UiT
THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Engineering Science and Technology/Department of Industrial Engineering

Product Quality Assurance using Engineering Strategies for an SME with an ATO Manufacturing System Located in the Arctic Region depending on a Global Supply Chain

Case Study of a provider of LED based lighting systems

Stud. Techn. Peer Steinhauer

Master's thesis in Industrial Engineering - June 2019

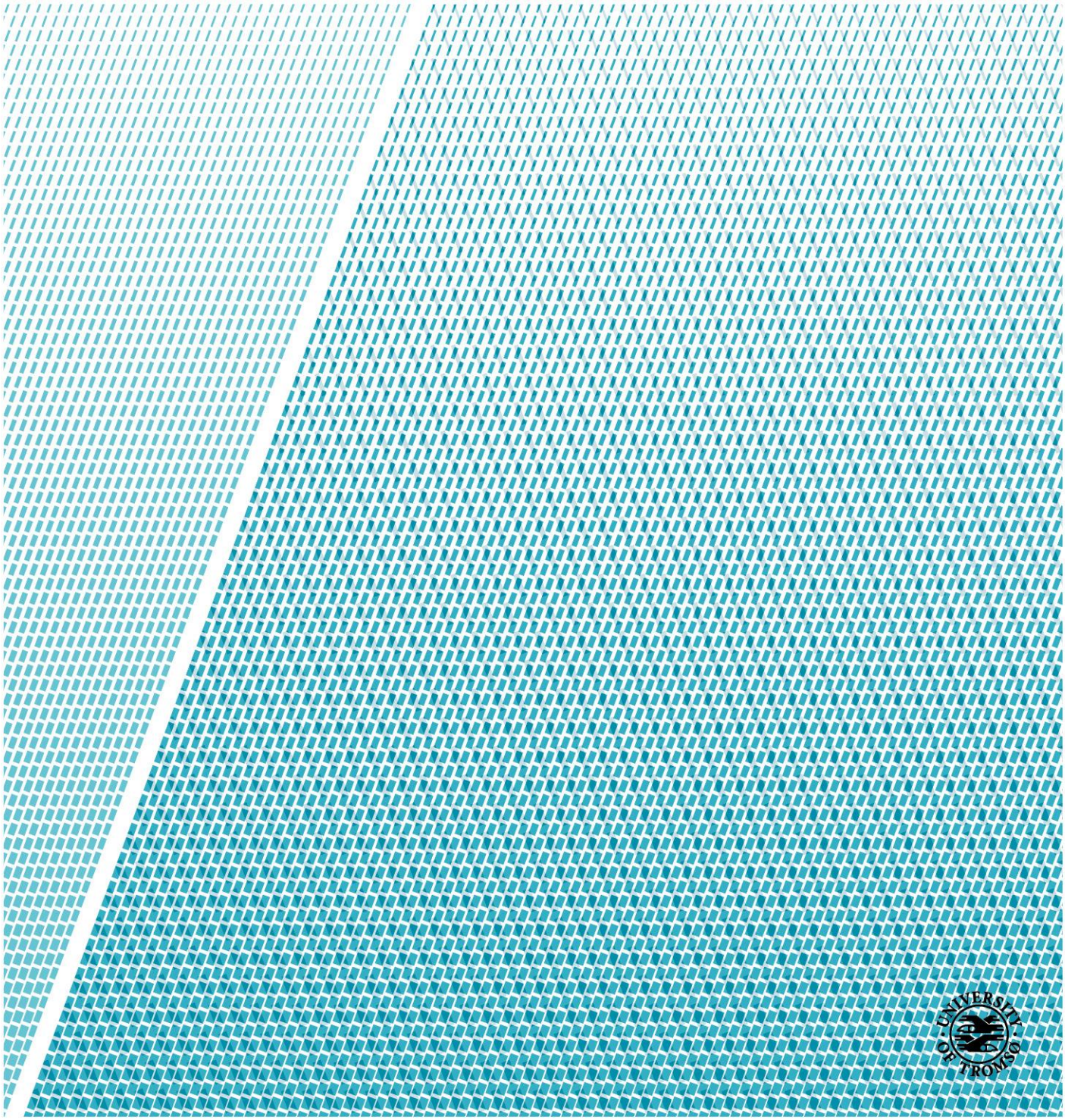

Table of Contents

Product Quality Assurance using Engineering Strategies for an SME with an ATO Manufacturing System Located in the Arctic Region depending on a Global Supply Chain 1

