity: ■ = Enabled, ■ = Disabled.

#### 1.7.8 Main elevator platforms for KONE Renova slim doors

The three main elevator platforms offering AMDS doors are: MonoSpace, MaxiSpace and NanoSpace. These platforms include not only ADMS door, but an entire elevator with all its essential components. In addition to these platforms there are important modernization packages for slim car- and landing-doors. AMDSL and AMDSC modernization packages include only the main parts of KONE Renova slim car or landing doors, allowing the possibility to order the AMDS doors packages for an existing elevator. As they are two separate modernization packages, the landing and car door can be ordered individually. The car door modernization package always includes door operator, door panels, fixing brackets, lock ramp, photocell device, traveling cable, lintel and sill and apron. Whereas the landing door modernization package contains door railing, door panels, fixing brackets, lock ramp, lintel, frame, sill and toe guard.

First of the main elevator platform to be mentioned that currently offers an AMDS door is MaxiSpace, which is a machine roomless SEB platform designed to fit into an existing building. MaxiSpace is offered with full replacement (FURE) and existing building (EBULI) solutions. In case of an EBULI solution, the building does not have an existing elevator and MaxiSpace can be fitted into an integrated steel shaft, which is cut into, for example, the staircase of the building. In FURE solutions the target building had an

existing elevator, which is now removed and MaxiSpace installed into the existing shaft. MaxiSpace has no counterweight, which enables it to utilize the 50% greater car sizes compared to elevators with a counterweight in the same size shafts. The rope force balancer included in MaxiSpace keeps and sustains a favorable rope force ratio and compensates for rope elongation. The MaxiSpace performance specification is as follows: Max travel = 25 m, max number of floors = 10, roping = 1:6 or 1:10, max speed = 0.63 m/s and load range = 225 kg to 450 kg, car entrances = single entrance or through-type car. The MaxiSpace platform will be retired at the end of 2016 and the NanoSpace platform will replace it.

NanoSpace was released in 2014 and is a machine roomless SEB platform used only for FURE applications. NanoSpace can be delivered in small groups consisting of two elevators. NanoSpace is not suitable for EBULI solutions, because no steel shaft is included in the offering as with MaxiSpace. NanoSpace is without a machine room and is a space efficient solution that combines rope suspension and a belt drive. NanoSpace utilizes dual counterweights which are located on the each side of the elevator car. Due to this feature the amount of balancing weight can be set accordingly, which makes NanoSpace an energy efficient solution compared to MaxiSpace. Currently NanoSpace is offered only with AMDS doors. The performance specification of NanoSpace is as follows: Max travel = 40 m, max number of floors = 16, roping = 1:1, max speed = 1 m/s and load range = 240 kg to 630 kg, car entrances = single entrance or through-type car, counterweight balancing percentage = 0-30%.

Unlike the two other mentioned AMDS platforms the MonoSpace 500 is a NEB platform fully pre-engineered for new buildings. However the platform can also be delivered as a full replacement solution. MonoSpace 500 is a more flexible NEB elevator system compared to the more traditional types of NEB platforms. The flexibility is achieved through a design based on modular technology and an industrialised process throughout sales, engineering and delivery. With MonoSpace 500 the slim doors are delivered to new buildings and for full replacement solutions. The performance specification of MonoSpace is as follows: Max travel = 75 m, max number of floors = 24, roping = 2:1, max speed = 1.75 m/s, load range = 240–1,150 kg, car entrances = single entrance or through-type car counterweight balancing percentage= 40-50%.

## **2 ORDER-DELIVERY PROCESS RELATED THEMATIC ENTITIES OF A SHEET METAL PRODUCT**

In KONE the advanced modular door slim is often handled as a compact elevator door, but from a manufacturing point of view the door is essentially handled as a sheet metal product. The order and delivery process of a sheet metal product is a very extensive field of research. The purpose of this chapter is to provide literature based theoretical information regarding the most important subject areas related to this study. Hereby this chapter ensures a proper understanding of the subjects handled in the empirical part and supports the findings of the following empirical research.

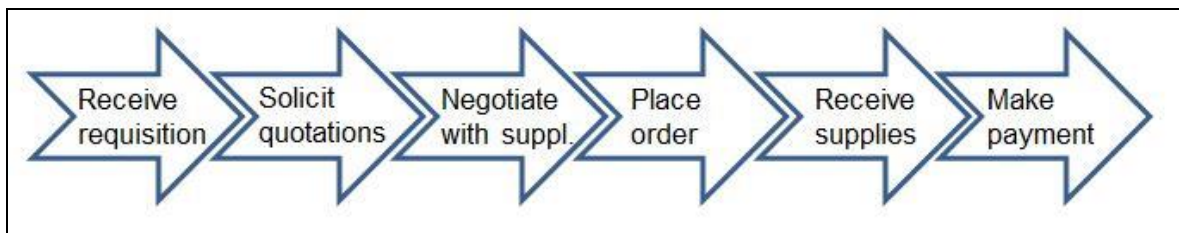
### **2.1 Definition of purchasing and supply chain related terms: Purchasing, supply management, materials management, supply chain, supply chain management, sourcing, purchaser's portfolio and outsourcing**

At first it is essential to define many terms related to the sourcing and supply chain because these subject areas are closely related to supply line of products in general. The following terms are characterized by complex and overlapping definitions and the definitions vary depending on the publication.

Purchasing is a wide ranging term which can be approached from various perspectives and at the same time it should be pointed out that no single definition can fully define the diversity of purchasing. The classic definition of purchasing is described in literature by the 5 rights. By these five right aims a purchasing group tries to deliver maximum value to the organization. Monczka et al. (2009) define the five right aims as: “getting the right quality, in the right quantity, at the right time, for the right price from the right source.” (Monczka et al., 2009, p. 39.)

In a wider perspective purchasing can be handled as function, process, profession, discipline, relationship or as a link in the supply or value chain. In this thesis purchasing is mainly seen as a function, but also as a process. When purchasing is defined as a function the purchasing department must also be considered. The purchasing function in a business context includes acquiring components, goods or raw materials, services for conversion,

consumption or resale. The purchasing organization is responsible for execution of the function described. In many organizations purchasing is part of a segmented and departmentalized structure. In this structure the procurement of commodities is a discrete activity in a series of multiple activities starting from purchase of commodities and ending to at the delivery of an end product to the final customer. Therefore the process of purchasing is a series of subprocesses or levels targeted to achieve an output. The various duties or levels can be pictured as a sequential chain of events which finally leads to the acquisition of supplies. Figure 17 below illustrates the process chain of purchasing. The binding link between events in the purchasing chain is information which enables events to answer questions such as “What are we required to purchase?” and “where and how the required commodities can be obtained?” (Lysons & Farrington, 2006, p. 34.)



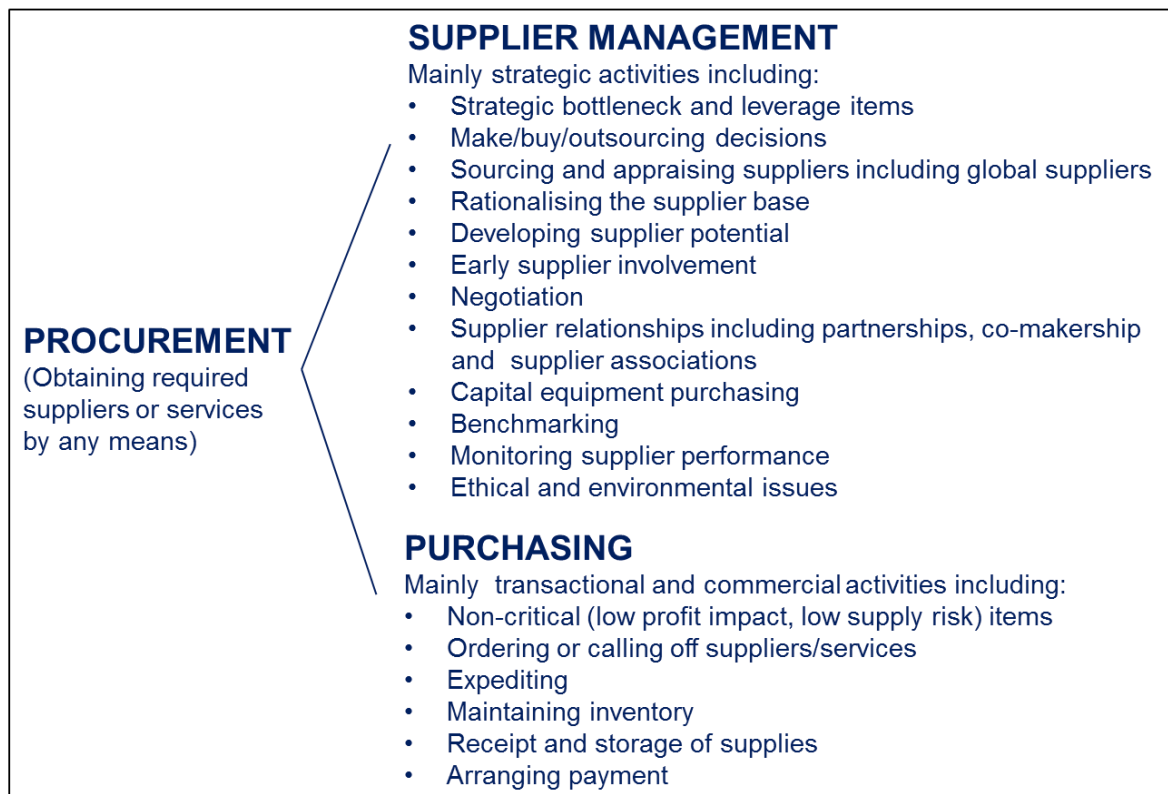
**Figure 17.** The process chain of purchasing (Modified: Lysons & Farrington, 2006, p. 4).

The importance of purchasing can be immediately noticed from the cost structure of manufacturing companies. Generally the purchased materials and services form the largest part of the cost related to sold products. More accurately by decreasing all the direct material costs the company's sales margin will improve and on the other hand if the net capital employed by the company is reduced, it will occur as positive development in company's turnover ratio. In addition to the savings on purchasing prices, the purchasing function can also improve the competitive position of a company in a more indirect manner. These indirect factors can occur as a reduction of stocks, as innovations related to products and processes or as a reduction of quality costs such as inspection, rejection and repair costs. Further the standardization level of the products range can increase and on the other hand production lead times can decrease. These indirect factors usually turn out to be even more significant than the amount of money saved directly. (Van Weele, 2005, p. 17–18.)

Also Monczka et al. (2009) notes the importance of purchasing: In the manufacturing sector it can be shown that expressed as a percentage of sales, purchased material is 55% of sales. This further proves why purchasing is a major area for cost savings. The savings are coming in different forms and the traditional approach is to achieve cost savings by driving hard bargains. This method is starting to lose its importance while the newer approach of relationship building is gaining more visibility. In relations building the aim is to pull the cost out of the product or service in collaboration with the supplier. (Monczka et al., 2009, p. 7.)

After purchasing, supply management can be seen as a more inclusive concept. Monczka et al. (2009) define supply management as: “A strategic approach of planning for acquiring the organization`s current and future needs through effectively managing the supply base, utilizing a process orientation in conjunction with a cross-functional team to achieve the organizational mission.” The four key elements of supply management are strategic responsibilities, supply base management, process-driven approach and cross-functional groups. Strategic responsibilities are the operations which have a major influence on an organization`s longer term performance. (Monczka et al., 2009, p. 39.)

Lysons & Farrington (2006) refer to supply management as supplier management and define the term as: “That aspect of purchasing or procurement concerned with rationalising the supplier base and selecting, coordinating, appraising, the performance of and developing the potential of suppliers and where appropriate, building long-term collaborative relationships.” According to this supplier management is a more cross-functional and strategic body than the traditional procurement “purchasing”. The figure 18 located below shows the relationship between supplier management and sourcing more accurately. (Lysons & Farrington, 2006, p. 7.)



**Figure 18.** The relationship of supplier management and purchasing (Lysons & Farrington, 2006, p. 8).

The next term, materials management, can be considered as the flow of raw-materials to production, including also the output flow of materials from production. A more specific definition of material management according to Lysons & Farrington (2006) is: “The planning, organization, work-in-progress, and distribution of finished goods.” (Lysons & Farrington, 2006, p. 86.)

The supply chain is also one of the general terms which have many varying definitions in the literature. Lyson & Farrington (2006) define a supply chain as: “Network of organizations that are involved, through upstream and downstream linkages, in the different processes and activites that produce value in the form of products and services in the hands of the ultimate customer of consumer.” Where “upstream” concerns the relationship between the enterprice and its suppliers and “downstream” the relationship formed between customer and the enterprise. More accurately in this thesis, the supply chain can be seen as a batch manufacture chain which has many customers and many suppliers included complicated relationship networks. Therefore an enterprise, depending

on the actions being undertaken, can be regarded as a customer, supplier, competitor or ally. (Lysons & Farrington, 2006, p. 91–93.)

The supply chain management is then the managerial level related to supply chains but the term itself has no universal definition. Lysons & Farrington (2006) state that all the introduced definitions can be categorized into a three varying groups which are supply chain management as a management philosophy, implementation of a management philosophy and set of management processes. As an example the set of management actions defines the supply chain management term by eight different managerial processes. According Lysons & Farrington (2006) the processes are: “Customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, supplier relationship management, product development and commercialisation and returns management.” (Lysons & Farrington, 2006, p. 95–96.)

According to Van Weele (2005) supply chain management concerns of all activities related to the flow and transformation of commodities and services from first tier suppliers (raw materials), second tier suppliers (components) and other suppliers. The aim is to fulfill or surpass the expectations of the final customer and the company. In addition to management of actions, supply chain management also responsible for information flows relating to the supply chain, knowledge and associated financial flows. Supply chain management differs from purchasing and supplier management by the fact that supply chain management is also responsible for logistics actions. (Van Weele, 2005, p. 15.)

The term supplier relationship management which is closely related to supply chain management is also an important term regarding the study area of this thesis. Supplier relationship management is about the method by which an enterprise interacts with the different types of suppliers. Relationships can be for instance short-or long-term and differ depending on the intensity of the relationship. The importance of supplier relationship management is increasing when organizations focus on core competencies and rely on suppliers as maintainors of organization's critical advantage or a superior position over its competitors. (Lysons & Farrington, 2006, p. 97.)

Purchasing, having a direct impact on the performance of companies is noted as one of the key activities in most industries. For companies that are purchasing various types of commodities, it is not recommended to apply a “one size fits for all” strategy. An approach developed by Peter Kraljic identifies that no perfect and common purchasing strategy exists for all types of commodities and introduces four different groups of commodities in an extensive purchasing portfolio model. A purchasing portfolio is also known as the Kraljic matrix. Kraljic (1983) determines a specific purchasing strategy for all four commodity groups. The varying strategies are based on the supply risk and strategic impact. Kraljic matrix has been accepted as the basis for various purchasing portfolio models and it has been widely used in the manufacturing industry. The following figure 19 defines the commodity groups and explains the material types included in a specific group. Despite the prevalence of the Kraljic matrix based purchaser’s portfolio, the models are criticized for implementation difficulties and lack of subjectivity and exactness. (Ferreira, Arantes & Kharmalov, 2015, p. 377–378.)

Strategic impact	High	<b>Leverage</b> Mix of commodities and specific materials	<b>Strategic</b> Scarce and/or high value materials
	Low	<b>Non-critical</b> Commodities, some specified materials	<b>Bottleneck</b> Mainly specified materials
		Low	High
		Supply risk	

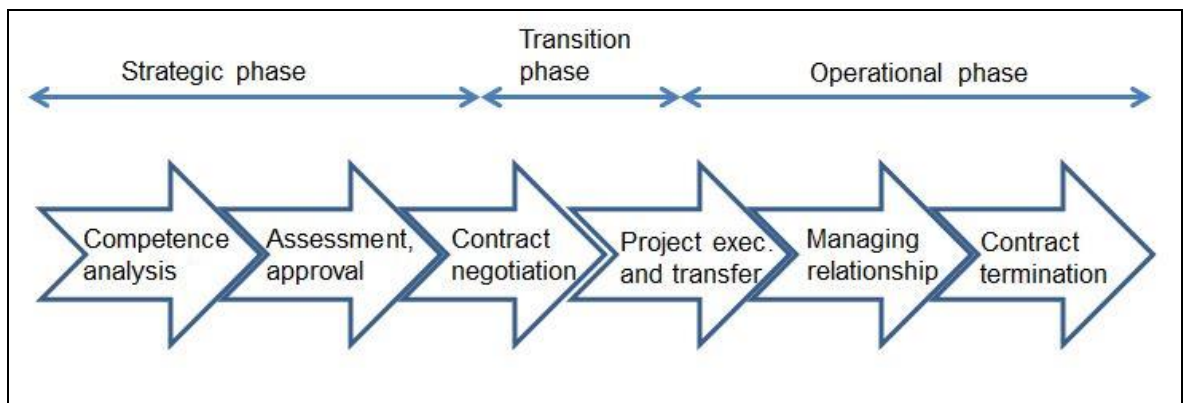
**Figure 19.** Kraljic matrix based purchasing portfolio and the typical items grouped into four commodity groups (Ferreira et al., 2015, p. 379).

For Non-critical routine commodities such as steel rods, coal and office supplies functional efficiency should be maximized and the purchasing cost minimized. Purchasing can be executed by a lower-level buyer and the suppliers should be local and selected after a good market review. Leverage commodities are for example electric motors, heating oil and EDP hardware. For this type of commodities there should be multiple suppliers with a chief local supplier. Cost and price should still be focused and material flow ensured in order to optimize contribution. Companies should exploit their full purchasing power and use targeted pricing strategies while optimizing the order volume. The purchasing action is recommended to be performed by a medium-level chief buyer. The third group of bottleneck items should be managed by a higher level for instance department heads. The

group includes commodities such as electronic parts, catalyst materials and outside services. For the bottleneck items supply risk should be minimized and continuity ensured by controlling the vendors and utilizing volume insurances if necessary. Back up plans should be developed and inventories secured. Favorable sources are global companies or newly emergent suppliers owning new technology. Key performance areas of bottleneck products are cost management and reliable short-term sourcing. The last and most important group of strategic commodities includes items and materials such as benzol, cyclo-hexane, scarce metals and high-value components. The key performance criterias of this group are long-term availability and risks and contribution should be minimized by established global suppliers. The related sourcing decision level should be the highest for example vice-president of purchasing. The required information should consist of highly detailed market data, industry cost curves and long-term demand and supply trend knowledge. The main tasks regarding this group are for instance accurate demand forecasting, development of long-term supplier relationships, make or buy decisions, risk analysis and contingency planning and the stragging of contracts. (Kraljic, 1983, p. 111–112.)

Sourcing is thus the key activity of purchasing and can be seen as a process which includes actions such as indentifying, selecting and developing suppliers. Sourcing can be subcategorized into a tactical and strategic sourcing. Tactical and operational sourcing execute lower level decisions regarding high-profit, low risk and non-critical items. Additionally it concerns short-term adaptive decisions, for instance how and from where certain supplier requirements are to be fulfilled. The second category of strategic sourcing is the top-level part of sourcing which concerns longer-term decisions regarding high-profit, strategic items with high supply risk and of bottleneck products with low-profit and high supply risk. Strategically important decisions and actions such as the formulation of long-term purchasing strategical directions, the supplier base, partnership sourcing, globalization, the purchase of capital equipment and ethical issues are also regarded as responsibilities of strategic sourcing. From the transactional sourcing point of view, purchasing is regarded as a function executing the placement of orders. (Lysons & Farrington, 2006, p. 367.)

In the literature, outsourcing is the term defining occasion when companies in the supply chain contemplate a make or buy decision. The make or buy decision can be seen as one of the most important strategic decisions of a manufacturing company, simply because it affects to the most of the other strategic decisions. In outsourcing the company contracts out a business function or process formerly performed in-house to an external subcontractor. In other words the company decides to split up some functions or processes and outsource them to external organizations, based on strategic considerations. The outsourcing process is illustrated in the next figure 20. (Rolstadås & Henriksen & O'Sullivan, 2012, p. 95.)



**Figure 20.** The serie of events in outsourcing process (Modified: Van Weele, 2005, p. 125).

Outsourced processes are usually not considered as core businesses. Typically support processes which are not adding great value to the main transformation activies are shifted to an external company. Advantages achieved with outsourcing are savings on wages and benefit payments. Driving factors for the outsourcing desicion can be seen also as transferring the uncertainty of demand to an external operator, or as gaining access to specialized skills and other inputs that the company itself does not own. On the other hand, various drawbacks are related to oursourcing and companies should consider the possible risks and misteps before making the final decision. Outsourcing related risks listed in the literature are the following: Communications costs between companies, inadequate mechanisms of governance and management, the possibility to lose control over the most essential knowledge and technical employees, the possibility to lose the leadership in business relations with stakeholders or subcontractors, resistance of the in-house team

currently working with the process, the selected supplier does not respect the ownership of the product and the costs related to contractors are dynamic because the subcontractor may change the pricing strategy. (Rolstadås et al., 2012, p. 96–98.)

Outsourcing is not limited only to domestic subcontractors. Companies are also transferring the processes to suppliers located outside their national boundaries. This type of outsourcing is referred to in the literature as off-shoring or offshore outsourcing. The advantages and disadvantages of off-shoring are equal to traditional domestic outsourcing, but by off-shoring companies are additionally trying to take advantage of global differences leading to cost reductions and increased competitiveness. (Rolstadås et al., 2012, p. 98.)

## 2.2 Manufacturing strategies and methods

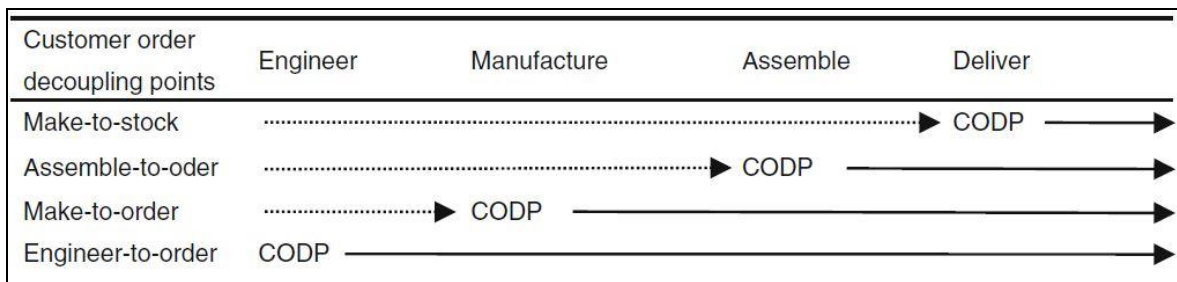
AMDSL is a typical sheet metal product with material thicknesses lower than 3 mm and substrates limited to the metallic materials. The main material types and thicknesses are already presented in Chapter 1.7 with the main door assemblies. The manufacturing of the main components related to this thesis consists of common sheet metal manufacturing methods. AMDSL manufacturing consists of various cutting, bending, coating and joining methods including in house assembly and packing. Chapters 2.2.3–2.2.8 introduce the principles of the current manufacturing methods. Before focusing on the manufacturing methods the outlines of manufacturing strategies are introduced in Chapter 2.2.1. Additionally the definition of economic order quantity and related calculation formula are introduced in Chapter 2.2.2.

### 2.2.1 Principles of manufacturing strategies

Before considering the different manufacturing methods it is essential to understand the many variations of the manufacturing function and especially the role of the customer in the manufacturing strategy. The broader supply chain strategies are stemming from the manufacturing environment. There are various manufacturing strategies available, but only two basic principles define how information and materials flow through the manufacturing process. These two principles are the pushing- and pulling-manufacturing. Push-manufacturing is defined as production-focused management relying on regular demand forecasts and long-term planning, whereas pull-manufacturing is an orientation which

responds simply to the demand of the markets. Additionally the combination of these principles is also often implemented in industry. (Hofmann, Beck & Fuger, 2003, p. 93.)

As mentioned earlier the customer`s role is the central factor when the information and material flow principles and the manufacturing strategy itself are compared. The Customer Order Decoupling Point (CODP) illustrates the influence that the customer has on the manufacturing process and it is selected in line with the manufacturing process. According to the CODP the responsiveness to the customer is enhanced by deferring the finishing of the end product. There are several different factors affecting the selection of a favorable manufacturing structure and the positioning of the CODP. The primary factors are market-related such as lead time, differentiation expectations of the product and demand volatility. Secondary factors are production-related for example production lead time and the level of flexibility in internal processes. Additionally there are also product-related factors such as modularity which describes the architecture of the product. The CODP position is influenced by the various manufacturing strategies. In the literature the manufacturing strategies are categorized in many ways, but the four most common strategies are Make-to-Stock (MTS), Assemble-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO). Figure 21 below introduces the positioning of Customer Order Decoupling Point in these manufacturing strategies. According to this figure, for the MTS manufacturing strategy the end product is already finished and only delivered when the customer`s order is triggered. When moving from MTS manufacturing towards ETO manufacturing the CODP is constantly positioned farther from the customer and in the extreme case of the ETO strategy the design of the product is only started when the customer order is received. (Hofmann et al., 2003, p. 93–94.)



**Figure 21.** Positions of CODP in MTO; ATO; MTO and ETO manufacturing strategies. (Hofmann et al., 2003, p. 94).

By analyzing the figure 21 above and it can be seen that the strategy with CODP located closest to the customer is MTS. MTS is more accurately defined as a push production strategy with the main aims of cost-efficiency and productivity. A MTS strategy relies on stable production planning enabled by regular long-term demand forecasts. In MTS the allowed lead times are long and the relationship between supplier and buyer are also long lasting. Uncertainties are dealt with by using safety buffers where end products are manufactured into a stock. Typically MTS production has high degree of standardization and the products are pushed into the markets in large batches. Generally, the customer does not have a great influence on the MTS production process as the CODP position illustrates. (Hofmann et al., 2003, p. 94–95.)

When moving the customer order decoupling point upstream as illustrated in figure 21 the next strategies after MTS are ATO and MTO which are manufacturing strategies consisting of both pull and push orientations. In these strategies the customer demands already have an impact to production related factors. The essential idea behind these strategies is to produce quality products at competitive prices based on the requirements of a single customer or a group of customers. In other words, the aim is to combine a high level of responsiveness and flexibility with high level of cost efficiency. ATO and MTO are typically implemented in environments where the company needs to satisfy multifaceted customer requirements with a highly varying product range. This is normally executed by introducing a product structure that permits the wide usage of standard components and the unfinished basic products can be customized with relatively low effort regarding customer specific demands. Because of the structural setup, companies are able to produce a great variety of products with small batches per individual order and still held the manufacturing cost down. (Hofmann et al., 2003, p. 95–96.)

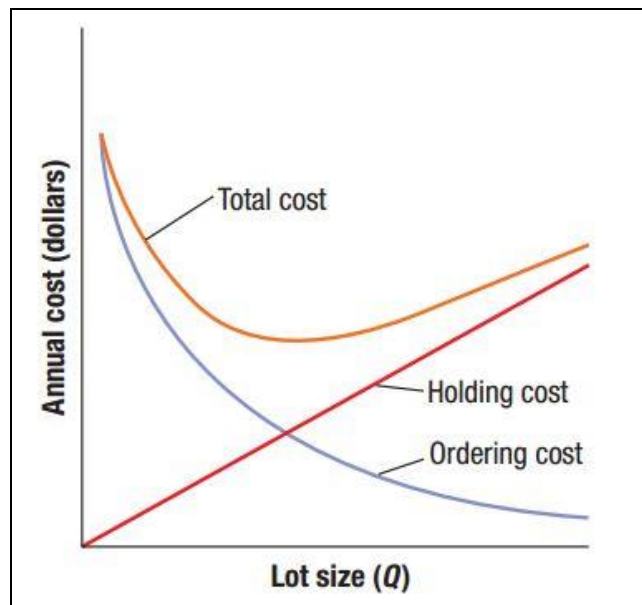
In addition to ATO and MTO the literature defines manufacturing strategy known as Built-to-Order (BTO). ATO and BTO can be considered almost equal strategies with a varying ratio of in-house to outsourced manufactured components. Furthermore if MTO and ATO are compared more accurately, many differences can be found. In an MTO strategy the components of the end product have to be produced before assembling, but in ATO strategy the assumption is that components are already prepared for assembly. This means the CODP is located closer to the customer in an ATO strategy and the lead times are shorter if compared to MTO. Secondly in an ATO strategy more parts and services are purchased from suppliers, whereas MTO has a greater level of vertical integration. (Hofmann et al., 2003, p. 95.)

The opposite extreme compared to MTS is the ETO manufacturing strategy. In an ETO strategy the influence of the customer's requirements are highest among the discussed strategies and the position of customer decoupling is point located farthest from the customer (figure 21). In ETO the customer's order essentially triggers a new design and production process. Requirements stated in the order are pulling the product through the entire production process starting from the design and engineering stage and ending when the product is finished. ETO is applied in environments characterized by large, complex and often unique projects with a wide range of varying products. End products of the projects are typically very complex with small batch sizes. Due to a very high degree of variation of the end products the flexibility can be seen as a crucial factor in ETO environment. (Hofmann et al., 2003, p. 96.)

### 2.2.2 Economic order quantity

One of the difficulties that supply managers are facing is how to keep storage levels low enough to avoid dramatically high warehousing costs but high enough that setup and ordering costs will not increase to an unfavorable level. Warehousing costs consist of the capital cost and variable costs related to keeping the items on hand. Variable costs are for example storage and handling costs, taxes and insurance and shrinkage costs. Ordering costs are those cost stemming from purchase or production order preparing actions for a supplier or for the job shop. The setup costs are those items of expenditure caused by changing machine settings to produce items with different demands. (Krajewski & Ritzman & Malhotra, 2012, p. 315.)

Above defined costs are causing conflicting pressures to managers. When dealing with the situation, a good starting point in balancing the complex pressures and in defining the most favorable cycle-inventory level for the items is to determine the economic order quantity (EOQ). EOQ is the batch size minimizing total annual holding and ordering costs of cycle-inventory. Figure 22 below illustrates the behavior of ordering costs, warehousing costs and the total costs. The EOQ is the lot size representing the lowest point on the total cost curve. On that point the annual costs are the lowest possible. (Krajewski et al., 2012 p. 315.)



**Figure 22.** Behavior of annual ordering costs, warehousing costs and total costs in cycle-inventory (Krajewski et al., 2012 p. 316).

The process aiming to determine the EOQ is based on the following assumptions: 1. Constant demand rate which is known with certainty, 2. There is no limitations towards batch size (exempli gratia material handling limitations), 3. Only significant costs are fixed cost per batch for setup or ordering and warehousing costs, 4. There is no advantage gained in combining many orders going to the same supplier, 5. Lead time is fixed and known with certainty (Krajewski et al., 2012, p. 315.). EOQ can be determined by following formula (Krajewski et al., 2012, p. 317.):

$$EOQ = \sqrt{\frac{2 \times S \times D}{H}} \quad (1)$$

Where: EOQ = Economical order quantity, H = Yearly warehousing costs of one unit, usually expressed as a percentage of the unit's value, D = annual demand, in units per year, S = cost of ordering or setting up one batch, in euros per batch. (Krajewski et al., 2012, p. 317.)

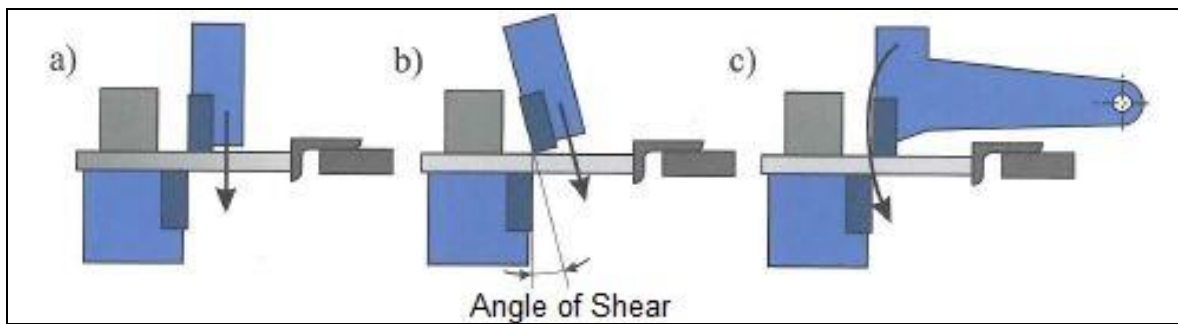
### 2.2.3 Cutting

Cutting is one of the first manufacturing steps related to sheet metal products. Several different cutting methods are available and depending on the chosen method the cut shapes can be rectilinear or shaped. All the methods are not suitable for all materials and the accuracy of the shearing process ranges between methods. For AMDSL sill, panel and frame both mechanical and thermal cutting processes are utilized. The mechanical cutting methods are guillotine shearing and punching. For some product variations thermal laser cutting is needed and the method will be introduced later in this chapter. (Matilainen et al., 2011, p. 142.)

Mechanical cutting is based on mechanical force and the actual cutting can be performed with different types of cutting edges or punches. Mechanical cutting methods are suitable for all materials types but the capacity of machinery limits the allowed material thicknesses. The first mechanical cutting method used in AMDSL manufacturing is guillotine shearing. The aim of guillotine shearing is to cut the metal sheet to the required dimensions. It is the most common cutting method used in sheet metal manufacturing for rectilinear shapes. In guillotine shearing the upper and lower tool are both shearing the substrate: The moving upper blade travels past the fixed lower blade and the substrate is sheared. The shearing process itself begins with elastic deformation which is followed by plastic deformation and strain hardening. After these two steps the cracks in substrate begin to integrate and finally there is the last step of shearing when the cracks grow and integrate leading finally to fracture. (Matilainen et al., 2011, p. 170.)

Guillotine shearing can be performed rectilinearly when the moving upper blade travels down perpendicularly towards the workpiece or alternatively the moving blade can be set to an angle or the moving blade can perform a pendulum movement while moving down.

Figure 23 illustrates all the guillotine shearing versions. The process used in AMDSL guillotine shearing is rectilinear. In rectilinear cutting the upper and lower blades are located parallel to each other. This causes faster wearing of the blades compared to the angled version where the upper blade is usually turned to a specific angle and the abrasive effect between workpiece materials and cutting blades is minimized. Due to the angle between cutting blades the needed shear forces are also lower than in rectilinear cutting. The accuracy of guillotine shearing is generally 0.1 mm and the quality affecting factors are machinery and substrate material properties. The most commonly occurring interface failures in guillotine shearing are twisting, bowing and cambering. The machinery used in AMDSL manufacutring is hydraulic and positioning of the metal sheet is performed with back and front gauge. (Matilainen et al., 2011, p. 170–171.)

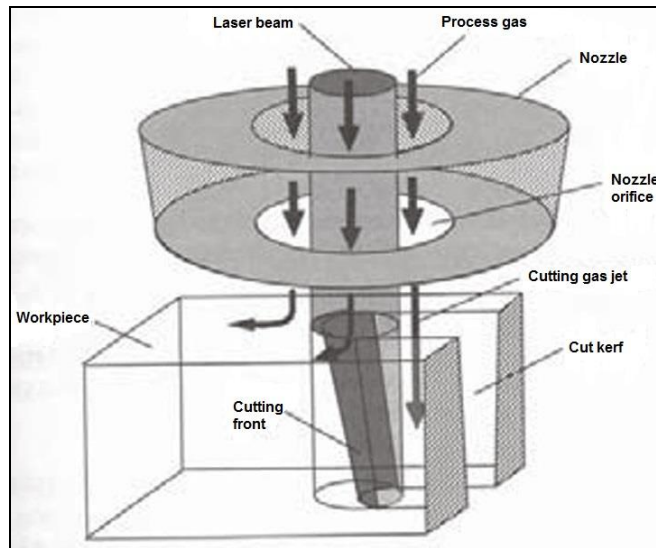


**Figure 23.** Three methods to execute the guillotine shearing: a) Rectilinearly, b) diagonally or c) by pendulum movement (Matilainen et al., 2011, p. 171).

The second mechanical cutting method used in AMDSL manufacturing is punching which is a metal forming process utilized in the cutting of closed shapes. The method is also suitable for the cutting of contours by a series of overlapping slits / notches, but in that case the more accurate name for the process is nibbling. Mechanical punching is executed by a tool consisting of a punch and die. The selection of optimal tools is very important in order to maximize the shearing quality and minimize the wearing of the tools. In punching the workpiece is placed on the die and the shearing movement is executed by the punch. At the beginning of the punching process the punch faces the worksheet material and the shearing process starts. At the end of the process the lower part of the worksheet fractures and the scrap falls off. In punching the created hole is the same as the shape of the tool. The shapes of punching tools are standardized and the most common shapes are round and square. (Matilainen et al., 2011, p. 171–182.)

In AMDSL manufacturing punching is the main cutting process used for the shearing of various shapes of frame, panel and sill components and nibbling for shearing the actual of the components. Punching is executed by an automated turret punch press with an automated tool changer to eliminate setup times. The worksheet is fastened to the claws of the automated punch press and the worksheet is then moved on the coordination table in the x-y axis relative to the punching tool position. The punching tool executes the shearing movement with a punching stroke ranging from 500/min up to 1,100/min with the state of art machinery. The axial positioning speed is usually 40–80 m/min, while the position accuracy is  $\pm 0.1$ – $\pm 0.15$  mm and repetition accuracy  $\pm 0.03$  mm. Modern punch presses are able to reach a nibbling speed of 10 m/min. (Matilainen et al., 2011, p. 181.)

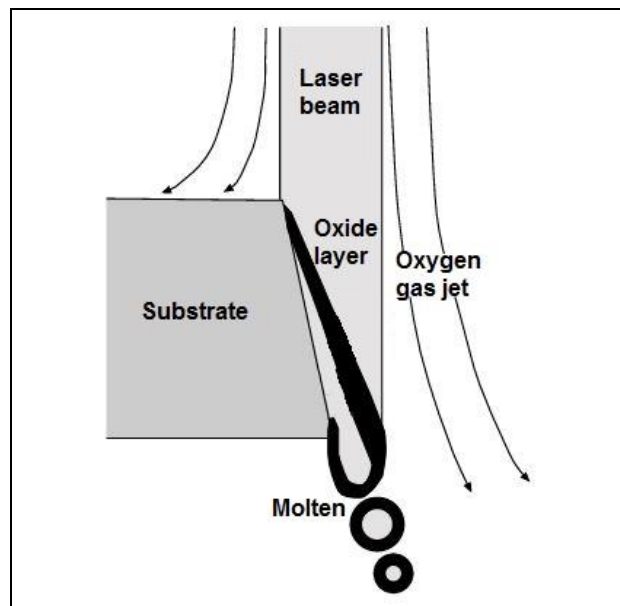
The third cutting method used in AMDSL manufacturing is laser cutting which is the most used industrial laser processing application. Unlike the first two cutting processes, laser cutting is a thermal cutting method mainly used for cutting sheets and moulded products to the required shape by vaporizing and melting the substrate with a focused laser beam. If an active cutting gas for instance oxygen is used, an exothermic oxidation reaction of the oxygen is ignited with the substrate. In laser cutting the beam is focused usually on the surface of the workpiece and the diameter of focal point is typically 0.1–0.5 mm. A sharp focal point combined with powerful laser beam creates a very high power density of over  $10^5$ – $10^6$  W/mm<sup>2</sup>. Due to high power density a cylinder like kerf is formed through the workpiece. Vaporized material inside the cylinder shaped cut kerf is rounded by the molten base material. Vaporized and molten material is blown away from the cut kerf by pressurized gas jet acting coaxially with the laser beam. The distance between the nozzle and workpiece is only 0.5–1.5 mm. This ensures that the gas flow will not disperse too much during the process. A continuous cut kerf is formed when laser beam and workpiece are moved relative to each other. The entire part is fractured when the laser cutting action is moved along the predefined cutting route. Laser cutting kerf extends through the entire base material thickness and the width of the kerf is only approximately 0.1–0.4 mm. Laser cutting can be performed one-dimensionally (1D), two-dimensionally (2D) three-dimensionally (3D). Figure 24 shows the principle of laser cutting. (Kujanpää, Salminen & Vihinen, 2005, p. 133.)