List of Tables 7

Abstract 7

Abbreviations: 7

1 Introduction 1

1.1 Thesis Objectives and Research Questions 1

1.2 Scope and Limitations 2

1.3 Background 2

2 Supply Chain 3

2.1 Supply Chain Performance Measures 4

2.2 The Development of the Supply Chain from a Local Market Place Arrangement to a Global Affair 5

2.2.1 The Internet 5

2.2.2 Containerisation 6

3 SME a weak customer 7

4 Manufacturing Systems 7

4.1 Supply Chain Objectives 7

4.2 Mass Customization 8

4.3 CODP 9

5 ATO-MS 9

5.1 The Structure of an ATO-MS Company 11

5.2 Quality Matters 12

5.3 Management 12

5.4 Design Phase 13

5.5 Procurement 13

5.5.1 Buying 13
5.6 Inventory 14
5.6.1 Dimension of Quality 15
5.7 Customer Order 16
5.8 Assembly 16
5.9 Delivery 17
5.10 After Sales Service 18
6 ISO 9001 and QMS 18
6.1 Process Approach 19
6.2 Implementation 19
6.3 ISO 9001 and Lean 19
7 Q A 20
7.1 Components 20
7.2 Quality Assurance Ability 22
8 Engineering Strategies 23
8.1 DFV 23
8.1.1 Product Variety Management Strategies 24
8.1.2 Product Families 25
8.1.3 DFSS 27
8.1.4 DFMA 27
8.2 Procurement 27
8.2.1 Collaboration 28
8.2.2 Commonality parts 28
8.3 Inventory 31
8.3.1 Delay Product Differentiation 31
8.3.2 Product postponement 31
8.3.3 Delaying of production 32

8.4 Customer Order 32
8.5 Assembly 32
8.5.1 Single Model Assembly Line 35
8.5.2 Mixed Model Assembly Line 36
8.5.3 Multi Model Assembly Line 36
8.6 Delivery to the Customer 37
8.7 After Sales Service 38
8.8 Cross-connections 40
8.9 Summary 41
9 Quality Tools 42
9.1 QFD 42
9.1.1 The VOC and Kano's Model 43
9.1.2 The HOQ 44
9.1.3 The Four Phases of Product Development 47
10 Summary 48
11 The Case of a Variety of LED Illumination Products for Vehicles 48
12 LED Lights 49
12.1 LED Circuits 49
12.1.1 Serial Circuit 50
12.2 LED 51
12.2.1 Colour Variations 52
12.2.2 COB 52
12.2.3 Lumen, Candela, Lux 53
12.2.4 Parameters 53
12.3 Power Supply/Driver 53
12.3.1 Parameters 54
12.4 Heatsink 54

12.4.1 Parameters 55
12.5 Reflector 55
12.5.1 Parameters 56
12.6 Housing 56
12.6.1 Lenses 57
12.6.2 Sealing 57
12.6.3 IP Classifications 58
12.6.4 Parameters 58
12.7 Control Units 58
12.7.1 Parameters 59
13 Product development 59
13.1 Customer Evaluation 60
13.1.1 Internal Customers 60
13.1.2 Intermediate Customers 60
13.1.3 External Customers 61
13.2 Product analysis 61
13.3 Parts development 65
13.3.1 LEDs 67
13.3.2 Driver 68
13.3.3 Heatsink 68
13.3.4 Reflector 68
13.3.5 Housing 69
13.3.6 Control Units 69
13.3.7 Accessories 70
14 Evaluation of the Case 70
15 Using the QFD 71
15.1 Part one 71

15.2 Part two 73
15.3 Part three 74
15.4 Part four 75
15.5 Part five 75
15.6 Evaluation of the HOQ 76
16 Conclusion 76
References 78

List of Figures

Figure 1 Strategic Fit [3] 4
Figure 2 CODP 9
Figure 3 Relations Assembly-Distribution[19] 10
Figure 4 ATO-MS 11
Figure 5 Quality tools[53] 22
Figure 6 Quality tools[54] 23
Figure 7 Variety Management Strategies [55] 25
Figure 8 Variety Management Strategies[17] 25
Figure 9 assembly lines [77] 35
Figure 10 Single Model Assembly Line 35
Figure 11 Mixed Model Assembly Line 36
Figure 12 Multi Model Assembly Line 37
Figure 13 Relationship Service-Design[41] 39
Figure 14 Affinity Diagram 41
Figure 15 Kano's Model of Quality[90] 44
Figure 16 The House of Quality [62] 47
Figure 17 QFD Total System Analysis [92] 47
Figure 18 LEDs in Serial Circuit 50
Figure 19 Parallel Circuit 51
Figure 20 Semiconductors[93] 52
Figure 21 Tricoloured LEDs 52

Figure 22 COB 53
Figure 23 Relationship Forward Voltage and Current[97] 54
Figure 24 Heatsink 55
Figure 25 Reflector 56
Figure 26 House 58
Figure 27 On-Off Switch 59
Figure 28 HOQ part one 72
Figure 29 HOQ part two 73
Figure 30 HOQ part three 74
Figure 31 HOQ part five 75