**Figure 24.** Principle of laser cutting (Modified: Kujanpää et al., 2005, p. 134).

Laser cutting has many advantages and the most important ones are: High cutting speed, very good quality and accurate workpieces, no need for post treatment, narrow thermal input area, narrow cut kerf, no tool wearing, easy to use, low operating costs and freedom to cut very complex and small shapes. On the other hand laser cutting machinery is very expensive and needs heavy investments. Also the cutting speed will decrease dramatically with greater material thicknesses and the lasers in industrial use are mainly built for low material thicknesses. (Ihalainen et al., 2003, p.267–268.)

Exact process used in AMDSL manufacturing is laser oxygen cutting with a CO<sub>2</sub> laser. In laser oxygen cutting the focused laser beam heats the base material. The additional reaction between base material and oxygen then enhance the cutting process by providing extra heat input which enables to use relatively greater cutting speeds. Figure 25 defines the idea of laser oxygen cutting. (Kujanpää et al., 2005, p. 134.)



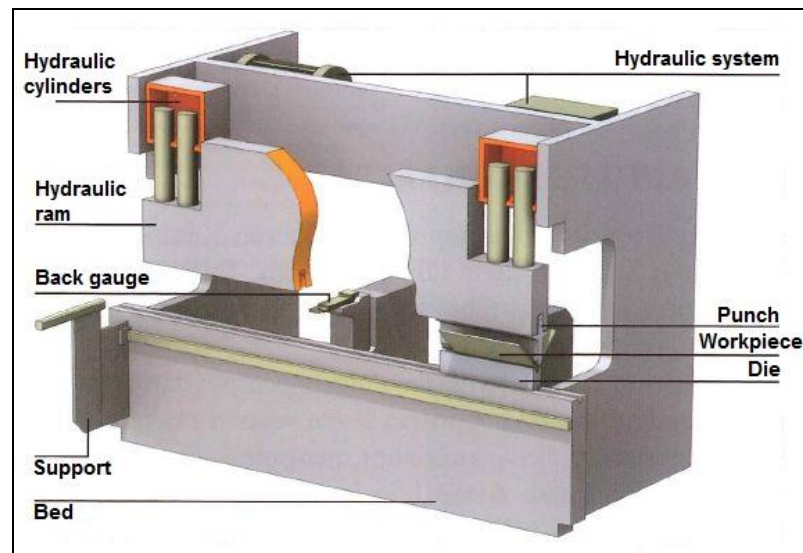
**Figure 25.** Essential principle of laser oxygen cutting (Modified: Kujanpää et al., 2005, p. 134).

#### 2.2.4 Bending

Bending is one of the most widely applied sheet metal forming operation in general, and is also used in AMDSL panel, frame and sill manufacturing. Bending is based on the plastic deformation of metals and can be implemented using several different methods. Hingole (2015) defines bending more accurately as “the uniform straining of material, usually flat sheet or strip metal, around a straight axis, which lies in the neutral plane and normal to the lengthwise direction of the sheet or strip.” (Hingole, 2015, p. 21.)

With regards to the stresses and stretching the bending action divides into three phases which are common for all the various bending processes: 1) Phase of elastic bending, 2) Phase of elastic-plastic bending and 3) Phase of plastic bending. During the two last phases the metallic material is stressed over its yield strength and a permanent bend is realized. The success and quality of the bending process is related to various factors, which are important to take into account in the design phase of the component. Many of these affecting factors are shared by all bending processes. During the bending process deformation occurs in the workpiece structure and especially “spring back” is a complex phenomenon to manage. Furthermore, the factors such as size of the workpiece, bending radius and bend allowance / deduction should be concerned carefully when a bending operation is designed. (Matilainen et al., 2011, p. 239–245.)

Bending of the AMDSL panel, frame and sill related components is performed with manual and robotized NC press brakes. Operations of the press brakes are executed by hydraulic cylinders. The structure of a hydraulic press brake is illustrated in figure 26. In AMDSL manufacturing bending of the worksheet is executed by the two corners of the lower die's v-shape and by the punch which presses the sheet. The movement of upper tool is stopped before the worksheet reaches the bottom of lower tool. This method is specifically known as free bending. In press brake bending the spring-back, dimensional bend development and pressing force need to be carefully considered in order to secure the best outcome. The angles of the tools used in AMDSL manufacturing are usually lower than 90°. (Matilainen et al., 2011, p. 240–242.)

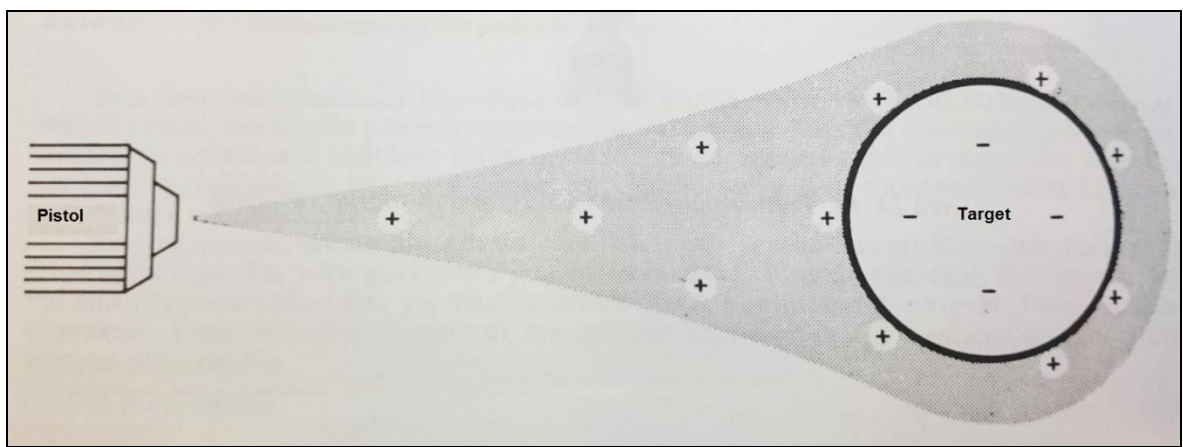


**Figure 26.** Structure of a hydraulic press brake. Sheet metal is positioned with the back gauge and the front support ensures a steady positioning process. (Modified: Matilainen et al., 2011, p. 240.)

### 2.2.5 Coating

The visible parts of AMDSL doors (frame and door panel decoration plates) are also offered also with several colours to meet customer demands. The coating method of AMDSL is powder coating. In powder coating the coating matter is in powder form and the powder itself is applied on the conducting substrate by electrostatic or friction charging. More accurately the workpieces are first hung on the hooks of a conveyor and earthed. Powder coating substrates are usually pretreated with mechanical abrasive blast cleaning or by chemical phosphating. When the powder is applied to the hooked substrate,

the substrate is surrounded by a powder cloud and the coating matter is transferred to the substrate by an electric charge. After the powder is applied, the workpiece is moved into a stove. The heat of the stove melts the powder and the heating phase is immediately followed by curing. During the curing stage chemical reactions occur and a durable coating is formed. The painted workpiece is ready for use after cooling. The coating type used in AMDSL manufacturing is Epoxy-Polyester and the process is executed by electrostatic charging. (Jokinen, Kuusela & Nikkari, 2001, p. 120, 134.)



**Figure 27.** Principle of electrostatic charging. Due to a electric charge the coating powder is also transferred to the invisible side of the workpiece and the powder can be applied only from one side of the workpiece. The coating losses are low because the coating is transferred only on surface of the workpiece and not over it. (Modified: Ihalainen et al., 2001, p. 416.)

The powder coat is a solid 2-component material. When the coated workpiece is moved to the oven, the 2-component reaction is activated by the increased temperature (140–200 °C). The adhesive and curing agent of the powder coat are cross linking when the surface temperature of workpiece is increasing and the paint film properties such as color shade, gloss, mechanical resistance, chemical resistance, UV-resistance and possible structure surface are formed. (Teknos Oy, 2015, p. 25–27.)

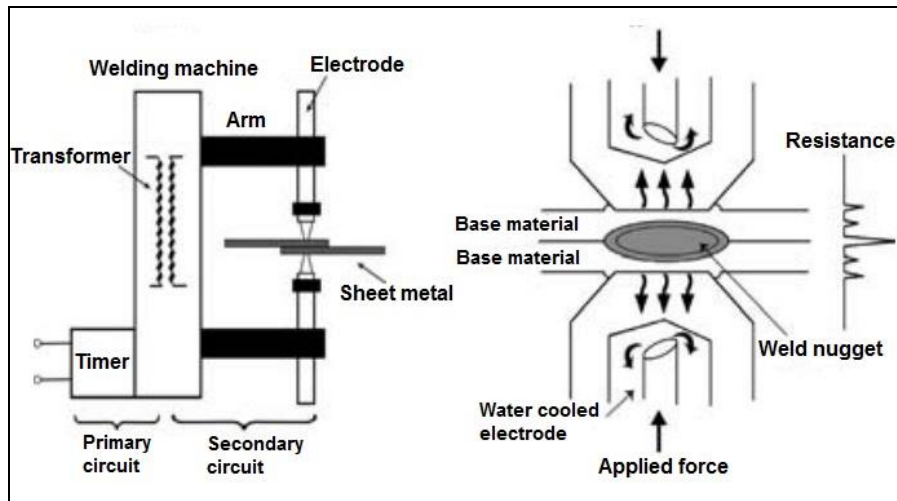
Powder coating is a quick, efficient and economic painting method and it has many advantages over conventional wet painting. Powder coating has shorter processing times and overall higher capacity. Surface quality of the paint film is high with enhanced corrosion resistance properties. Powder coatings do not contain any solvents and the

coatings are totally free of volatile organic compounds (VOC) which makes the process environmental and user friendly. On the other hand the powder coating process demands increased temperatures and the size of the stoves will limit the suitable size of workpieces. (Teknos Oy, 2015, p. 25–27.)

#### 2.2.6 Joining

In Sheet metal component production the workpieces and components can be joined with many varying technologies depending on the stresses affecting the product, operating conditions of the product, desired level of maintainability and the available equipment. ADMSL manufacturing is not an exception and with frame, panel and sill manufacturing several different joining technologies are utilized to reach the best final outcome. The existing AMDSL joint types can be categorized to weld joints, adhesive joints and mechanical joints. This chapter introduces the current joining methods used in AMDSL manufacturing. (Matilainen et al., 2011, p. 275.)

The welding method used in AMDSL manufacturing is resistance spot welding. The method is used to join the door panel bodyplate and stiffener or bodyplate and fire insulation structure together. Resistance spot welding (RSW) is a resistance welding method. In RSW two electrodes mechanically press the overlapped sheet metal workpieces together. After the precompression time the welding current is passed through workpieces. As the welding current is passing through the sheets, electrical resistance heats up the workpieces. When the process reaches the correct temperature the welding current is switched off, but mechanical pressure remains and electrodes cool the weld. This enables the molten metal to cure and form an electro-sharing metallurgical bond. Finally the weld is formed directly at the electro site and after postcompression time the electrodes are released. Figure 28 below illustrates the machinery and actual process of resistance spot welding. (Nuutinen et al., 1999, p. 67–68.)



**Figure 28.** Illustration of resistance spot welding machinery and the welding process (Modified: El-Banna, Filev & Chinnam, 2008, p. 220).

The process steps in RSW are quick and cycle time for one weld is approximately 1 s. In general the method is a relatively robust process and it has proven to be efficient and economical with many other advantages such as: Joints of dissimilar materials and material thicknesses, high dimensional accuracy, low thermal transformations of material structure. Despite all the advantages the method has its problems. The major disadvantage of resistance spot welding is the large-scale variation in weld quality. (Nuutinen et al., 1999, p. 69.)

The second joining technology utilized in AMDSL manufacturing is adhesive bonding also known as gluing. In industry the popularity of adhesive bonding has increased in recent years and the method has become as important as other more common joining techniques. In AMDSL production, adhesive bonding is used to join the slim door panel bodyplate and decoration plate together. Compared to welding the adhesive bonding is performed with relatively low temperature. Due to the low bonding temperature the heat transfer is very low and there will be no thermal defects on the external decoration plate. Gluing is based on the phenomena known as adhesion. Bhowmik et al. (2015) define the adhesion as: “The interfacial force of attraction between two materials. These physical attractions are mainly due to van der Waals forces and electrostatic forces.” (Bhowmik, Benedictus & Dan, 2015, p. 766.)

With gluing it is possible to join varying construction materials together which is usual for AMDSL production, because decoration and bodyplate materials are usually different. Using suitable methods gluing is also an economical process. Other benefits of adhesive joints in sheet metal construction are light structures and good mechanical properties. The final outcome of the adhesive joint depends on the quality of the adhesive, type of the joint and direction of applied stresses. Before applying the adhesive, the faces of the joint need to be very clean. Impurities such as dirt- and oxide layers decrease the quality of the adhesive joint. Due to this mechanical or chemical cleaning of the faces is needed before the adhesive is applied. (Matilainen et al., 2011, p. 325.)

The adhesive type used in slim door manufacturing is a 1-component silylmodified polymer. It cures with air moisture and full curing time is 3 mm / day or 10 mm / 7 days (23 °C, 50% relative humidity). The silylmodified adhesive sealant is developed especially for gluing and sealing of various types of construction materials in highly demanding structural applications for example in the marine industry. The adhesive sealant is usable on most metals, glass, glazed surfaces, polystyrene, polyurethane, concrete, stone and epoxy- and polyesterifibreglass. Thermal resistance of the adhesive sealant is from -40 °C to + 90 °C or + 180 °C / 30 min, tensile strength at failure 2.1 N/mm<sup>2</sup>, tension shear strength at failure 2.2 N/mm<sup>2</sup>, elongation at failure 400% and shore A strength 40. (Kiilto, 2016, p. 1.)

The third joining technology used in AMDSL manufacturing is joining by forming also known as mechanical joining in various publications. Mechanical joints can be produced with or without additional fasteners. Additional fasteners are the parts forming the connection between workpieces. Mechanical joining with fasteners can be subcategorized into three subcategories depending of the transformation of the workpiece and the fastener itself. Common mechanical joints with additional fasteners are screw and rivet joints. In cases where no separate fasteners are utilized, the joining process is completed by transforming the workpieces. Mechanical joining methods without separate fasteners are for example crimping, hemming, clinching, lock forming and joining by expanding. The advantages and disadvantages of mechanical joining technology are listed in the figure 29. (Böllinghaus et al., 2009, p. 686–687.)

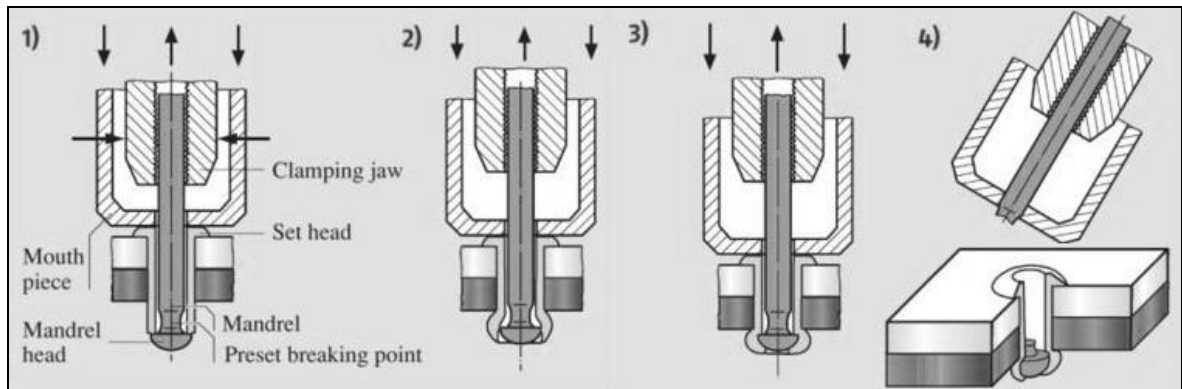
<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>• No thermal structural transformation of work pieces and therefore neither distortion nor residual stresses nor embrittlement</li> <li>• Big variety of metallic and non-metallic materials and material combination can be joined as well as different material thicknesses</li> <li>• Simple quality control mechanism</li> <li>• High economic efficiency (small investment cost of machinery, rarely pre-and post-treatment of work pieces necessary)</li> <li>• Materials with surface coatings can be joined without additional expenditure</li> <li>• Very good environmental behavior (neither emission nor pollution)</li> <li>• High process reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Only lap joints possible, with redirect of power flow and higher weight of work pieces and therefore higher costs</li> <li>• Lower tolerable static strain compared to e.g., welded joints</li> <li>• Geometrical unevenness due to nature of processes (local protrusions of joining area)</li> <li>• Usually more difficult correction and repair of improper joins</li> <li>• Poor standardization and calculation methods</li> </ul>

**Figure 29.** All the advantages and disadvantages of mechanical joining technology (Modified: Böllinghaus et al., 2009, p. 687).

In AMDSL manufacturing screw and rivet joints are used in various applications mostly in the assembly of sill, door panel and frame. Screw joints are based on the additional two-part fastener producing the closing force between at least two workpieces. First of the parts (screw) is set through the workpieces and the second counterpart is then connected to it from the opposite side of the work pieces. The first part (screw) set through the workpiece is then rotated and the axial rotation movement produces a compressing force between the parts of the fastener. Function of the counterpart is to close the connection permanently. A screw thread is designed in such a way that deformation occurs during the closure rotation. Screw joints can be opened again after fastening, but the deformation prevents self-opening of the joint. Closing-heads used in AMDSL manufacturing are mainly nut screws. (Ihalainen et al., 2001, p. 329.)

Similar to screw joints rivet joints also use additional fasteners. Literature defines several riveting methods such as punch riveting, self-pierce riveting, locking ring bolt connections and blind riveting. Blind riveting is widely utilized in AMDSL panel assembly. By blind riveting different materials can be joined permanently and the joint can only be opened by the destruction of the rivet. The workpieces must be predrilled, aligned and fixed before blind riveting is usable. The tolerance and size of the drilled holes depend on the type and diameter of blind rivet. Various types of blind rivets have been introduced during the history of the method. The rivets vary based on their mechanical properties, required

joining forces and costs. More specifically the most used rivets consist of the closing-head also known as a mandrel and the rivet body. The process steps of blind riveting are introduced briefly below in figure 30. (Böllinghaus et al., 2009, p. 692–693.)



**Figure 30.** The four process steps of blind riveting, where the arrows describe the direction of affecting forces (Modified: Böllinghaus et al., 2009, p. 692).

### 2.2.7 Assembly

Assembly can be defined as a step performed in the production factory where the components produced in earlier manufacturing steps, components purchased from outside and standard components / accessories are integrated resulting a functional product (in this case ADMSSL sill, panel or frame). The high level of integration in assembly is preferable, because assembly at the customer's site without a controlled environment is more complicated. Small batch ADMSSL assembly is traditional handwork, which is performed manually with traditional hand tools on a fixed work bench. Usually the percentual proportion of assembly of total manufacturing cycle time is from 10% to 30 % depending on the type of the manufacturing. The design of the product has also a great influence on the assembly and in general the design for assembly theory receives too little attention in the design phase of the product. Significant disruptions in the assembly flow are lack of hand tools and components. Additionally the mistakes in earlier manufacturing steps, for example inaccurate dimensions complicate assembly causing more repair tasks and increased time for fitting. (Ihalainen et al., 2001, p. 478–487.)

### 2.2.8 Packing and transportation arrangements

Packing and transportation arrangements can be defined also as activities related to sheet metal component manufacturing. Specifically in ADMSSL manufacturing the packing and

transportation arrangements is the last step before delivery of the order to the distribution centre. In packing the door components are packed into the wooden shell which is covered regarding the selected packing type. When the goods are packed the final shipment box is moved to the shipment dock and transportation of the order to the distribution centre starts. (Ollikainen, 2003, p. 14.)