List of Tables

Table 1 Enclosure Gasket[100] 57
Table 2 Customer needs 61
Table 3 LED Product 65

Abstract

A small and medium sized enterprise (SME) with an assembly to order manufacturing system (ATO-MS) depending on a global supply chain has especially challenges when it comes to secure the quality. The parts procured from a global supply chain represent a big amount of value invested in to the short line of the MS. Depending on the definition of quality from the suppliers, how can the company react to this challenges? This project is focused on finding good engineering strategies for each step of the MS which contributes to assure the quality of the procured parts. Finally based on a theoretical case and the use of the house of quality as a quality tool, the impact on the quality of the procured parts, by using this engineering strategies is done.

Abbreviations:

ALB	Assembly line balancing
ASP	Assembly Sequence Planning
ATO	Assembly to order
CEO	Chief executive officer

COB	Chips on board
COC	Certificate of conformity
CODP	Custom order decoupling point
CTO	Configure to order
DD	Delayed differentiation or delayed product differentiation
DFMA	Design for manufacturing and assembly
DFSS	Design for Six Sigma
DFV	Design for variety
DMAIC	Define, measure, analyse, improve, control
FMEA	Failure mode and effect analysis
HOQ	House of quality
IDOV	Identify, design, optimize, validate
ISO	International organization for standardization
MC	Mass Customisation
MS	Manufacturing system
PDCA	Plan, do, check, act
PDSM	Polydimethylsiloxane
QA	Quality assurance
QC	Quality control
QMS	Quality management system
QMP	Quality management principles

SOP	Standard operating procedures
VOC	Voice of the customer
WHO	World health organization

1 Introduction

In a world where the global supply chain is a fully established fact. The increasing global competition and the quest of competitive advantages makes it necessary to search for enablers that can respond to those conditions and that can help companies to supply customers with high-quality products able to compete in this market[1]. One of this area where companies try to use the fact of a global supply chain as an advantage are companies located in remote regions. With products that are especially designed to solve problems that are specific for those regions, like climate challenges for arctic or warm region, or logistic challenges for remote regions.

Manufacturing systems like an ATO-MS have evolved, and trying especially to take advantage of the possibilities of a global supply chain like big competitive markets and decreasing cost prices of each part, saving developing costs of parts, changes in production technologies and MSs et al. The development of new production technologies and new engineering techniques offers new opportunities for companies, which are trying to compete on a global base. The Fact of a global supply chain has also contributed to other effects. The average product life cycle has significant decreased over the last decades also depending other reasons. The markets have also been more unpredictable because of the number of influencing variables from a global perspective.

1.1 Thesis Objectives and Research Questions

As mentioned in the introduction there are new challenges, which are a result of the changes and the directions from a typical supply chain before and a global supply chain today. This thesis will look in to the challenges regarding quality issues, which are emerging of supplying parts from a global supply chain. The term quality is much harder to agree on, when the company cannot use normal negotiations techniques to secure the definition of the term quality. For an ATO-MS where the quality of the parts procured and put in to this type of MS is of essential importance, this is a challenge to be dealt with. Because the quality of the finished product depends in a high degree of the parts purchased from a global supply chain. When we take every step of this type of MS, is it possible to find engineering strategies which can be applied to support a quality assurance system. A company with an ATO-MS will try to supply high quality products to their customers.

To test those engineering strategies for every step of the MS there will be established a case of a product that can offer different variations to provide a wide range of needs from customers.

Those products need to be broken down to their parts to be able to test the engineering strategies against those parts.

In the end a quality evaluation tool needs to be provided, which is able to evaluate the impact of the engineering strategies against the parts of the products.

1.2 Scope and Limitations

For the ATO-MS the different steps of this MS have to be defined. Then their responsibilities needs to be established. What is really needed from each step? Which are the difficulties that needs to be handled? As a result of this, a research on applicable engineering strategies for each of the steps of the MS and how they are capable of handling the challenges.

The case study needs to be able to supply parts which can be used against the engineering strategies and those parts need to be able to supply variations of the products. Finding a product which can be produced with an ATO-MS needed in the arctic region.

To measure the effect of the engineering strategies to the parts and the impact to the quality a quality assessment needs to be found which is capable of handling a variety of inputs from different angles.

1.3 Background

The most important reason for customers, when it comes to why to buy the products they need, is the quality of the product. After working in industry production for decades, the experience of the author on this thesis is, that quality seems to be a difficult and comprehensive challenge for each company. Some of the difficulties that always comes up, related to quality are, the definition of the term quality, the communication of this term, and the ownership to those terms. And the fact that knowledge always is a temporary state end never complete, at least when it comes to this type of scientific. Since the conditions and the knowledge is in constant evolution, so must also the research on this topic grow equivalent. The lack of research on the field of the precise combination on SME with an ATO-MS depending and a global supply chain, and that there seems to be no ideas around the possibilities of QA techniques when it comes to ensure the quality of parts that are procured from global suppliers. So how can companies that try to deliver their products to customers in areas that are not close to the production, use the given facts and exploit the possibilities and cope with the challenges. To have no manufacturing of

parts means at the same time to let go of the control of the quality of the parts during the production.