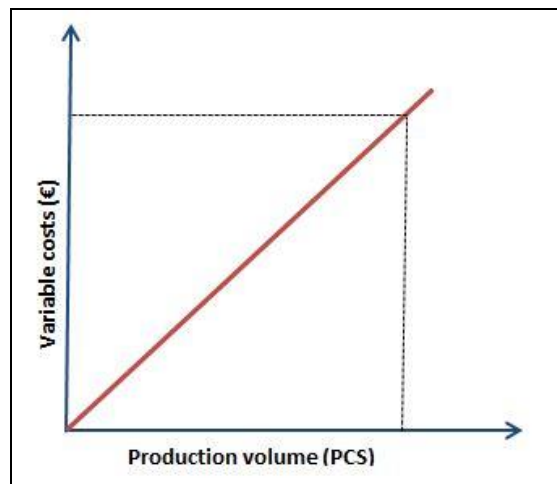
## 2.3 Cost estimation & pricing

Regarding manufacturing methods, cost accounting and price forming are also highly important subject fields related to a sheet metal product and its supply. In the following chapters the reader is familiarized with costs regarding manufacturing, cost accounting strategies and pricing strategies in general.

### 2.3.1 Costs in generally

Business activities cannot run without any costs. Costs have a central role in a corporation`s accounting and should be well-known in order to fully investigate the profitability and economic efficiency of the company. In the literature several different costs principles are defined. Because diverse accounting tasks require different cost principles, different methods generate different costs. In this chapter the concept of cost with its details is handled in general with respect to the capacity utilization rate of machinery. (Neilimo & Uusi-Rauva, 2012, p. 46.)

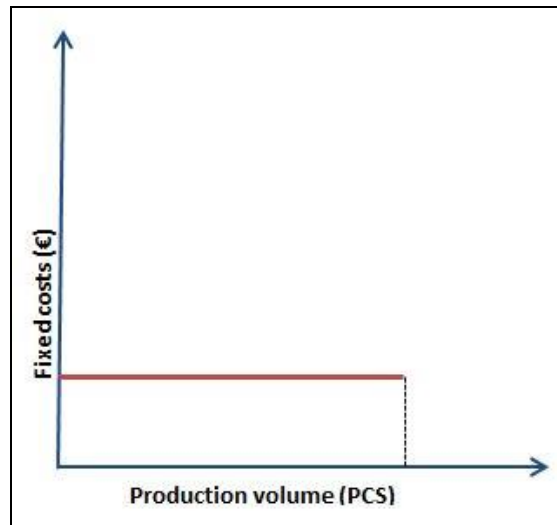
According to literature the costs are most often divided into fixed costs and variable costs. In a corporations cost accounting the relation between cost and the capacity utilization rate determines if the cost is seen as variable or as a fixed one. The variable costs are assumed to grow and decrease according the capacity utilization rate. This means the more the company manufactures products e.g in one month the greater the variable costs are during that month. The next figure 31 defines the relation between variable costs and the amount of outputs produced in one month. Costs should be defined as variable costs only if the dependence on the operating rate is clear enough. (Neilimo & Uusi-Rauva, 2012, p. 56.)



**Figure 31.** Cost function of variable costs (Modified: Jyrkkiö & Riistama, 2004, p. 47).

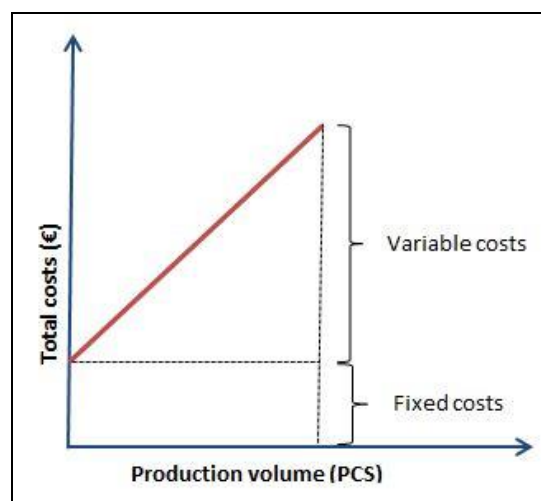
Typical variable costs of a manufacturing company are costs stemming from raw materials, purchased components, purchased semi-finished products, purchased subcontracting and from other services used for production activity. Also the main proportion of work activity required producing the output, fees of the manufacturing unit, energy consumption costs, maintenance of the machinery, patent and license expenses and overtime / shift work costs are considered traditionally as variable costs. (Jyrkkiö & Riistama, 2004, p. 50.)

Unlike variable costs, fixed costs are not changing according capacity utilization rate, but are still dependent on changes in capacity and potential factors. Additionally the costs which have only minor dependence on the operating rate are mainly classified as fixed costs in financial calculations. Fixed costs can further be subcategorized into a standing and availability costs. Standing costs are realized even if the manufacturing unit is not operating at all. The operating readiness of the manufacturing unit causes the availability costs. Figure 32 below illustrates the cost function of fixed costs. (Neilimo & Uusi-Rauva, 2012, p. 56–57.)



**Figure 32.** The cost function of fixed costs (Modified: Neilimo & Uusi-Rauva, 2012, p. 53).

Traditionally recognized fixed costs of a manufacturing company are for example rents of the premises, heating and cleaning costs, base electricity costs, various governance, IT and entertainment expenses, interest expenses of the machinery related to invested assets, insurances and depreciations. Also costs of the main proportion of directive work actions can be classified as fixed costs. When fixed and variable costs are determined the total costs can be formed. The next figure 33 illustrates the total cost function of a manufacturing company. Total costs can be calculated by adding up the fixed and variable costs from a specific period. (Jyrkkiö & Riistama, 2004, p. 50.)



**Figure 33.** The total cost function of a manufacturing company (Modified: Jyrkkiö & Riistama, 2004, p. 51).

Earlier the variable and fixed costs were handled with respect to a company and it was clear that fixed costs are fixed and variable costs are variable. If the costs are now studied from the individual product point of view the situation is vice versa. Variable costs per unit are fixed with respect to an individual unit, but fixed costs per unit are varying with respect to amount of outputs produced. Accordingly a company should utilize the purchased machinery effectively in order to reach the lowest possible fixed costs per unit which are following capacity utilization rate. (Neilimo & Uusi-Rauva, 2012, p. 54.)

The classification of variable and fixed costs with respect to capacity utilization rate described above is not the absolute truth and can be even misleading in some situations. The situation regarding costs can vary dramatically depending on the character of the manufacturing. For example in highly automated and mechanized manufacturing environments the fees of production employees and obligatory social costs are fluctuating only a little, because the automatized processes demand constant and standard staff. Highly automatized factories can change also the production volume by stopping the production for a certain time period. A second factor affecting the costs classification is the length of the reference period. If the costs are studied over a long time period almost all the costs are variable. On the other hand if the reference period is short enough all the costs are fixed, excluding only raw materials. Additionally if the costs are studied according to activity based costing principles, all the costs are varying with respect to some factor. It means that there is always a factor which explains why certain costs are increasing or decreasing. (Neilimo & Uusi-Rauva, 2012, p. 56.)

In output-based accounting the fixed and variable cost are further divided into a direct and indirect cost. Direct costs are mainly defined as variable costs and can be directed to a specific product or product group already in different steps related to manufacturing of an output, because the connection of the costs is clear. Typical direct costs are accumulating for example from raw material, equipment, subcontracting and salaries of production employees. (Neilimo & Uusi-Rauva, 2012, p. 59.)

Indirect costs are not directable for a specific product, even though these costs are also obligatory. Indirect costs demand an individual processing which is introduced in more detail in Chapter 2.3.2. The fixed costs of a company are often defined as indirect costs,

but also some of the variable costs such as non-returnable materials are included to the category of indirect costs. (Neilimo & Uusi-Rauva, 2012, p. 59.)

### 2.3.2 Product related cost accounting methods in general

In practice the cost estimation situation can vary dramatically between industries and there is no absolute way to determine the costs related to the product and services of the company. Basically the costs can be estimated according to the traditional cost accounting system or alternatively with cost accounting methods such as activity-based costing and standard cost accounting. This chapter focuses on traditional cost accounting and describes how the information providing cost accounting system is build and determines the factors shaping the accounting system for the certain purposes. (Neilimo & Uusi-Rauva, 2012, p. 108.)

As defined above there is no absolute way to determine the cost regarding a product. As an answer to this state of affairs the costs can be divided into different groups. This use of categorization is known as accounting by type of the cost. On the other hand the cost accounting system could face high precision demands which can require the utilization of cost centers. Additionally the calculation type must be chosen when output-based costing is executed. (Neilimo & Uusi-Rauva, 2012, p. 108.)

Production and consumption by and within companies are governed by economic principles based on scarcity. Production is highly affected by demands regarding efficiency. The highest possible return is governed by the available resources and products must be manufactured efficiently with reasonable manufacturing costs and quality. The exact method of product related cost accounting depends on the situation of cost accounting which further depends on the type of the company and its business. The first factor shaping the accounting procedure is the type of the company's output which can be exempli gratia a physical product or service. The companies can be divided into manufacturing companies producing physical products and service companies. The main difference between these companies is that products are material but services immaterial. If manufacturing companies are now investigated more closely the type of the production can be seen as the second factor affecting the type of cost accounting procedure. For instance the cost accounting method of a company producing one standard product according to a MTS

strategy is clearly simpler than the accounting method executed in a company which produces individual products according to orders from the customers with tight lead times and varying cost structures. (Neilimo & Uusi-Rauva, 2012, p. 108–111.)

As mentioned above the three sections of traditional cost accounting are accounting by type of cost, accounting by cost unit, and output-based accounting. The first step of cost accounting is to account for the type of cost where a company's production related costs are investigated by types in a certain period. The categorization of costs is based on production factors. Even in small companies there can be dozens of different cost types and in bigger companies the costs must be divided into a hundred different types in order to enable operative accounting. Table 1 located below illustrates an example of a way to categorize the cost based on production factors. (Jyrkkiö & Riistama, 2004, p. 89.)

*Table 1. Example of production factors and related type of costs (Remodeled: Jyrkkiö & Riistama, 2004, p. 90).*

<b>Production factor</b>	<b>Cost groups</b>
Work performances	Labour expenditures (Wages, obligatory and optional indirect employee cost)
Materials	Material costs
Short term means of production	Cost stemming from short term means of production (Rents, accessory costs, energy costs, transportation and service costs)
Long term means of production	Cost stemming from long term means of production (Interest costs, insurance costs and investment allowances)

The second step of the cost accounting is cost unit accounting. In cost unit accounting the main target of investigation is the determination of indirect costs regarding individual cost units. Cost unit accounting is essentially needed in a transitional period with the investigation of output-based costs but also when observing a company's efficiency and effectiveness (Jyrkkiö & Riistama, 2004, p. 117.). The cost unit itself is the smallest functional unit or area of responsibility with the cost that needs to be investigated individually. Typically a cost unit is a department of a company and in some instances cost

unit accounting is also known as departmental accounting. The actions of the cost unit should be simple enough that only one unit of measurement is needed to measure the amount of outputs. By the simple structure of a cost unit, it is possible to observe the cost of the unit by comparing it to the amount of outputs. (Jyrkkiö & Riistama, 2004, p. 118.)

Cost units are usually categorized according to their functions, for instance raw materials, production, marketing, R&D, administrative and to common cost units. Alternatively the categorization can be achieved in the relation to the cost unit's actions regarding the accomplishment of an output. In this way the costs units are divided into two groups which are primary cost units and auxiliary cost units. (Jyrkkiö & Riistama, 2004, p. 119.)

When the cost units are determined the costs need to be allocated. In case of indirect costs, the allocation must be executed according to the matching principle. According to it, the cost unit receives the costs which are caused by its own actions. The allocation of costs is based on wages accounting, inventory accounting and for instance on accounting of service and rent costs. Additionally specific supportive documents need to be produced considering interest and allowances. After the costs are allocated, the cost units are followed and observed with cost units reports. In these reports the realized numbers and target numbers are compared. For example indirect, direct and fixed costs of the cost center are aligned, realized and budgeted costs are compared and differences are checked and analyzed. (Jyrkkiö & Riistama, 2004, p. 121.)

After accounting by type of the cost and utilization of cost unit accounting, the final stage of cost accounting is output-based accounting. Cost related to an individual output can be determined with three varying calculation methods which are variable-cost calculation, average total cost calculation and normal cost calculation (Jyrkkiö & Riistama, 2004, p. 131.). Variable-cost calculation will provide the minimum production value; while the average total cost calculation determines the production value and normal calculation is utilized in the determination of normal production value. Production value consists of material and manufacturing costs. Based on these calculations the absorption cost can also be determined. Absorption costs consider all the cost related to actions needed to produce the output. (Jyrkkiö & Riistama, 2004, p. 135.)

In output-based accounting the cost center accounting and accounting by type of costs are utilized in order to determine the costs regarding a single output. The manufacturing process type used by the company has a central role, when defining how the other two cost accounting methods will affect to the output-based accounting. For different manufacturing environments there are available two major output-based cost accounting methods which are process costing, including related applications and job order costing. (Jyrkkiö & Riistama, 2004, p. 138.)

Process costing is mainly utilized in environments where company produces one standard product according to mass production principles. Process costing can be executed by dividing the costs occurred in a certain period by the amount of outputs. This is the simplest example but in practice process costing can be more complex even though the case company focuses on mass production (Neilimo & Uusi-Rauva, 2012, p. 127.). Job order costing is used in environments where a company produces several varying products which demand different materials and different production methods. This type of environment is often seen as one-off production, batch production or as mass production. Job order costing is typically executed using the following six steps: First the job receives a title number and the calculations are completed according the titles. Secondly the related costs are categorized into direct and indirect costs. Then all the direct costs are allocated to the title and indirect costs are divided among cost units. In step five the costs of auxiliary and common cost units are transferred to the primary costs centers and the overhead cost increments are calculated. Finally the indirect costs of primary cost centers are allocated again to the work titles according to the overhead cost increments. (Neilimo & Uusi-Rauva, 2012, p. 133.)

### 2.3.3 Price determination in general

Manufacturing companies can utilize several different methods when estimating the accurate price for manufactured products or services. Essentially companies are trying to define a price which enables the possibility to reach financial and other targets, but also to succeed in a highly competitive environment in related markets. Companies need to define manufacturing costs for the product or service and set the price that covers the manufacturing costs and fulfils cost-effectiveness and competitiveness targets. The correct level of pricing can be determined according to methods such as market pricing, target

pricing or the price can be set purely based on the costs related to the manufacturing of the product. All these three price setting methods are introduced below. (Neilimo & Uusi-Rauva, 2012, p. 185.)

Market based pricing starts by analyzing the current level of the market price for example by executing a margin analysis. When the market price is known, it can be seen as the recommended retail price which will guide the price fixing process of the output by setting the upper limit for the actual price. Market based pricing suits well for those cases where similar products as the company's output can be found already in the market and the reference prices are clear. Typical products for the market based pricing are standard components with high manufacturing and sales volumes. For instance daily consumer goods such as food and core services such as bank transfers are examples where market based pricing is possible. If the service or product is very unique and no competitors or substitutes exist in markets or the product is a brand the price estimation regarding market price can be difficult. (Neilimo & Uusi-Rauva, 2012, p. 190–191.)

The second method of price estimation is cost based pricing. Cost base pricing is essentially relying on the manufacturing costs of the company's product. A favorable price needs to be greater than cost related to producing the output and the price must additionally cover the profitability targets that the company has set for the product. Cost based pricing emphasizes the importance of covering the cost related to producing the output. The main difference between market and cost based pricing is the fact that cost base pricing emphasizes manufacturing cost where market based pricing emphasizes the current market price. In both methods the market price and manufacturing costs need to be compared if the values are to be visible. Cost based pricing is used primarily for price determination of individualistic products, projects and for maintenance and installation services. Cost based pricing is executed mainly using margin costing or alternatively absorption cost pricing. (Neilimo & Uusi-Rauva, 2012, p. 191–192.)

Target costing based pricing is the third price estimation method introduced. The method starting to develop in tandem with the emergence of modern global markets during the 1990s, which led to increased overall competition. In target costing -pricing the basic principle is that allowed manufacturing costs are equal to the market price minus the

amount of sufficient profit margin. The aim is to adjust the manufacturing costs to the market price and control the profit margin at the same time. For instance in conventional cost based pricing described above price determination starts by covering the costs and the required profit margin is added on top of the manufacturing costs which leads to the target selling price. In modern markets characterized by intensive competition it is possible that the company is not able to sell its products at a cost based price. In this case the current market price needs to be considered as the upper limit for the target price and adjust the manufacturing cost, but also the profit margin according the latest price level. Target cost pricing emphasizes cost awareness and cost management within the company. (Neilimo & Uusi-Rauva, 2012, p. 195–196.)

#### 2.4 Value stream and value stream mapping as a lean tool

The origin of the lean manufacturing philosophy can be traced to Japan in the late 1940s after the Second World War. At the time lack of human resources and raw materials forced the Japanese to seek ways to improve efficiency of contemporary industry. Driven by depression and the American automotive industry, the engineers of the Toyota Motor Company started to develop more efficient manufacturing process principles in order to survive in the marketplace. The outcome of the Toyota engineers' development work is traditionally known as the Toyota production system. Decades later in the early 1990s, James Womack, Daniel Jones and Daniel Roos were inspired by the Toyota production system and developed an untraditional manufacturing philosophy known as Lean. The general idea of the philosophy is to eliminate all the waste from the processes of the company. (Womack, Jones & Roos, 1991, p. 48–49.)

As one of the main aims of lean production philosophy is the elimination of all waste, it is necessary to define the term of waste. Waste in manufacturing systems according to lean philosophy is something which does not add any value or bring any benefits for the company and can therefore be removed from the process without affecting the quality and profitability of the final product. Waste could be also defined as something that is not essentially needed but still consumes resources in terms of money, time, space, operators etc. (Hosseini, Kishawy & Hussein, 2015, p. 255.)

Root causes of waste differ; naturally there are various types of waste classified in lean philosophy. By analyzing the sequence flow of service implementation processes or production, the root causes of waste can be determined which finally leads to the identification of actual waste. The seven types of waste according the lean philosophy are (Chiarini, 2013, p. 19.):

- Over production – producing too much, too early or too late
- Inventory – work in progress (WIP), raw materials and stored final products
- Motion – unnecessary movement of the body part
- Defectiveness – non-conforming services and/or final products
- Transportation – unnecessary product movement between process steps
- Waiting – queue times before performing the next activity
- Overprocessing – adding value to the product which is not required by the customer

Lean philosophy is implemented in a series of by quick events known in literature as Kaizen workshops, Kaizen events, Kaizen week, Kaizen blitz etc. Kaizen means waste reduction and value adding across the entire value stream. Kaizen workshops lasting usually a week are managed by a specific team which focuses to identify and eliminate waste in a specific area. The speed of operations performed in Kaizen workshop is the key to success: It avoids more significant cost further down the line, increases understanding of the concept of waste among the staff and helps the entire organization to understand the high priority related to the elimination of waste. (Chiarini, 2013, p. 63–65.)

A value stream can be defined as a sequence which considers all actions taken to bring the product through its essential main flow. From the production point of view this flow considers all actions to bring the product or group of products from raw materials to the point when the product is delivered into the hands of a customer. The operations included in a value stream are classified as value adding (VA) or non-value adding (NVA) actions. (Gurumurthy & Kodali, 2011, p. 446.)

Value stream mapping (VSM) is closely related to lean manufacturing and is based on the material and information flow diagram first introduced by the Japanese car manufacturer Toyota. VSM is an effective lean tool for communication, planning and continuous development. It focuses on the customer, removal of waste and value creation. The basic idea of value stream mapping is to support the understanding of material processing steps

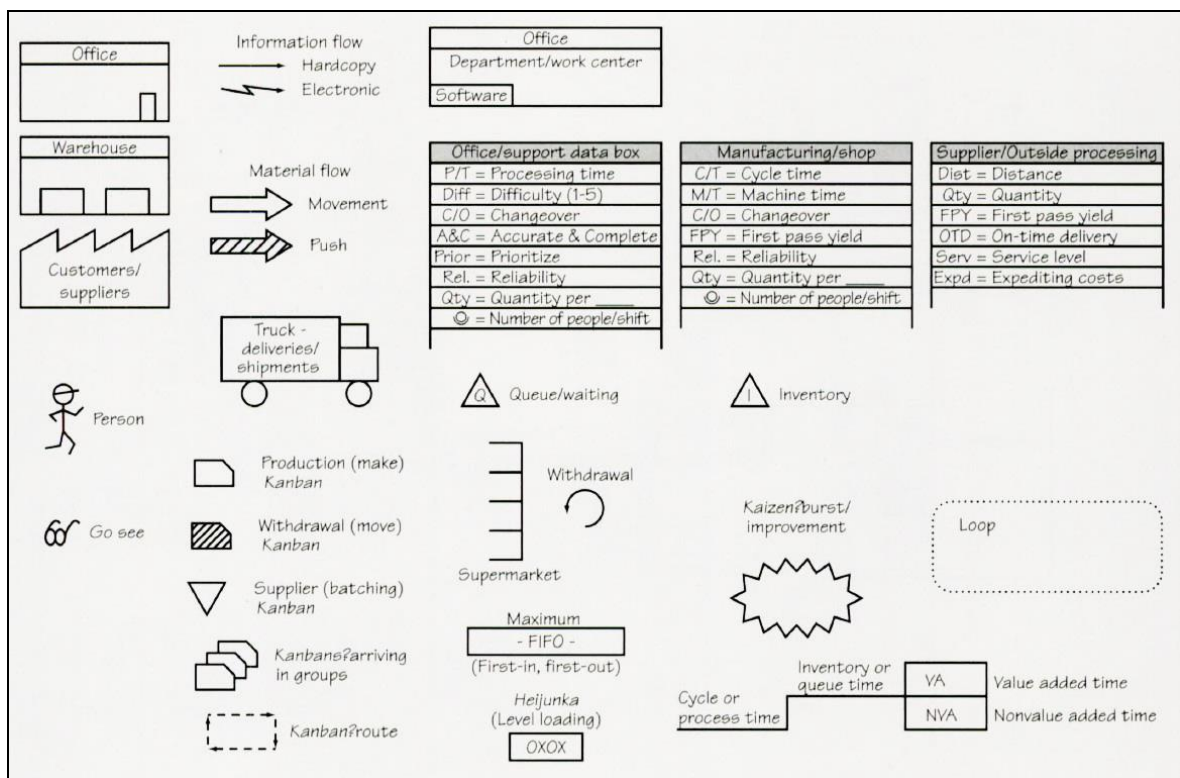
and information flows and the analysis of possible improvements. (Ström et al., 2013, p. 823.)

VSM provides a pictorial process step description from order entry to the final delivery to the customer. The value stream in VSM is defined as a point where the actual value is added to the product or service by converting the market form and/or function in order to meet the customer`s demands. These value adding operations (VA) are for example machining, drilling, folding, welding, painting and assembly etc. Operations not adding the value for the product (NVA) are probably adding waste. (Manos, 2006, p. 64.)

The first step when starting value stream mapping is to form cross functional Kaizen team for the VSM event. The desired team size is between seven and 10 members including supervisory or managerial level members. The larger the team is the harder it is to manage, so team sizes over 10 members should be avoided. Too small teams are also not favorable because they may cause barriers when searching for well-rounded input. As a special note, a VSM map should never be created by a team of one. One member alone may not find enough valuable input and cross functional dialogue could be lacking totally. Finally there is a risk that the final results of studies are biased for one area, department or person. (Manos, 2006, p. 65.)

After the team is formed, a three day Kaizen event is started. During the first day of the event VSM is introduced to the team members and product families are determined. A product family is a group of products which are moving through the same or at least 80% of the same process steps. The product families can be determined with a matrix that aligns all the facility level processing steps on the top row and observed items are listed vertically next to those steps. An X mark is placed on the row of the specific item if it goes through a certain process step. After the listing is done the items which are moving through at least 80% of the same process steps are determined and product families are formed. This is done because the items of the same product family can be produced by the same processes and only one stream map is needed. Then the team evaluates and selects product families which have for instance “biggest bang for the buck”, largest volume or quantity, biggest impact to customer or largest reduction in lead time. The most important product family according to the organization`s needs is selected. (Manos, 2006, p. 65–66.)

After the product family is selected, the team starts plotting the current state of the value stream by collecting the process data. This is done by walking through the flow and interviewing the employees performing the steps. The team collects data about processing times, changeover times, quantities, reliability of equipment, number of operators and shifts first pass yield, queue and waiting times, inventory levels, hard copy information and electronic information. When the data is collected and the team has agreed the most valuable points, it's time to draw a current state map. VSM maps are illustrated by using simple symbols shown in figure 34. (Manos, 2006, p. 67.)

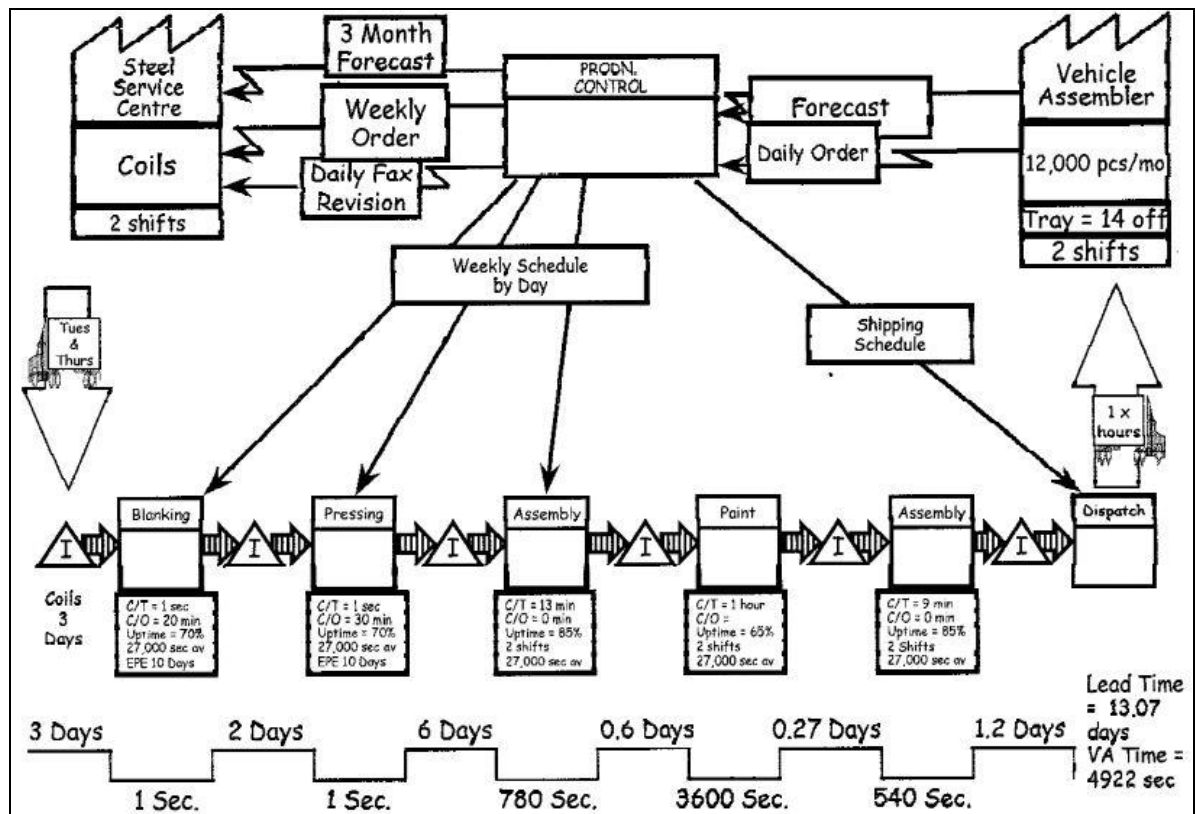


**Figure 34.** Common VSM symbols (Manos, 2006, p. 65).

The current state map illustrates how the process performs currently in the working environment. Figure 35 below illustrates one example of a current state map. Every VMS map looks different depending on the exact processes, but the main framework usually follows general design principles. VSM maps usually consist of five different main sections (Manos, 2006, p. 68.):

- The upper right corner covers the customer information
- The upper left corner consist of supplier information

- Top half of the map describes information flow
- Bottom half of the map describes material or product flow
- Gutter lines on top and bottom for determination of cycle and inventory and/or waiting times.



**Figure 35.** Example of a current state map (Brunt, 2000, p. 262).

When the current state map is completed, the team can begin to focus on the creation of a future state map. The future state map evolves from the current state map with the use of guiding questions. The making of it requires a basic understanding of lean principles. The guiding questions differ depending on the business area and the team needs to be careful and ensure that only suitable questions are selected. The most common questions that suit most types of business are listed below (Manos, 2006, p. 68–69.):

- What is the current takt time? Takt time defines the demanded production frequency of a part to be able to meet the customer needs. Takt time can be defined by dividing the production time available per shift by the demanded amount of parts per shift.

- Can bottlenecks or constraints be found in the process? Cycle and processing times should be compared to the calculated takt time. In case some of these are greater than the takt time, possible candidates have been found. Bottlenecks and constraints should be deleted because, those points may cause, extra processing time (overtime) to meet the demand, overproduction wastes, or work in progress (WIP).
- Where the inventory and queue times can be reduced or supermarket inventories exploited? Investigate raw material, safety stocks, finished goods inventories and WIP to define the levels that can be reduced. Are there points where it would make sense to put in a supermarket replenishment system? A supermarket system is a controlled inventory where the downstream process removes parts from the shelving and the process owners upstream fills the inventory by the same amount.
- Is there possible ways to improve flow? Is it possible to delete stopping and waiting points of materials or place materials into a cell? If the flow cannot be improved, is it possible to utilize first in, first out lane between the processes?
- Are there any other improvements which are needed? Are the reliability of equipment, first pass yield or quality levels high enough.

By these questions main improvement points of the current process can be found. A kaizen burst is then placed on the map. It marks the points where improvement is needed. Kaizen burst items can include points defined above, but also signals about long changeover times, large batches or any other waste such as motion, transportation, adjustment, defects, over processing etc. According to these findings the team will draw a future state VSM. It illustrates the state of process the team wants to reach in six or 12 months. When the future state map is drawn the new NVA and VA times and queue and waiting times should be calculated. After the future state VSM is completed and analyses done, the team creates a draft plan. The draft plan answers the question: How to reach the future process state determined in the future state VSM. A good draft plan should also include information about the required resources and budgets to complete the tasks. (Manos, 2006, p. 69.)

#### 2.4.1 Value stream mapping the in make-to-order environment

VSM was tailored primarily for the high-volume-low-mix products manufactured according to MTS principles. Because production systems of MTO and MTS companies are different, the VSM design guideline recommendations are of limited use for the

products of MTO companies. This is due to multiple reasons, but the most important one is the different logistic objectives of MTS and MTO strategies. Conventional VSM does not consider the most crucial logistic goal of MTO production: Delivery reliability, which defines the ability to keep agreed delivery dates. Also manufacturing environment and manufacturing control tasks differ between MTS and MTO. To ensure the best practical approach for the empirical part, the shortcomings of conventional VMS for MTO production need to be analyzed. (Koch & Lödding, 2014, p. 391.)

The method guidelines included in the design stage of conventional VMS focuses on how to control manufacturing. These guidelines work according to MTS production logistic goals. Next the common guidelines are evaluated with respect to specific characteristics of MTO production (Koch & Lödding, 2014, p. 394.):

- Takt time: The takt time to customer fluctuates highly in the MTO environment, so the calculation of takt time is harder than in high volume MTS environments.
- Usage of Kanban supermarket inventories: Not usable in the MTO environment because Kanban logic is responsible for refilling of the inventory. Kanban logic is the order generation method for MTS environment and it is not applicable to MTO production.
- Production planning information to be provided only for one pacemaker: Not usable in MTO environment because this demands the usage of supermarket inventories.
- Implementation first in first out sequencing and continuous flow: Not often usable in MTO environment because of highly variable processing times and complex material flows.
- Levelling of the product mix: Not often usable in the MTO environment because this would need information from a constant pacemaker / bottle neck system and very accurate demand forecasts.
- Distribute evenly the production volume: Not often usable in MTO environment because the product mix cannot be often evenly leveled.
- Capability to produce every part every day: This guideline is also useful for the MTO environment as it focuses on reducing the setup times and batch sizes in order to react flexibly to demand changes. Also by reducing the setup time, there is no need to build setup families.

The shortcomings of conventional VMS for the MTO environment can be turned into improvement requirements for conventional VSM and based on these a more suitable VMS for MTO can be evolved. Firstly the requirements consider the value stream analysis stage: The first step of conventional VSM analysis included the selection of a product family. In MTO production the amount of different products and product variations is very wide which would cause the selection procedure to be very extensive. Instead of trying to determine one product family, the VSM for MTO should focus on the entire work system of a MTO company. This way the whole complexity of the production system will be covered including information of backflows and shared resources. In conventional VMS the logistic aims are measured by work in progress (WIP) and throughput time. In the MTO environment more appropriate manufacturing control tasks have to be taken into account, including the order releasing, the backlog and sequence deviation which are better measures for schedule reliability, because ordering delays affecting delivery reliability can be taken into account. (Koch & Lödding, 2014, p. 396.)

Secondly the requirements can be also added to value stream design guidelines. A VSM tailored for the MTO environment should include information of all manufacturing control related tasks instead of concentrating on single tasks of manufacturing control. This means that information is needed about variables such as WIP, order release mechanism, backlog results, capacity control and sequencing. Next the design guidelines of VSM for MTO should support the user when the future state map is being developed. Guidelines should provide a simple, consistent and logical sequence of how to introduce all the manufacturing control tasks. Furthermore the guidelines for VSM for MTO should be independent which would prevent the situation in which failure of one guideline leads to the failure of another guideline. (Koch & Lödding., 2014, p. 397.)

### **3 KONE RENOVA SLIM RELATED SOURCING STRATEGIES, SUPPLY LINE AND DEVELOPMENT OF VOLUME TRENDS UNDER INVESTIGATION**

This chapter will introduce the empirical information related to the research questions. Data is gathered by interviews, site visits and according to statistical analysis based on the data exported from KONE's ERP system. Additionally the manners of execution are illustrated in the case of value stream mapping and volume distribution analysis.

#### **3.1 Current state of AMDS sourcing and KONE supplier relationship management regarding the supplier Stora**

The KONE purchasing organization responsible for AMDS purchasing operations in Finland is divided locally into a two functional units which are strategic sourcing and operative purchasing. Operative purchasing is responsible for the practical purchasing processes such as order agreements, no return point statement and giving the permission to start production. Alongside the purchasing order management duties, the operational purchasing unit monitors delivery times of orders, sends invoices and measures delivery reliability of the suppliers. Above the operative purchasing is Strategic sourcing. It is responsible for the sourcing strategies. Strategic sourcing for example agrees suppliers of materials and negotiates contracts.

From the purchasing demand perspective slim doors have low volumes and too many variations. The lead times are very tight and prices must be competitive because of high competition in the EMEA market area. Due to difficult demands related to the product, pricing and lead times, it is hard to find suppliers who have the needed competence to turn AMDS production into a profitable business. From purchasing portfolio perspective the AMDS product can be placed between bottleneck commodity and Strategic commodity. The supply risk of the AMDS product is high with a medium product value. From the purchasing point of view the supply risk of these commodities should be minimized and continuity optimized.

Slim doors are currently out-and dual-sourced. The outsourcing decision was made at the time when KONE transferred the AMDS production from France. At the time KONE's own factory in Hyvinkää was focusing on efficient A-process production. AMDS with low volume and high variability did not suit to the production plan of the KONE factory and slim door manufacturing was transferred out. Dual sourcing is then the common strategy used in KONE. The strategic sourcing organization always strives for dual sourcing to minimize the supply risks and to gain negotiating power. This is especially necessary with AMDS because of the high supply risk. KONE has also investigated that the benefits reached with dual sourcing are greater than the possible benefits of using single source. Conversely, there is no need for more than two suppliers, because the AMDS volumes are low and the additional workload which would come with a third supplier is heavier than the potential benefits. As the AMDS is a very variable product, it is clear that there are easier and more favorable orders, but also very complex and rare orders which are hard to deliver in time. While KONE strategic purchasing relies on dual sourcing, it must be strict with the order distribution supervision. In dual sourcing it is not possible to direct the favorable order flow to one supplier and let another one struggle with the complex orders. This would only cause shrinkages in the offering and uncertainties in the delivery of complex and rare variations which still form a significant proportion of total AMDS volume.

KONE supplier management is globally based on the segmentation of all external suppliers. Segmentation itself is based on the supplier's importance and criticality to KONE. The importance and criticality are measured by the evaluation of relevant sub-criteria's. All the supplier segments have their own specific applications of the management principles. According to KONE, the management approach comprises of four key areas which are: Supplier quality management, supplier relationship model, contract & risk management and process & system integration. The utilized management principles differ between direct materials which have a direct affect on the quality of KONE products and services, installation and other non-product related materials. The essential aim of supplier segmentation is to have a defined uniform methodology for the managing of supplier relationships in each category. Segmentation also enables a consistent global management of the entire supplier base concerning also critical sub-tier suppliers. KONE's suppliers are divided into a five segments which are global partner, global strategic, unit

strategic, validated and selected use. The global partner segment represents the most important suppliers. At the other end of the scale, the selected use suppliers are easiest to replace.

Stera and KONE have over 30 year's history together and Stera is seen as a reliable supplier for KONE. KONE defines Stera Technologies as a global strategic supplier. These suppliers are important for KONE business globally or regionally. Typically global strategic suppliers are utilized by multiple units at once. The supplier relationship with a strategic global supplier is managed by category teams in collaboration with the local units.

A significant factor between the two AMDS suppliers is that Stera is truly interested in the manufacturing of AMDS whereas Wittur regards the manufacturing of AMDS as an unfavorable business. Stera is also located near KONE's Hyvinkää R&D department. Due to the location and mutual language the improvements in supplier relationship and product development projects are easier to implement. On the other hand Stera has no manufacturing premises in Central Europe. Consequently transportation expenses of the orders traveling to South-Europe are dramatically higher compared to Wittur which has a factory in Italy. Additionally the distance between Finland and Fara Gera where the third AMDS related distribution center is located is long and Stera has problems with the requested lead times. Currently Stera is not able to deliver AMDS doors for MonoSpace 500 orders which are required at Fara Gera (Bracchi distribution center).

With both current AMDS suppliers KONE pursues long-time contracts, because alternative suppliers are hard to find. KONE and Stera also share the common strategies of the beneficial global growth which deepens the relationship. Negotiations can be seen as win-win negotiations which are performed in collaboration and KONE has an open dialogue with the two AMDS suppliers. An aggressive relationship is avoided since the TRB service repairs business requirements are set by the customers and both parties have a mutual understanding of the situation. KONE encourages both of the suppliers to propose cost cutting and development actions. Possible benefits are then divided and both parties will gain advantages.

From Stera's point of view, KONE as a customer represents approximately 20% of Stera's turnover while the next three largest clients are collectively 30% of the turnover. Accordingly KONE is clearly main customer of Stera. If KONE's percentage order value increases further regarding Stera's turnover, it will be a risk for both KONE and Stera.

### 3.2 Information flow between KONE and Stera

The information exchange between the collaborating parties KONE and Stera is executed in many ways. For instance Stera's sales managers have regular meetings with KONE sourcing persons and KONE purchasers exchange emails with Stera's colleagues about the orders and daily matters regarding the supply of KONE products. Yet Stera is not permitted to log in to KONE'S ERP system. To provide the essential information for Stera, KONE also sends forecasts to Stera on a weekly basis, in order to support its manufacturing.