2 Supply Chain

The genesis of the term supply chain started early on when human kind started to decouple the part of collecting food from the part of its consummation. When it was discovered that the meat was better after it was treated by fire, or the skin of the animals could be used to protect against the cold. The next step in the supply chain was the step to developing tools for the purpose of food collecting and processing. The completely decoupling was achieved when the process from gathering to consumption included more than one or two steps, and even different individuals were included in that process. Then over a very long period this was the state of the art necessary to provide enough terms to handle the communication of the supply chain from the raw material to the end consumer, not just being about food, but other products which were invented on the way, like building accommodations, making things that improved the way of living.

One special branch in the term supply chain at this time was the art of trade. When people met, they exchanged gifts to each other, to build good will and confidence. By contact with more and more different people, the experience, that there were some products that seemed to be especially popular for exchanged in opposite to other products, those products then started to be exchanged with the purpose of profit. With the growing of cities, merchants travelled over longer distances from city to city to exceed their range of products and making a living out of trading. Special products like silk from China lead to the development of trade routes like the silk road from China to Europe [2]. The first regular trade route over a very long distance on this planet. But for those supply chains the transportation where associated with very high risks. While the profits where very high, also was the risk. And the term lead time was not even invented.

This changed during the first industrial revolution, when the British cotton industry demanded a regular supply chain that could deliver raw material in a predictable way. The development of a predictable supply chain from around the world to the British cotton industry. Another product desired of British customers at the time was Chinese tea. In 1866 it led to the great tea race where two ships competed of the shortest travel time with tea from China to England. It took the two leading ships 99 days to complete the race. The term lead time started to be important in the supply chain.

2.1 Supply Chain Performance Measures

Effectiveness and efficiency are two important expressions when it comes to determine the performance of a supply chain. To build the right supply chain it is important that the supply chain follows a balanced evaluation. To find the strategic fit between the customers demand and the capability of the supply chain.

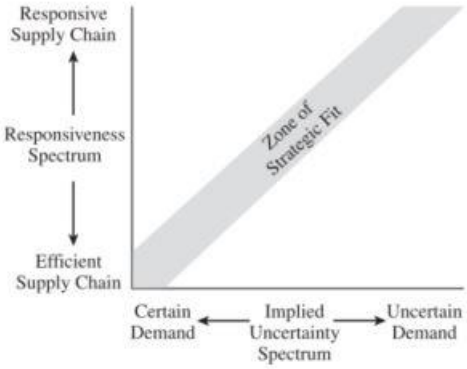

Figure 1 Strategic Fit [3]

To find the strategic fit some measure points need to be defined and the importance of each of the measure points needs to be defined to an overall evaluation. Not all points need to be equally important for all parts that are purchased from suppliers. Important measure points are:

- Cost
- Flexibility
- Quality
- Responsiveness
- On –time delivery
- Backorder/stock out
- Lead-time
- Shipping errors

All those are important measure points for an evaluation [4]. How those objectives are met, must be measured and compared with standards[5], or an evaluating by a) sending questionnaire forms, b) visiting the premises of external providers, c) qualification testing of items, d) catalogues of external providers, or e) trial orders[6].

To visualize the importance of the supply chain a little example. We are living in a time where the leader of one of the most innovative companies of the world (Apple) no longer is a product based engineer, but an industrial engineer specialized in supply chain. Cook was quoted as saying: *"You kind of want to manage it like you're in the dairy business. If it gets past its freshness date, you have a problem".* After that Steve Jobs died it was Tim Cook who took over the company as CEO.

2.2 The Development of the Supply Chain from a Local Market Place Arrangement to a Global Affair

The main function of a supply chain consisted of the movement of raw materials, sub assembly and finished parts for a very long time[2]. But with the development of supply chain planning, management and orchestration, the evaluation and risk assessment and the compliance with laws and regulations made it necessary to develop the idea of supply chain management. Over the last decades the term supply chain management experienced an extremely extensive change in its contents, while the supplier-customer relationship over millenniums had more simple relations, now it needed to be comprehensive. Two things happened, that changed the supply chain completely.