Because Stera is relying on batch production the production planners need to optimize the manufacturing in order to achieve steady manufacturing flow which leads to favorable unit costs and quality. The information of upcoming orders plays an essential role within production planning. Stera Technologies receives two different forecasts from KONE concerning exempli gratia AMDS doors and railing. The content of the two forecasts are about same subject but the time span and accuracy of information vary. The first document is known as the short term forecast and is provided by Supply Operations Italy & SSE on a weekly basis. The short term forecast is based on KONE's order book and KONE front line forecasts. The time span of the forecasts covers the next 15 weeks from receipt of forecast. From the short term forecasts Stera is able to see the upcoming orders marked as grey, current orders marked as blue and completed orders marked as green. This forecast does not include accurate details of the orders and its purpose is to give Stera an idea how the flow of orders will develop in the near future. The second forecast provided by KONE concerns the grey marked orders that are also visible in the short term forecast. The second forecast presents all the data needed for manufacturing the doors, for example dimensions, materials, fire rating etc. Stera is interested especially in the materials included to orders and the fire ratings. The decoration material TS1 and fire insulation material related to fire class S and O are difficult to manage because of long lead times. To be able to deliver KONE orders in the required time frame, Stera needs to order the materials beforehand

according to the forecast. Regarding the forecasts introduced above Stera has the essential understanding of upcoming coming orders but it can start production only when the binding order is received from KONE.

### 3.3 Current AMDS manufacturing strategies and processes

The manufacturing methods relating to the AMDS were already described in Chapter 1.7 and introduced more specifically in Chapter 2.2. This chapter discusses AMDS manufacturing in a wider perspective in order to define the current manufacturing processes and strategies. AMDS doors total 1/3 of Stera's turnover with KONE so the manufacturing of AMDS has a significant role in Stera's business. Stera's type of manufacturing is batch production and the company has two different manufacturing processes which are the standard process and the claim process. For normal KONE AMDS A-process orders the standard manufacturing process is used. It starts when Stera receives orders from KONE and from other clients. When the orders are received Stera's ERP system places the orders to the most optimum project. Since Stera uses batch production, the batch size must be optimized. All the rows included in the same project are moved to production at the same time. The projects must be planned carefully to be sure that work is fed steadily into the production and lead times of the orders are still reachable. Projects stay in planning system for 1-2 weeks depending how well the production can be optimized. In case of an express order, the production planning and MRP can be conducted in one day, but this is not the standard mode of operation.

The claim process is a separate process from the standard version and it handles the advancement request orders and cases where there are claims against an original standard order. In the claim process Stera receives an advancement request. The request is checked and if the order is accepted, a new claim order will be made and the order is produced immediately according the request a minimum lead time. Claim process orders are not manufactured as part of a large project. An original standard order will be still produced with an original project. Standard order materials are then placed in stock and sold in future if a suitable order is received. This is the current procedure because cancellation of a standard order would cause too much manual work and misunderstandings. Accordingly it is better not to interfere with the standard process after the production projects are

launched. At-worst there can be as many as five advancement requests during one business week.

From the production strategy perspective Stera's current production strategy related to AMDSL A-process is divided into two different models. In general it can be seen as a hybrid approach with respect to the manufactured components which are classified according completed ABC analysis. In the case of A-class components such as certain AMDSL panels, sideposts and lintel related components, the production strategy is MTO. In MTO production the manufacturing of the components is started from the beginning of manufacturing stream, after a confirmed order is received from KONE. Table 2 presents the current batch sizes of AMDSL3 sill, panels, lintel and sideposts with specifications of the components.

*Table 2. Current batch sizes of AMDSL related A-class components.*

<b>Name</b>	<b>Specification (mm)</b>	<b>Material</b>	<b>Batch size / PCS</b>
Sidepost	HH=2,000, HH=2,100	Z,F	104
Lintel	LL=700, 800, 900	Z,F	99
Sill	LL=700, 800, 900, Carpet profile=48, 92	Z,F	122
Panel	LL=700, 800, 900	Z,F	384

The rest of the components are then classified as B- and C-class. These B and C components for instance sill profile, brackets etc. are managed according an ATO strategy. According the production strategy, B and C components are manufactured to stock beforehand and only assembled when the binding order is received. The minimum stock levels and production batch sizes of ATO controlled B and C components vary according to the ABC analysis. In 2009 cost reduction based on manufacturing optimization was implemented to B and C components.

In the wider picture over 70% of all AMDSL components are defined as B and C components which are manufactured to stock as push manufacturing and assembled to order. Less than 30% of the AMDSL components belong to the A-category. A-class components are still produced as pull manufacturing when a binding order is received. These pull controlled components are currently produced once in a week. Even though the A-components cover only 30% of total AMDSL components, those still form a significant amount of the total manufacturing costs related to the AMDSL door.

### 3.4 Current state of AMDS value stream

The lean tool known as value stream mapping was the selected tool used to illustrating the AMDS related order-delivery process. Nevertheless the tool has significant defects when used in the MTO environment for high-mix-low-volume products. However it provided a clearly processed and swift approach and standardized method for illustrating the current state and the possible future state of AMDS order-delivery process. The range of the method, starting from the placement of the customer order to the delivery of the final product was also suitable for the requirements of this thesis. Additionally a clear process was obligatory in order to ensure the quality of the step by step analysis. According to the clear process it was simpler to observe if all the affecting factors were concerned. The main goal of the order-delivery process illustration was to obtain a more clear understanding of the steps related to the AMDS A-process and measure the times and utilized employees per process step. The executed analysis concerns the entire AMDS work system which is the approach suggested in literature. The analysis covers KONE purchasing actions and the included customer service, supplier Stera Technologies and the external transportation provider. Second tier suppliers were limited out, except one supplier which is responsible for powder coating.

Analysis started with interviews and site visits (walking through the process flow). Five persons from KONE Corporation were interviewed from the Hyvinkää R&D department and also from the supply unit department in Finland. Also one person from Stera was interviewed. Collaborating members in the data collection phase consisted of employees working at different levels. Also managerial level employees were included. Based on the included employees the team size of the Kaizen event can be seen as seven which is the desired team size according to literature. All in all over 20 interviews were executed. To ensure the proper understanding of the AMDS manufacturing steps the production line was also investigated during two site visits. The data was collected and documented during the interviews and site visits and the opinions of participating persons were recorded according rules of neutrality.

Because value stream mapping is mainly designed for MTS production it was not possible to utilize all the related features of VSM in the AMDS related MTO environment. Batch sizes and times per production steps could not be measured accurately due to the highly

varying product variations and batches. Additionally the value adding and non-value adding times were hard to classify in the MTO environment because of the requirements of MRP and project optimization related to batch production of Stera. Under the circumstances, the value stream mapping executed in this thesis mainly focuses on describing the steps included in the order-delivery process and determining the amount of employees per step despite the aims described above.

When all the order-delivery process related steps were analyzed and data documented the current state value stream map was illustrated. In Appendix I the full scale current state map of AMDS is presented. Current state map illustrates all the process steps, the amount of employees needed per step and information flows. Arrows on the map illustrate pull-manufacturing flow. Normally the arrows are presenting push-manufacturing flow, but because of the MTO manufacturing strategy this approach could not be implemented. Additionally all the small storages between all the production steps illustrate intermediate storages of the production which are inevitable in MTO batch production.

### 3.5 Difficulties and defects affecting AMDS manufacturing

According to the executed interviews carried out and production site visits in Stera, many difficulties and defects related to AMDS as a sheet metal product and the manufacturing of it were identified. These defects and difficulties affect the effectiveness and efficacy of the product directly or indirectly. In the worst scenario, the negative factors are realized as increased manufacturing costs or as a decreased order book. The first and most visible factor which was noted already at the beginning of this thesis is the variability of the product.

The current AMDSL modernization package offering consists of 38 different options with 256 different values. On the AMDSC side the amount of options is 47 with 227 different values. In a situation where all the options and values are available and the already chosen options do not limit the availability of other options, the amount of AMDSL variations is approximately  $2.9E+25$ . The comparable number on the AMDSC side is  $3.6E+22$ . In practice there are limitations between the options and values, so the actual amount of possible variations is lower. This example however illustrates the high level of variability of AMDS. A closely related factor to variability is the consequent low volume. When high

variability is combined with low volumes the outcome from the manufacturing perspective is small batch size and the fragmented manufacturing of single variations. Manufacturing of AMDS is then characterized by one-off production and new individual doors are produced monthly which leads to the increasing number of product variants and titles. The high amount of variants causes additional upkeep costs and a new CNC program is needed for each new variant which increases the process steps

Offering and variability of the AMDS is expanding all the time because of the new options that are added constantly. For a sales person it is easy to ask if one option can be added to the offering based on a query received from the customer. For the manufacturing supplier it means they have to maintain the capability to manufacture all the variations of doors. The risk in this situation is that totally irrelevant options exist in the offering, which are ordered for instance once in two years. Even though the ordering pressure is not focusing on rarely ordered options the suppliers still need to maintain the ability to produce doors with the these rare options. This maintenance of the ability to produce increasing amount of rarely ordered options is decreasing efforts and focus directed at the relevant options and actual manufacturing work. Additionally it is not clear to the parties if there are options which are always ordered unnecessarily and then thrown away (for example drill bits and plumb lines added to every ADMS order).

Because of high AMDS variability the suppliers are forced to produce varying product variations almost as one-off production. When there is a lot of individual doors manufactured the possibility of external and internal process and product related quality problems increases and the amount of scrap regarding AMDS manufacturing is higher because of varying products compared to the environment where similar products are produced daily. Elevator doors consisting of large surfaces are also vulnerable to getting scratched and require a lot of raw material to produce. The scratching is especially possible during the packaging and on site when the doors are installed. Door packaging is designed in such a way that an installer needs to unload a remarkable amount of components to be able to install one specific part. After the components that are currently not needed are loaded back to the package scratches can result.

Advancement requests introduced earlier in Chapter 3.2 are also one defect that affects AMDS manufacturing. These requests are undesirable, because negotiated lead times should be respected and the request further disrupts the production planning of the supplier. According to Stera the advancement requests are caused by incompetent KONE frontline assembly orders.

### 3.6 Current AMDS cost structure and pricing method

Stera utilizes traditional cost accounting including cost unit accounting and output-based accounting. Stera is a group of companies and the operating statement is presented monthly. At the company level Stera is divided into three operational business areas: Stera Saue, Stera Engineering and Stera Technologies. Monthly operating statements are presented for all the business areas. Under these operational business areas are the cost units. The operating statements of the cost units are then covering also the production margin and fixed / variable costs are presented per cost unit. AMDS manufacturing belongs to cost unit locating under the Stera Technologies.

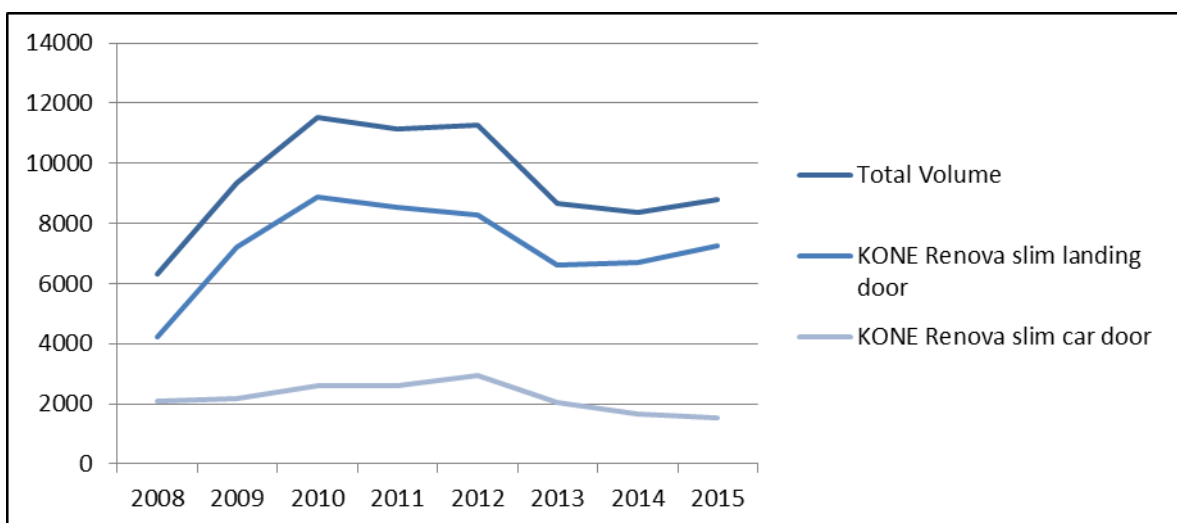
Stera Technologies output-based accounting is relying on exact formulas that are determined for every single production step and for raw materials. The company calculates the manufacturing costs per output by these formulas. The formulas provide hourly costs for every production step stemming from variable and fixed costs. Manufacturing drawings of a single item provides information about needed raw materials and the number of punches, bends, welds etc. demanded to produce the component. According to the demand of raw materials and needed work stages including assembly and packing, the component's exact manufacturing costs are defined. When costs of every component are measured the total costs of an AMDSL output are clear.

Stera's pricing principle is based on market pricing and cost based pricing. Before accepting a manufacturing request of a customer, the company tries to determine the current market price of the output. When the market price is clear, Stera Technologies defines the company's own cost structure of the output and calculates the total manufacturing costs by the formulas defined above. After the total manufacturing costs of an output are clear, Stera calculates the price for the output by the same formulas of manufacturing steps and raw materials. The formulas of hourly costs and required raw

materials are now just multiplied by Stera's marginal profit. The result is the cost based price of an output. The cost based price is then compared to current market price. In case Stera Technologies price of the output is greater than current market price, it means that the company is not able to include the target profit margin to the price of the output and must consider if the manufacturing request is beneficial to produce at all. The price of the AMDSL is also estimated according to this process. Markets define the prices and Stera Technologies ensures that their actions are profitable.

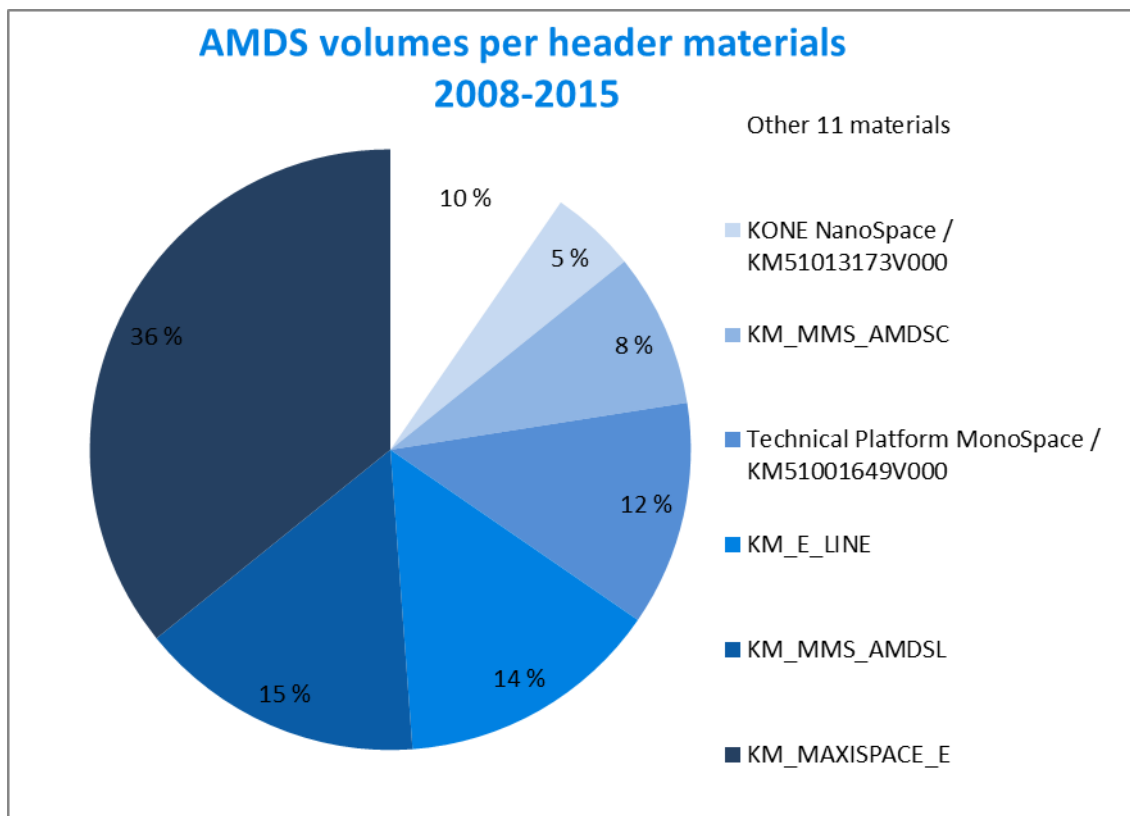
### 3.7 AMDS Volume trends

KONE AMDS is a low volume product. Total annual volume (landing doors + car doors) has been 8,000-12,000 delivered doors from the beginning of the 2010s until the end of 2015. Figure 36 presents the development of total volume with landing door and car door volumes during the years 2008-2015. As the table illustrates, the main proportion of total volume is coming from landing doors. This is due to the technical fact that normally residential and office buildings have for instance 2-99 floors and quantity of landing doors can be equal to the total number of floors or even doubled, however an elevator car have a maximum of two doors. In the 2010s, the highest amount of the orders was delivered in 2012. During years 2012-2013 AMDS order book contracted because of two major reasons: First the Finnish government ended financial support for elevator modernizations and at the same time in Sweden a large statutory project ended which focused on adding car door for every existing elevator.



**Figure 36.** Volume trends of KONE Renova slim doors during business years 2008-2015.

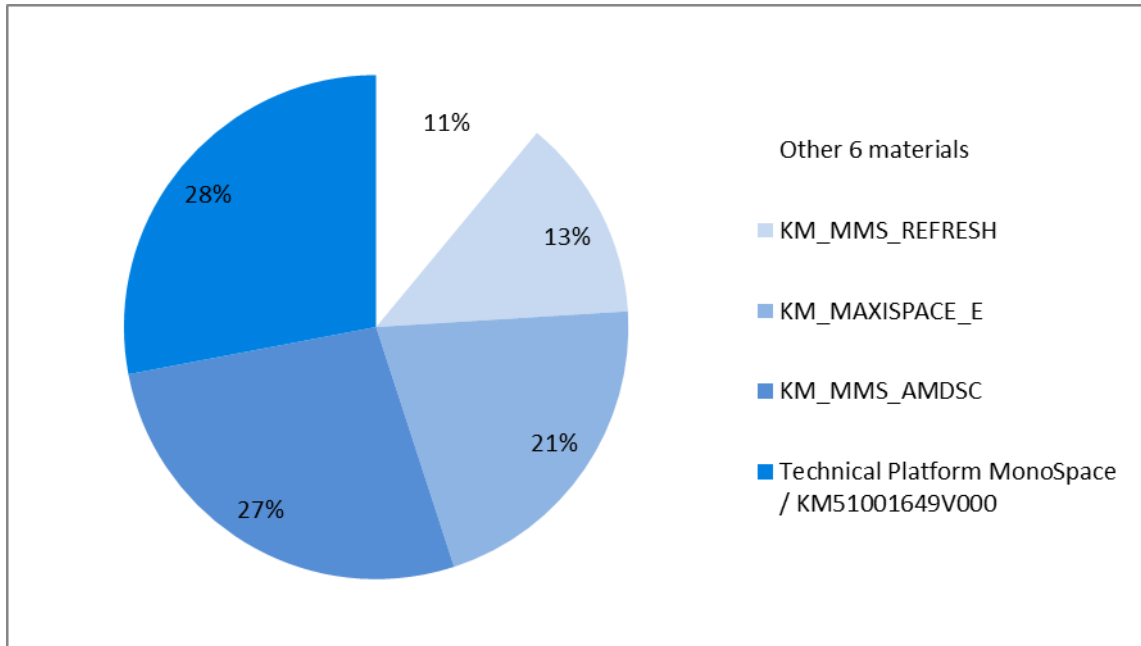
One important statistical factor is the header material of slim doors. Header material defines the actual platform or in other words the main material with which the AMDS is delivered. The most common header materials were introduced with details in Chapter 1.7.8. The platforms in Chapter 1.7.8 were chosen according to the years 2014-2015. This analysis will now introduce the development of header materials more accurately. Figure 38 shows that during the years 2008-2015 AMDS doors have been delivered with 17 different materials. In figure 37 all the completed AMDS orders are considered, meaning that both car door and landing doors orders are included. The most significant individual AMDS platforms have been elevator platforms MaxiSpace, MonoSpace and NanoSpace. Also modification packages AMDSL and AMDSC are among the foremost products. The remaining 11 header materials form together only 10% of the total volume.



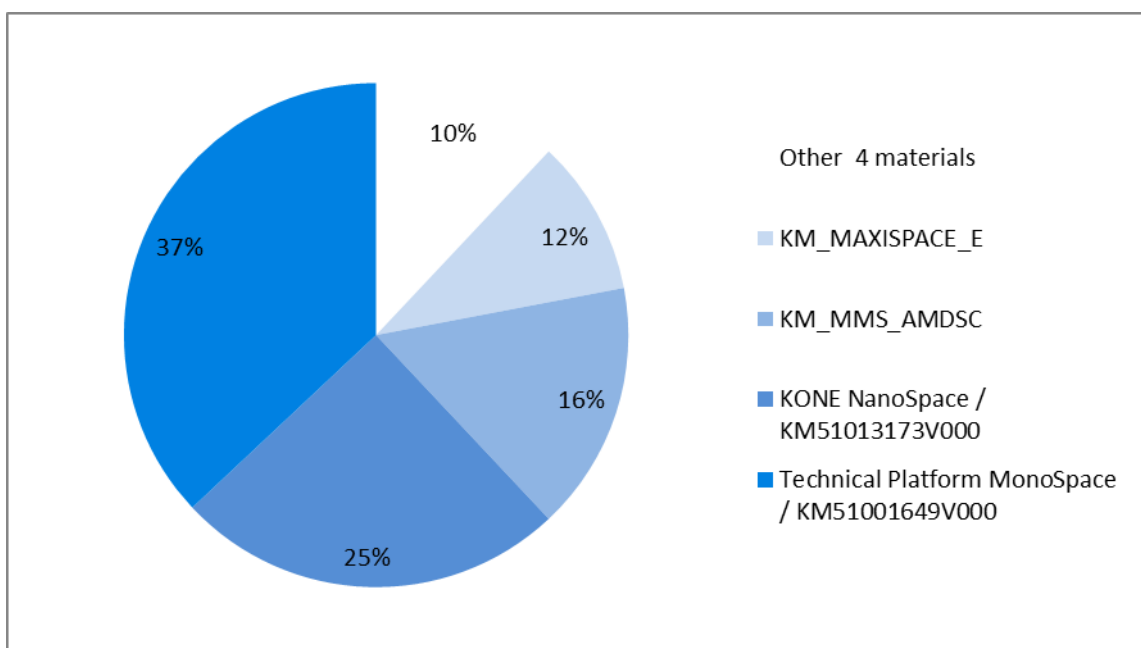
**Figure 37.** Header materials of KONE Renova slim landing and car door 2008-2015.

In addition KONE Renova slim landing and car doors can also be ordered individually. The next figure 38 shows the header materials of AMDSC orders in 2014 and the following figure 39 illustrates the same situation in the year 2015. The three most popular header materials were in 2014 elevators platforms MonoSpace, MaxiSpace and

modernization package KM\_MMS\_AMDSC. During 2015 the situation has changed and currently the three main individual header materials are the modernization package KM\_MMS\_AMDSC and elevator platforms MonoSpace and NanoSpace. This is due to the retirement of the elevator platform MaxiSpace and its replacement by the platform NanoSpace.

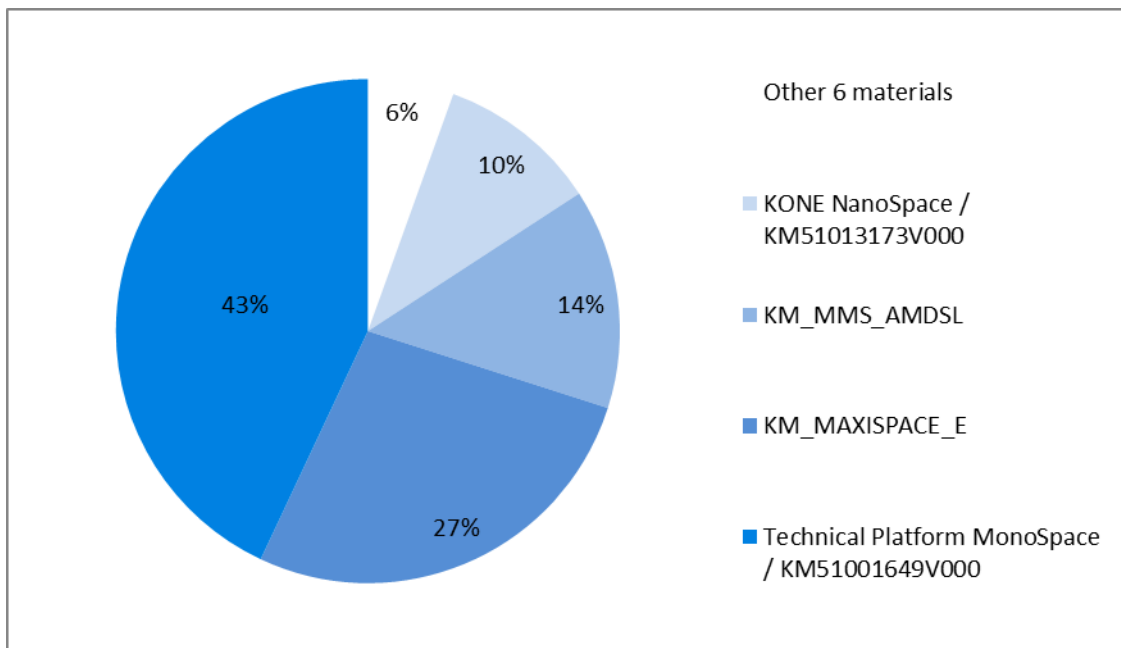


**Figure 38.** Header materials of KONE Renova slim car door in 2014.

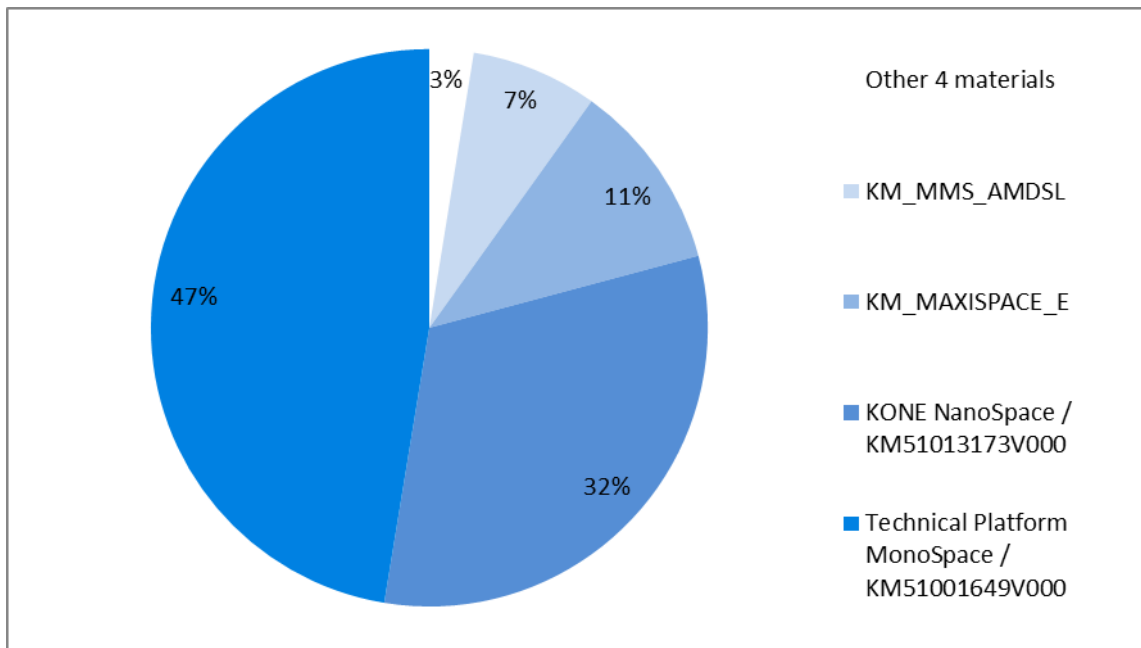


**Figure 39.** Header materials of KONE Renova slim car door in 2015.

As the AMDSL generates the most of the AMDS orders totally, it is also necessary to investigate the AMDSL header material development. Figure 40 below defines the header materials of delivered AMDSL orders in 2014 and the following figure 41 present the comparable situation for the year 2015. Equally for AMDSC header materials, and on the AMDSL side the MaxiSpace platform volumes have been decreasing during the years 2014-2015, but it is still among the three most important AMDSL header materials in 2015 even after the loss of volume. It is notable that in the year 2015 the three most important AMDSL header materials were elevator platforms MonoSpace, NanoSpace and MaxiSpace. The modernization package KM\_MMS\_AMDSL was only the fourth most important header material.



**Figure 40.** Header materials of KONE Renova slim landing door in 2014.



**Figure 41.** Header materials of KONE Renova slim landing door in 2015.

Another notable factor when analyzing the AMDSL order volumes is the destination distribution center. When Stera manufactures the AMDSL doors it has three different terminals where the order can be requested. The distribution centers are defined in KONE as KHEH, KNEP and KNEV. KHEV indicates the distribution center located in Kouvola, Finland. From Stera's factory located in Tammela, Finland the transport time to KNEV is one day. KNEH is the Central Europe's distribution center locating in Hamburg. Stera's transport time to Hamburg is three business days. KNEP is the Bracchi distribution center located in Fara Gera d'Adda in Italy. It is remarkable that Stera's transport time to Bracchi distribution center is five business days. It means that Stera must make the order shipment seven days earlier than KONE has requested the order to arrive at the distribution center. Because of this, Stera is not able to deliver AMDS orders with the MonoSpace 500 platform to the KNEP distribution center. The next figure 42 shows the distribution of AMDSL orders directed to Stera for the three KONE distribution centers in the years 2014 and 2015.

2014		
Terminal	Quantity	Percentual Proportion
KNEH	2151	41 %
KNEP	691	13 %
KNEV	2455	46 %
<b>Grand Total</b>	<b>5297</b>	<b>100 %</b>

2015		
Terminal	Quantity	Percentual Proportion
KNEH	1815	31 %
KNEP	1732	29 %
KNEV	2389	40 %
<b>Grand Total</b>	<b>5936</b>	<b>100 %</b>

**Figure 42.** Distribution of Stera`s AMDSL volume to the three KONE distribution centers in the years 2014 and 2015.

### 3.8 AMDSL volume distribution analysis in order to determine the main scope of variations

This analysis is based on the hypothesis that even for AMDSL which is characterized by small volumes and high variability there is a narrow main scope of the most important variations which generate the bulk of the total volume. This analysis is based on the 2014-2015 order book of AMDSL focusing especially on the orders directed to Stera. The order book including all the information of completed orders was exported from the KONE ERP system. The AMDSL characteristics guiding the completed analysis were identified with the help of the door supplier. According to the door supplier the door type, HH dimension, LL dimension, LAL / LAR dimensions and frame and panel decoration materials of AMDSL are the most essential characteristics regarding door manufacturing and especially pull-manufactured components. The analysis was then implemented accordingly and the main scope of variations searched using these seven factors.

As the figures 40 and 41 illustrated the elevator platforms MonoSpace 500, NanoSpace, MaxiSpace and modernization package KM\_MMS\_AMDSL formed approximately 96% of total orders during the years 2014 and 2015. The analysis focused then only on these four door header materials and the rest of the header materials consisting of 4% of the total orders was excluded. At first all the chosen header materials were observed individually. This led to four varying kinds of main scopes. After the main scopes were identified for all

the essential AMDSL header materials, one common main scope was formed. Due to the varying individual main scopes, tradeoffs had to be made. Because this thesis focuses especially on NanoSpace platform, it had the main weight in evaluation.

The main research per header material started with a door type analysis. The second factor investigated was the HH dimension of the door and the third factor LL dimension. After these, the LAR and LAL dimensions were checked. The first goal was to identify the main door types and dimensions individually. After individual main values were identified per factor, the proposed main scope was formed. The next step of the analysis was to observe the proposed main scope as a whole. The aim was to reject the values which are individually significant, but lose importance when combined with other main scope values. For example the LL dimension of 670 mm can be among the most important door LL dimensions when investigated individually. But if the LL dimension is dependent on the other six factors the 670 mm value loses its importance because the other values chosen with the 670 mm were rejected from the main scope as not being important values. After the proposed main scope was analyzed as a whole and values that did not suit the general picture of the scope were dropped off, the main scope of individual header material was formed. The resulted individual main scope was still purely based on the dimensions and door type. The final aim was to determine the main panel and frame decoration materials ordered with the dimensions/door type based on the main scope. After the materials were clear those were combined with the dimension/door type based main scope. The result was a total main scope of individual header materials. All the main values of dimensions, door types and materials were identified according to the volumes. The aim was to choose most the important values until those values covered over 50% of the total volume. Some exceptions were made for example if the first value totaled 50% of the total cases and second value had a proportion of 25%. Both of these values were then chosen in the main scope because of their importance. The remaining 10 values totaling 25% of total cases were nevertheless rejected. Next the executed main scope analysis is introduced in more detail from the perspective of the four individual header materials. Finally the total main scope combined from these individual main scopes is also illustrated with details.

The AMDSL modernization package KM\_MMS\_AMDSL had the lowest volume of the four main AMDSL header materials. Door types 3L and 3R formed over 83% of total

cases. The HH dimension 2,000 mm was chosen in 94% of the orders, while the rest of the analyzed diameters were spread more widely. The most common frame and panel material was F which formed over 50% of the orders. Also materials TSI and K had a significant proportion of the total volume, so those were also included into KM\_MMS\_AMDSL main scope. The next table 3 illustrates the identified KM\_MMS\_AMDSL individual main scope covering approximately 40% of total cases. The total coverage of 50% was hard to reach within a narrow range, because LL, HA, LAL and LAR dimensions varied highly between the orders. In order to reach the total coverage of at least 40% of KM\_MMS\_AMDSL orders, some second priority values had to be added to support the first priority peak values.

*Table 3. The individual main scope of modernization packet KM\_MMS\_AMDSL.*

<b>Door type</b>	<b>HH (mm)</b>	<b>LL (mm)</b>	<b>HA (mm)</b>	<b>LAL (mm)</b>	<b>LAR (mm)</b>	<b>Frame material</b>	<b>Panel material</b>
3R	2,000	680	0	0	0	F	F
3L		700	99.5	99.5	99.5	TS1	TS1
		800	370	170	150	K	K
		850	400	180	170		
		900	470	300	180		
			600				

The elevator platform MaxiSpace had the second lowest volume compared to the other four AMDSL main header materials. With MaxiSpace header material, the door type 3R formed almost 95% of total cases and HH dimension 2,000 mm was chosen in 94% of the orders. Three HA dimensions together formed over 60% of total cases, so those were also easy to identify. Nevertheless LL but also LAR and LAL dimensions varied highly between the orders and clear main dimensions were hard to identify. The most common frame and panel material was F which formed over 50% of the orders. Also materials TSI and Z had a significant proportion of total volume, so those were also included in MaxiSpace`s individual main scope. The next table 4 illustrates the identified MaxiSpace individual main scope covering approximately 51% of total cases. In order to reach the total coverage of 50% of MaxiSpace orders, some second priority values had to be added to support the first priority peak values.

*Table 4. The individual main scope of MaxiSpace elevator platform.*

Door type	HH (mm)	LL (mm)	HA (mm)	LAL (mm)	LAR (mm)	Frame material	Panel material
3R	2,000	600	0	0	0	Z	Z
		650	99.5	99.5	99.5	F	F
		680	570	170	170	TS1	TS1
		690		180	180		
		700		200	200		
		730		220	220		
		740					
		750					
		770					
		780					
		800					
		850					
		900					

The NanoSpace elevator platform had the highest volume of the all AMDSL main header materials directed to Stera during the years 2014 and 2015. With NanoSpace header material, the door type 3R formed 100% of total cases and the HH dimension 2,000 mm was chosen in 85% of the orders. The HH dimension 2,100 mm covered the rest of the cases and was ordered with 15% of the total cases. HA, LL, LAR and LAL dimensions varied highly between the orders, even compared to the MaxiSpace platform. Due to this clear main dimensions were hard to identify for the narrow main scope. The most common frame and panel material was F which formed over 50% of the orders. Further the materials TSI and Z both had a 20% proportion of total cases. The next table 5 illustrates the identified NanoSpace individual main scope covering approximately 57% of total cases. In order to reach the total coverage of 50% of NanoSpace orders, several LL, HA, LAL and LAR dimensions had to be included in the main scope.

*Table 5. The individual main scope of NanoSpace elevator platform.*

Door type	HH (mm)	LL (mm)	HA (mm)	LAL (mm)	LAR (mm)	Frame material	Panel material
3R	2,000	670	0	0	0	Z	Z
	2,100	680	99.5	99.5	99.5	F	F
		700	120	170	170	TS1	TS1
		740	530	180	180		
		750	570	190	190		
		800	580	210	210		
		810		220	220		
		850					
		900					

The MonoSpace 500 elevator platform formed the second highest volume of Stera's AMDSL orders during 2014-2015 compared to the other AMDSL main header materials of Stera's orders. With MonoSpace 500 header material, the volume was spread evenly over the door types 3R, 4R and 4L and the HH dimension 2,000 mm was chosen in 80% of the orders. The HH dimension 2,100 mm covered the rest of the cases and was ordered with 20% of the total cases. Also with MonoSpace the dimensions HA, LL, LAR and LAL varied highly between the orders. Due to this clear main dimensions were hard to identify for the narrow main scope. The most common frame and panel material was F covering approximately 70% of the total orders. Further the materials TSI and Z were the next most common materials. The following table 6 illustrates the identified MonoSpace 500 individual main scope covering approximately 52% of total cases. In order to reach the total coverage of 50% of NanoSpace orders, several LL, HA, LAL and LAR dimensions had to be included to the main scope.

Table 6. The *individual main scope of MonoSpace 500 elevator platform*.

Door type	HH (mm)	LL (mm)	HA (mm)	LAL (mm)	LAR (mm)	Frame material	Panel material
3R	2,000	700	0	0	0	Z	Z
4L	2,100	780	99.5	99.5	99.5	F	F
4R		790	200	310	140	TS1	TS1
		800	360	320	150		
		830	480	360	170		
		840	540	390	180		
		850	560				
		900	570				

The total AMDSL main scope regarding Stera's AMDSL orders was then formed after the individual main scopes of most important header materials were identified. According to Stera, the individual main scopes identified above were too wide and the resulting main scope thus created would also suffer from high variability. The total main scope needed to be as simple as possible, even if it meant dramatically decreasing the coverage of the orders. When the main scope was formed NanoSpace had the highest weight in decision making. Only the obviously main values ordered with the most important AMDSL header materials were placed in the total main scope. The following table 7 presents the total main scope created according to Stera's AMDSL orders. Total coverage of the main scope is 27% of the AMDSL orders directed to Stera (2,226 PCS / 8,183 PCS). From the header material perspective the total main scope covers 27% of KM\_MMS\_AMDSL orders, 28%

of MaxiSpace orders, 34% of NanoSpace orders and 17% of MonoSpace500 orders. The 17 values included in the main scope cover less than 8% of the total values available with these seven options. The margin of error related to the executed analysis is  $\pm 1\%$ .

*Table 7. The total main scope of AMDSL.*

Door type	HH (mm)	LL (mm)	HA (mm)	LAL (mm)	LAR (mm)	Frame material	Panel material
3R	2,000	700	0	0	0	Z	Z
3L	2,100	800	99.5	99.5	99.5	F	F
		900					

If the situation is also observed from the AMDSC point of view the main scope identified based on Stera`s AMDSL orders can also be edited to suit the AMDSC. The next table 8 illustrates the AMDSC main scope based on the AMDSL analysis. First of all the coverage of KM\_MMS\_AMDSC, MonoSpace 500, NanoSpace and MaxiSpace header materials volume of Stera`s AMDSC orders is 85% of total AMDSC orders in the years 2014 and 2015. Secondly the main scope covers 36% (984 PCS / 1,700 PCS) of all Stera`s AMDSC orders filtered by the four header materials.