2.2.1 The Internet

To be able to satisfy the claims that a modern supply chain carries with it, one of them being the flow of information, the possibility of communication also had to develop. The global supply chain needed a cost and time effective information systems, that can link multiple companies together [7]. Even it was possible to have an instantly communication over long distances over the Phone for a very long time, the development of a comprehensive supply chain communication that can manage the vast amount of data that is needed [8]. The communication also had to include, handling value added services like quality validation, custom clearings, payment and other documentations. Something that the internet could provide easily.

The benefits that the growth of internet communication provided for the firms are [9]:

1. On-line vendor catalogues from which byers can find, select, and order items directly from suppliers without any human contact
2. The ability to trach shipments using a wide variety of modes including truck, rail, and air transport

3. The ability to contact vendors or byers regarding customer service problems from late deliveries, stock-outs, alterations in schedule shipments dates, late arrivals, and a wide variety of other service issues
4. The ability to reserve space in public warehouses for anticipated deliveries to market locations
5. The ability to schedule outbound shipments from private and public distributions centres on a 24-hour basis
6. The ability to provide 7-day/24-hour worldwide customer service
7. The ability to receive orders from international customers
8. The ability to check the status of orders placed with vendors
9. The ability to place bids on projects issued by government and industry buyers
10. The ability to notify vendors of changes in configurations in products that are produced orders
11. The ability to pay invoices electronically and to check outstanding debt balances
12. The ability to track equipment locations including rail, cars, trucks, and material handling equipment
13. The ability to directly communicate with vendors, customers, etc. regarding supply issues on a 7-day/24-hour basis via Email
14. The ability to schedule pickups and deliveries
15. The ability to be more responsive to customer service problems
16. The ability to reduce service costs and response time

2.2.2 Containerisation

The Container was invented in the 1960s to respond to the problems that occurred, in the process of handling the goods at the harbours all over the world. The time craving process of unloading small till medium sized parts from a truck and then loading the cargo to a ship. That could take from hours to even days, depending of the size and weight of the freight. Then the logical question arises, why is it not possible to load the complete truck in one peace on to the ship and secure it there? While the cranes in all harbours where absolute capable for this task. The invention of a box that could easily be moved from a truck on to a ship, capable of holding all kind of goods, and which could easily be secured during the transport, and easily unsecured for the next movement. The principle of intermodal transportation was also not a new topic in the logistic.

After the introduction of containers as transport box in the 1960s, the container had a game changing influence on the global freight distribution. The container was able to provide more space that could be handled in less time in the distribution of goods. From than the handling of goods has grown in all harbours all over the world. And all this by a lower cost [10].

“Containerisation has transformed global trade in manufactured goods as dramatically as jet planes have changed the way we travel and the Internet has changed the way we communicate” Joseph Bonney, editor of the Journal of Commerce [11]. The container also influenced the term of supply chain management, since it opened for a complete change of the way to transport goods from A to B.

3 SME a weak customer

A weak customer is described as a customer, who has normally just one choice when it comes to resolve quality problems with the suppliers. The only way the company has is to find a new supplier which has a more compliant definition of the quality of the products with the definition of the own company. With other words move from one supplier to the next[12]. Weak customers have not the commercial power to impact the decision making of their suppliers regarding to quality definitions. This applies to all areas of supplier customer relationship like product quality, service quality, lead time specifications and the most important factor the cost of the goods. For a weak customer it can even get worth, when they are dependent on a monopolist for their products.

4 Manufacturing Systems

The ability to meet customer expectations when it comes to price, product variety and response time is critical for the decision making of choosing the right MS [13]. In times of globalisation suppliers face the pressure of customers expecting better quality for lower cost and that the lead time is as short as possible [14]. And for all of those demands there are other suppliers that try to beat you. Two of the effects of globalisation that had an important impact on the supply chain, are MC and the shortening of product life cycles.

4.1 Supply Chain Objectives

Since we defined the term supply chain, the next logical step is the improvement of the supply chain, to be able to improve it, we need to establish some understanding about, what is the supply chain about and what can be improved. Since we know about the necessity of the supply chain, to provide our customers with our best final product, the main objective is to maximize the overall value generated [3]. The value that the supply chain adds to the final product must be more than the costs of the supply chain.

But there are more objectives that needs to be considered when we talk of the supply chain [15].

- Objective 1: To improve customer satisfaction and customer responsiveness
- Objective 2: To improve flexibility and risk aversion
- Objective 3: To improve information and material flow integration
- Objective 4: To optimize costs (other related performance measures are total cost, sales value, profit, inventory holding cost, return on investment, and others)
- Objective 5: To optimize suppliers' performance

4.2 Mass Customization

Finding ways to differentiate your company from your competitors in a high competitive and segmented market, always with the focus on the customer [16].

To be able to satisfy the needs of your customers to the highest level of service, it needs the understanding that customers are a homogenous group of people. That all customers are individuals with their own preferences, needs and expectations. To be able to meet those expectations, it is necessary to offer variations of configurations of products. Other causes for variations are a) various customer requirements b) diverse regional needs c) different market segments d) rapid technology changeovers e) price discrimination f) avoiding price competition [17]. And this needs to be done to the efficiency of mass production [15, 18]. A variety of products with the same essential elements is one way to fulfil the expectations of customers [19]. More important is the ability to translate demands of customers in to new products and services need. That requires the skill of listening to the VOC [16].

There are different success factors that drive the MC. Such as the demand for variation and customization and that the customers are also willing to pay for the services delivered. Ore that the market conditions are appropriate, that the services that is delivered gives your company a competitive advantage. And that your supply chain is capable of delivering the services or products needed. That the technology needed is available in your supply chain. That the nature of your products allows customization in an efficient level [16].

Starting in the 80s, three factors arises that were crucial for the ideas of MC. The ideas of flexible manufacturing and information technology was properly enough developed, for those tasks. That an increasing demand for customizable products needed to be meet. And that includes a significant shortening of the product life cycles where a fact.

One of the disadvantages of MC is, that the complexity of products, needed for trying to satisfy the variations of the customers, needed to be increased. That would give each company an

extended supply chain, but as a reward the capability to better respond to the different needs of all customers.

4.3 CODP

The CODP is traditionally the point in the supply chain where the custom order arrives [18]. The CODP is that specific point where the supply chain is divided from the part where production of the parts and components is based on forecast orientated from expected demand relied on experience and market surveys, and where the production of the finished product is orientated toward specific customer order requirements [20]. Or the point that departs the mass service with a lower unit service cost from the customized service with a higher unit service cost [21]. Because of the intention to keep a maximum grade of efficiency in the upstream activities and a maximum grade of customer satisfaction in the downstream activities [18]. The point where the parts and components kept as inventory are assembled towards the finished products. Where the value of goods changes from an investment in to realizable value.

In the times of MC and the needs of satisfying customer demands, the requirements of finished product variations will inevitably move the CODP upstream in the supply chain, while the To be able to keep the CODP as fare as possible downstream, the variety of the finished products shall be realized on different strategies like using the same essential components for all finished products [17, 19].

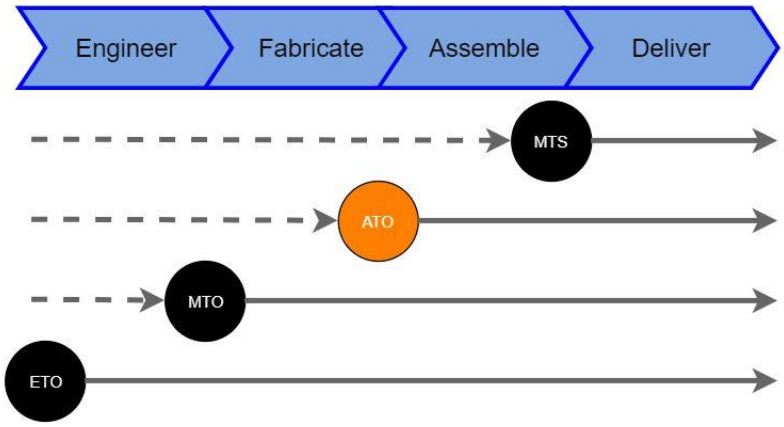

Figure 2 CODP

5 ATO-MS

The ATO-MS is characterized by assembling procured components directly in to finished products [22]. That offers the opportunity of delivering products that are taking care of a

brought spectre of customers that have differentiated expectations, and in the same time keeping the lead time and the costs down [19].

Therefor this MS is often used when it comes to implement the ideas of MC in to the products that a company is offering to their customers. The system offers short lead times and fast responds time, based on the twos step core system of procuring, inventory and assembly. And at the same time taking advantage of mass production systems from global suppliers.

An ATO-MS includes both elements of assembling and distribution system. As shown in figure 2, the supply chain of an ATO-MS requires several components that are configured in to several different products [19, 23]. Demands occur only for the finished products, while the system needs an inventory of components that the company needs to store to keep the lead time as short as possible. But if the customer can agree on an extended lead time, then the configurations to fulfil the customer expectations to the finished product can be meet in a greater extend.