*Table 8. The total main scope of AMDSC based on the AMDSL analysis.*

Door type	HH (mm)	LL (mm)	Frame material	Panel type
3R	2,000	700	Z	Steel
3L	2,100	800	F	
		900		

## 4 RESULTS AND DISCUSSION

The aim of the chapter three was to answer the selected research questions by observing the current AMDSL situations regarding sourcing, supply line, manufacturing, cost estimation, pricing, and sales volumes. Additionally statistical analysis was implemented and the main scope of AMDSL variations identified. Now when the answers for the five guiding research questions are given and a comprehensive understanding of the AMDSL order-delivery process is gained, this chapter focuses on the discussion and answering the identified research problems. The given proposals are based on the empirical studies and literature review and aim to fulfill the essential goals of this thesis: decreased costs related to AMDS and increased competitiveness.

### 4.1 Discussion

KONE and Stera share the same strategy of profitable global growth and the collaboration between the companies is essentially focusing on mutual benefits. Stera understands that the tight demands complicating AMDS delivery are resulting from by the end customer and highly competitive market in the EMAE area. Even though the AMDS is a low volume, highly variable product Stera is genuinely committed to AMDS manufacturing where as other supplier would have given up the opportunity. According to the studies, AMDS manufacturing would be more competitive if all the volume is directed to Stera. Since a single source model is too great a risk regarding for instance continuity and because Stera has problems with requested lead times to certain parts of Europe due to the lack of a factory in Middle-Europe, the sourcing transition to single source in case of AMDS is not considered as an option.

KONE forms 20% of Stera`s turnover where AMDS represent a third of the total. Accordingly Stera is not totally reliant on KONE or AMDS. Shrinkage in KONE`s order book would not cause insurmountable problems. Nevertheless Stera is categorized as a global strategic supplier and Wittur as a global partner which is the highest category in KONE`s supplier classification. This is indicating that KONE`s collaboration with Wittur is considered more valuable in general. On the other hand Wittur is also a competitor of the AMDS door with Wittur fine line compact door. This fact does not impact on the sourcing

policy of AMDS. Door suppliers with the demanded competence and strategy are in generally difficult to find.

Even though collaboration between Stera and KONE is close and actions executed with a view to produce a win-win situation, collaboration is still not totally visible. Firstly the companies do not have an open discussion of the acceptable level for a supplier's profit margin and in practice Stera has decreased the profit margins to be able to respond to KONE's demands. This is not seen as a truly collaborative partnership today and might even cause problems to KONE if this important supplier was not able to operate effectively. On the other hand KONE is a large scale corporation and is able to ensure the continuity the business of a smaller important supplier. Secondly Stera is not able to log on to KONE's ERP system which would make the order-delivery process more transparent and the effectiveness of information flow would increase. Finally the collaboration between Stera and KONE is complicated by the KONE's own factory located in the Czech Republic. The Ústí factory is complicating Stera's actions with KONE because Stera can be seen as competitor in the field of other Renova doors.

Stera's AMDS manufacturing is currently relying on batch production. In 2009 Stera implemented an ABC-analysis for AMDS components. Following the analysis, high priority A-class components are produced as pull-manufacturing according to the MTO principle. Where B- and C-class components are controlled regarding ATO and push-manufacturing principles. The A-class components are causing the main share of AMDS related manufacturing costs and production lead time because with the A-class components the manufacturing must be start from the first step of the production process whereas the B and C components only need to be assembled. Manufacturing methods utilized in AMDS manufacturing are traditional and robust processes. Additionally Stera has invested in FMS (Flexible Manufacturing System) machinery. The upcoming FMS combining turret punch press and fiber laser will increase the flexibility of Stera's manufacturing, aiding the production of more one-off doors in future

Based on the empirical research, most of the defects affecting Stera's AMDS manufacturing stem from the extended offering and tight lead times. The advancement requests are individual defects that cannot be linked to the variability and lead times.

Advancement requests are mainly caused by a limited number of KONE front lines. New process models for those front lines should be developed in order to decrease the amount of the unwanted requests which hamper Stera's manufacturing dramatically.

Because of high AMDS variability, Stera must produce a significant amount of individual AMDS products. This has caused a large number of different variants which are hard to manage. Because of the high amount of variants and individual orders, Stera's production is characterized by several batches of material in intermediate storage, leading to complex overall material flows. The factors defined above then because increased risk of quality problems and internal scrap related to manufacturing.

AMDS variability is essentially stemming from the wide offering which has extended year after year: The various header materials have a different offering regarding AMDS and new options are constantly added to those offerings in order to meet the needs of the front lines. Despite the extending offering, no studies have been implemented that focus on the relevance of the values and options currently available. According to the studies related to this thesis, there are options available at the moment which are ordered only once in two years. Even though AMSD orders are not focusing on those rarely-ordered values and options the suppliers need to maintain the ability to produce all the possible product variations. This is decreasing the efforts directed to the actual manufacturing work related to the relevant options. In order to maintain the efficiency of AMDS A-process, KONE should investigate more carefully what variations have been ordered and which have been not. Based on this research, outline more accurately the A-process offering of AMDS doors. Rarely ordered options and values should not be totally deleted, but to those should be transferred to C-process offering.

Value stream mapping was also implemented during this thesis. Because of the complex MTO production environment the VSM tool had some significant shortcomings. Most of the quantities defining the state of AMDS supply line were unable to be defined. VSM was then used to illustrate the process steps included in the order-delivery process in general. The current state map was generated according to the collected raw data. The future state map was also generated to support the upcoming proposals. One significant point identified during the VSM project was that in regarding AMDS no one in R&D and the

supply unit had a clear understanding of the order-delivery process steps taking place between KONE front line, end customer and the distribution center. KONE employees in R&D organization and SSE responsible for the competitiveness of the AMDS had only made assumptions on how the orders are handled within the area in question. Because of this the employees are not sure what are the essential acts that provide most value for the end customer.

Finally the variability of the AMDSL orders directed to Stera was observed. As a result of statistical data analysis a main scope of variations based on seven major factors affecting to the manufacturing was developed. The identified main scope covers 27% of the completed orders directed to Stera during the years 2014 and 2015. The main scope consists of 7.5% of values currently available for the seven factors. The aim of the analysis was to determine the main scope which would cover more than 50% of all the AMDSL orders directed to Stera within the analyzed business years. However the 50% level was unreachable because the main scope would also suffer from high variability as in the original AMDSL offering. The final decision was to keep the main scope as simple as possible even if it causes coverage losses. Because variability is the ultimate problem regarding AMDS manufacturing and the supply line, the proposals are given based on the main scope of variations resulting in benefits for the narrower offering.

#### 4.2 Guidelines for cost cutting and lead time reduction

The variability of the AMDS product was identified as the ultimate problem affecting the costs structure and competitiveness. The problem affects all the most important AMDS header materials. Despite high variability, the main scope of variations exists. The existing main scope of variations (introduced in page 100) indicates that a certain narrow section of the AMDS offering generates a larger part of the orders than the percentage contribution of the offering illustrates. The focus of this proposal is on AMDSL while AMDSC is only mentioned briefly as a lower priority item. The aim of this proposal is to focus on the narrow main offering and introduce a more efficient A+ process and present supportive facts based on empirical research. The A+ process would cover 7.5% of the order variations generating 27% of the total AMDSL orders generally and 34% of NanoSpace orders in particular that are directed to Stera.

Stera is currently manufacturing all the A-class components as pull manufacturing. Production is triggered when a binding order is received from KONE. This means that the first step in AMDSL A-class component manufacturing is currently the guillotine shearing or generation of the CNC-program for the variations which have not been produced earlier. With the narrow main offering, the annual demand of AMDSL related Stera A-class components can be accurately determined. Because the narrow main offering presented in Chapter 3.7 is formed to include only the main door types, materials and main LL, HA, LAR and LAL dimensions, the variation in demand is assumed to be steady.

The A+ process is then based on the idea that within the narrow main offering the AMDSL doors could be fully manufactured according to push-manufacturing principles. Even the A-class components could be manufactured to stock and assembled when the binding order is received. This means that all the AMDSL related A, B and C components would be controlled according ATO principles and only assembled when the order is received. In this way the AMDSL main variation lead time would shorten and manufacturing costs decrease.

If the AMDSL A-components are transferred to push manufacturing the batch size of the manufacturing lots can be increased. When the batch size is increasing the setup costs per unit will decrease. This is realized as lower manufacturing costs. Currently Stera produces AMDSL A-components once per week. With push manufacturing the components could be produced in larger batches, for example once in a month. In addition to lower manufacturing costs, the larger batch size increases quality of the A-components and decreases internal scrap. On the other hand the manufacturing to stock causes stock holding costs and risks related to warehousing.

First the annual warehousing costs per AMDSL A-component were calculated. Then the costs stemming from order handling and machinery down time caused by setups was also identified. To maximize the suitability of push-manufacturing, the EOQ was measured according Wilson's formula (formula 1). The most favorable lot sizes according to the formula were observed and compared to current actual lot sizes. For sill, uprights, lintel and door panels the formula suggested significantly large lot sizes. The batch sizes were then used to determine the new manufacturing costs for AMDSL main variations. When

the annual warehousing costs per component were taken into account the potential profit regarding the manufacturing costs is approximately 1.7% compared to the current manufacturing costs.

*Table 9. The push-manufacturing related proposal batch sizes for AMDSL A-components.*

<b>Name</b>	<b>Specification (mm)</b>	<b>Material</b>	<b>Batch size / PCS</b>
Sidepost / Upright	HH=2,000, HH=2,100	Z,F	594
Lintel	LL=700, 800, 900	Z,F	391
Sill	LL=700, 800, 900, Carpet profile=48, 92	Z,F	270
Panel	LL=700, 800, 900	Z,F	505

Above was described how the transfer from pull-manufacturing to push-manufacturing creates savings to manufacturing costs of AMDSL A-components. In addition the lead time of the door variations included in the narrow main offering would decrease 5 business days according to Stera. This is essentially due to the changing position of CODP. If all the door components are manufactured to stock beforehand, the manufacturing of certain AMDSL main variation can begin directly with assembly when the customer's binding order is finally received. As a result, the manufacturing steps, such as cutting, bending, welding, etc. are executed beforehand, resulting in the lead time from customer being reduced by the time required to carry out these advance actions for main scope AMDSL variants. Additionally, when KONE front lines are able to offer AMDS doors with a cheaper price and lower lead time in the case of the A+ offering, the ordering pressure in future could focus more on the main scope.

The transfer from pull-manufacturing to push-manufacturing would also simplify the manufacturing process and also the supply line of main AMDSL variations. Because the more complex product variations are excluded from the narrow main offering certain manufacturing process steps are not needed. The VSM future state map illustrated in appendix II presents the simpler order-delivery process of AMDSL main scope produced by an ATO strategy. For example robotized bending, CO<sub>2</sub>-laser and powder coating are not needed in the simplified supply line. The simpler manufacturing process will primarily bring benefits for the supplier because the new process is easier to manage. Additionally, the CO<sub>2</sub> laser is an example of an expensive process that can be excluded from the simplified process. In future Stera could be able to produce the main AMDSL variations with the simpler and unified process and direct the more complex variations to the FMS

system. Regarding the studies, the above principles can also be utilized for AMDSC. Due to the lower AMDSC volumes compared to ADMSL, the relation between warehouse costs and manufacturing setup costs should be however calculated separately.

As stated above warehousing also causes risks. Corporations need to consider the possibility of industrial accidents damaging the materials in stock and plan how to deal with situations when the manufacturing drawings change to be able to avoid obsolescence problems. Also the development of the main scope should be reviewed once a year. In this way companies could notice if the focus of orders is transferring to other variations outside of the main scope. This can prevent the scenario where stock is full of door variations that have a very low cycle time. Additionally KONE and Siera should make the final decision of the allowed warehousing levels together. Predicting the exact demand of AMDSL A-component's different variations is challenging even when the main scopes demand should be constant. This might cause problems if some variations cycle a lot of faster than others. This could cause a problem that for example, stock levels of door panel variations vary dramatically and manufacturing of the new batches to stock would be interrupted by the unequal stock levels.

#### 4.3 Research areas for further study

Regarding the studies of this thesis, two research areas were identified for the further study. Firstly the variability of the AMDS doors is very high and the problem is essentially stemming from the offering of the product being extended year after year: The AMDS offering should be investigated and redundant options and values moved from A-process offering to the C-process offering. Secondly, in the AMDS order-delivery process the area within front line, customer and distribution center is currently almost invisible for the AMDS product owner and SSE employees handling the AMDS orders. Further study should also investigate this area of the order-delivery process and identify the optimal ways to bring benefits for the end customer.

## 5 CONCLUSIONS

ADMS is a low volume product with high variability. The AMDS main market area EMEA is characterized by high competition regarding pricing and lead times. The manufacturing of the compact elevator door is outsourced to two individual suppliers Stera and Wittur. Competent suppliers for the compact door are hard to find because of tight demands regarding lead time and manufacturing costs. With the two selected suppliers KONE pursues a long term and close relationship and the collaboration is seen as a partnership. Dual sourcing is used in order to decrease the risk of discontinuity. However the manufacturing of AMDS would be more efficient from a single source. This sourcing strategy has however too many risks and cannot be considered as an option.

Stera as a flexible manufacturer is very important supplier for KONE and especially for KONE Supply Operations Finland (SOF). Even though Stera and KONE strive for a partner relationship operations are not mutually visible, detracting from the effectiveness of the partnership which complicates the development of further collaboration

In this thesis the entire order-delivery chain of AMDS was analyzed using the VSM process. The information flow between Stera and KONE is at an adequate level but Stera's access to KONE ERP system would still increase and simplify information transfer. Manufacturing methods used in AMSD manufacturing are robust sheet metal processes and due to the use of batch production and a large amount of different variants Stera's manufacturing includes a lot of work in progress. Also significant was that the order-delivery process sector formed by the KONE front line, end customer and distribution center was almost totally unknown to the employees responsible for the AMDS competitiveness. This leads to the situation that KONE employees are not sure about the best practices to bring benefits to the end customer, in other words; how to increase the competitiveness of AMDS.

Most of the AMDS manufacturing related defects are essentially stemming from the high product variability. To control this problem in longer term the offering should be investigated on a regular basis and redundant options moved to C-process offering. In this

way the focus on the significant factors related to AMDS A-process manufacturing could be simpler to maintain. Additionally the urgent order process complicates Stera's manufacturing. The circumstances relating to those KONE frontlines who generate the most advancement request should be investigated and improved solutions proposed to control this issue.

For the AMDS product, characterized by low volumes and high variability, a narrow main offering generating a large part of the demand was identified. Identification was based on completed AMDSL orders during the years 2014–2015. The seven most significant factors regarding AMDSL manufacturing were then observed. All in all the narrow offering includes only 7.5% of available values in the total offering within the seven factors. However this 7.5% of values generates 27% of total orders and 34% of NanoSpace orders directed to Stera. Even though the main scope was identified to be as narrow as possible the amount of components to be manufactured to stock is still relatively high. The high amount of component variations for example door panel variations increases warehousing costs. On the other hand the manufacturing batch size is relatively small which further limits the amount of achievable cost savings from setup and order costs. These facts make the push-manufacturing of main A-components of AMDSL more challenging.

An efficient A+ process was finally developed to answer the aims of the study. The developed A+ process covers the identified main AMDSL variations. For those variations the manufacturing strategy would be transferred totally to ATO manufacturing. This would lead to decreased manufacturing costs, lower lead times and increased quality for 27% of Stera's AMDSL orders. While the analysis was executed by focusing on AMDSL; the AMDSC is determined to be also suitable for the AMDSL based narrow main offering. Using the A+ process KONE would then achieve a lower price level and increased competitiveness regarding lead times for certain AMDS variations. Stera would receive benefits stemming from simplified internal processes. Another significant benefit for Stera is that by using the A+ process the company would be able to deliver doors with the challenging MonoSpace 500 platform to the Bracchi distribution center. Stera's reduced manufacturing costs and opportunities regarding MonoSpace 500 could also lead to increasing volumes AMDS orders to Stera. In addition to all the benefits, A+ process also includes risks. These risks should be carefully considered before making further decisions.

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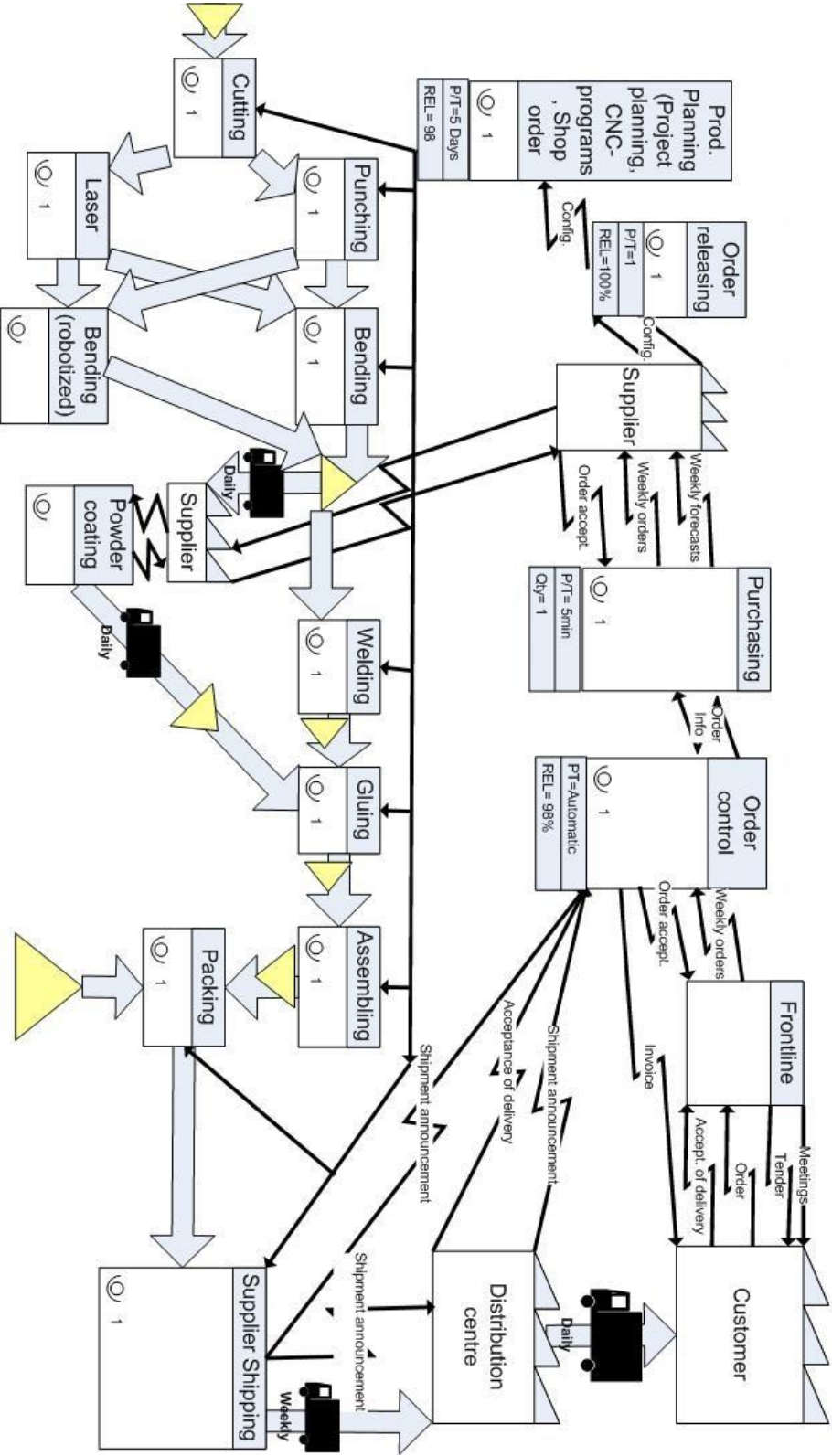
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Current state map of AMDS value stream.



Future state map of limited AMDS main variations