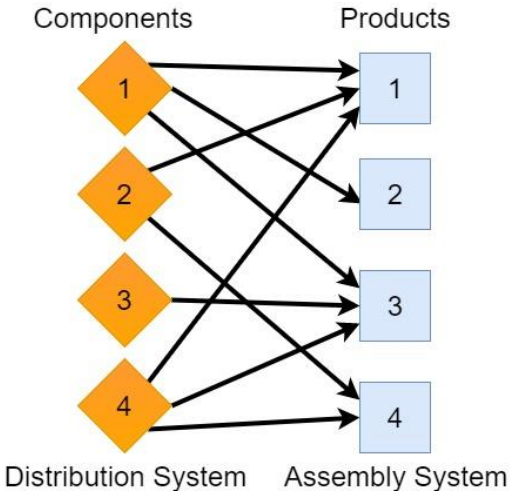

Figure 3 Relations Assembly-Distribution[19]

ATO-MSs are difficult to analyse and manage. The difficulty appears when looking in to several factors as a) demands for the different components being correlated, b) supply lead times for different components being different, and c) order fulfilment being dependent on the availability of multiple components. While the multiple components kept as inventor have to be allocated to different finished products for different customers [24]. The two most important bottlenecks in an ATO-MS are the assembly capacity and the amount of inventory that the company keeps [25].

This two-step system has because of the shortness his challenges. Since there are just two steps where the value of the end product can be effected, both parts have a big impact on the end value and therefore need to be especially careful be analysed of what happens there.

5.1 The Structure of an ATO-MS Company

Beside the two step core system, the procurement/inventory and the assembly before delivery, an ATO-MS needs more in order to develop and offer products which fulfil the needs and requirements of the customers. Comparable with every other company and independent of the MS the building parts are almost the same, listed here as 7 steps (a-g) starting with a) a strong management that is responsible for decision making and implementation, b) a pre-design and design phase where development of new products is realized responding to the needs of internal and external customers c) the procurement phase, one of the core systems for an ATO-MS, who provides a constant flow of components/modules for assembly the finished products ultimately responsible for the company revenue d) inventory which is a necessary evil, needed for constant supply flow but should be kept low to reduce the amount of captivated capital, e) assembly, the place of the MS which needs to be analysed and constantly improved to be efficient, and simplified as much as necessary to avoid mistakes, since each mistake here will directly lead to consequences for the finished product and the customer experience, f) the customer delivery, where the exchange between the product of the company and the equivalent value from the customer mostly paid in money, and g) the service phase, important for each company to increase the revenue stream and include quality and reliability evaluation. Beside those parts from the MS the custom order is also an important part. In figure 4 are the steps from the core system realized with the black arrows, and the information flow is realized with blue arrows.

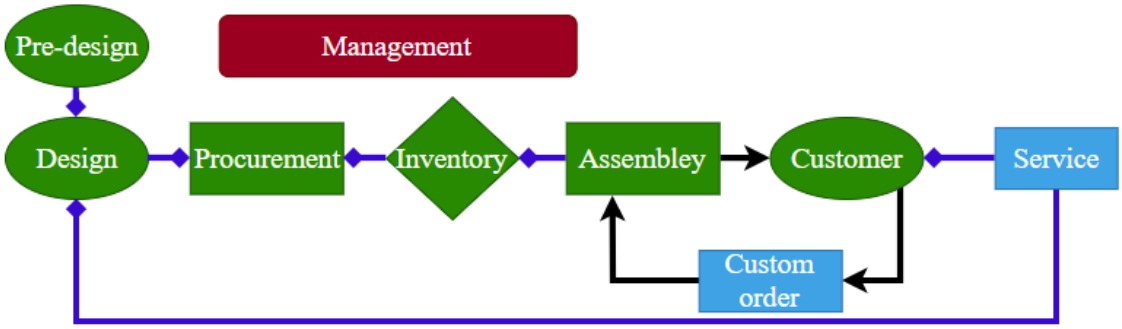

Figure 4 ATO-MS

5.2 Quality Matters

When it comes to an ATO-MS the company will face a vast amount of quality challenges which has to be focused on. The main focus naturally is belonging to the customer. The concept of quality is always those of a contract between a supplier and a customer, and the fulfilling of this contract. While the customer has expectations related to the product covering different dimensions of quality, defined by Garvin [26] as a) performance (primary product characteristics) b) features (bells and whistles) c) reliability (frequency of failure) d) conformance (match with specifications) e) durability (product life) f) serviceability (speed of repair) g) aesthetics (fits and finishes) and h) perceived quality (reputations and intangibles), so is the suppliers interested in identifying as many as possible of those expectations and translate them in to requirements, of which the company try to meet as many as possible. And first when there is a sufficient balance between those two parts, then we can talk about good quality. The company has the responsibility to ensure that the interests of the customers is taking care of through all steps of the MS, including parts that are procured. And to develop systems that not only can respond to scheduling manufacturing but to be able to respond to emergency conditions, to be able to serve customers that experience situations that needs instantly response [21].

For an ATO-MS it is the supplier which holds the key for the quality of the products purchased. It is the supplier who has the right to define the quality characteristics for their products. So what the supplier delivers is what the customer get[12].

5.3 Management

As any other company an ATO-MS needs a strong management with focus on a company philosophy regarding to quality and economy results, which needs to be established trough each step of the MS. Those are goals that the company wishes to achieve over a) a long time period and b) goals on a daily basis operation. Establishing those gaols and provide support needed to achieve those goals. Specific for an ATO-MS is that the company is trying to respond to different customers with different problems that needs to be solved. Therefore the management needs to focus on the requirements of the customers, understand the needs and translate those in to finished products. With a special focus on the global supply chain, while the components/modules procured are so important for the value chain of the company.

The management, keeping it all together with the main task to find the best quality tools for all of the organization’s activities. Focus on customers, suppliers, planning and leadership,

improvement and learning, empowerment and teamwork, human resources, management structure and quality tools [27].

5.4 Design Phase

To be successful in the design phase, the manufacturer must understand the functions that a customer has to perform, the constrains that the customer is experiencing and the desired outcomes that the customer wishes to achieve [28]. Because of the idea of MC, the complexity of the products has to increase, to be able to satisfy the variation of needs of the customers. In the start of the design phase the company needs to be aware of the different causes for product variations, which are a) various customer requirements b) diverse regional needs c) different market segments d) rapid technology changeovers e) price discrimination f) avoiding price competition [17]. When it comes to solve challenges resolving out of that context, then the solutions found have to implement three different layers of design as product design, process design and network design [15].

Since every decision that is taken in this phase can create a bullwhip effect for the rest of the MS, it is important to ensure that the design phase is collaborating with all the other steps of the MS [29]. The decisions made in this phase should rely on a comprehensive evaluation for every step taken. The design phase is carrying most of the weight in the whole MS when it comes to the costs and the satisfaction of both internal and external customers and of the end-users.

5.5 Procurement

5.5.1 Buying

Procurement is an upstream phase in an ATO-MS. Therefore, procurement is depending on estimation based on experience and market surveys. Important for the procurement phase is to ensure that the products procured have the best overall quality performance in the next steps of the MS and for the finished products. While an ATO-MS is depending on the global supply chain, the quality of the products supplied will differ from supplier to supplier. Therefore an comprehensive assessment of all the aspects of quality as well as the factors of cost and lead time is needed [15]. Another important aspect about the procurement is the amount of value which the procured parts represent, related to the overall value of the finished products. The two-step core system of an ATO-MS means that the parts which will be added in to the inventory and further to the assembly.

5.5.1.1 Supplier Assessment

In opposite to in-house manufacturing the company must relate to other companies for the production, and there are several challenges related to that. And since the company operates in a mass customization branch, where the customer shall be enabled to choose from more than one finished product, the number of suppliers will increase equivalent so will the amount of information needed to be exchanged. To be able to choose the right supplier that fits all the specifications for your parts needed, a method for the evaluation on all available suppliers must be developed. The main objective of supplier selection is to identify suppliers with the highest potential for meeting company's needs consistently that will provide benefits to the supply chain such as better quality, low costs and on-time delivery for all products [30].

The quality of the assessment of suppliers in general depends on the quantity of relevant information and the criteria used for the selection. Criteria's for supplier assessment are a) the quality of products and the ability of securing the quality b) competitive in price c) timing of supply, including aspects as lead-time, delivery fulfilment, d) flexibility, including ability to speed up supplies and capability of communication d) administration e) after-sale support f) technology g) finance h) risk j) public relations k) environment [30-32].

5.6 Inventory

For an ATO-MS the inventory part is the first part of the core system where the parts, components, subassemblies which are procured are stored and waiting to be used for the finished products. When it comes to inventory there are a lot of things to consider. Big companies try to eliminate the need of keeping inventory. They rather shape the supply chain in a way, that the delivery of the parts needed, happens directly in to the assembly line. To hold the lowest amount of inventory by keeping the capability to supply the assembly line with parts, components, subassemblies needed to keep the lead time for the servicing the customers as low as possible. In general, there are factors that forces all companies to keep stock, also the amount of stock needed. Inventory costs money but is necessary [31].

- The uncertainty of market demands that for all parts and components where the demand is based on forecasting, the company needs to keep stock of those. Since a continually service and all the time availability must be guaranteed[14].
- There is always a more or less big variety in the demand of parts (e.g. some of the factors that impact the demand may be a nature occurrence that will affect not just your company, but all

the companies that work in the same branch. The variation of demands which includes following patterns a) trend b) seasonality c) random variations d) cycle [33].

- Lead time of delivering purchased parts will always be a very important issue. Inventory of parts kept on the reason of lead time[24].
- One reason for inventory is to be able to deliver parts that are malfunctioning with a very short lead-time.
- When it comes to serve customers demands there should be considered that there will not just be the normal service scheduling after a designed plan, but also customer that have special or emergency
- Some of the parts purchased will be hold back as long as possible to give the chance of customizing those parts after the specifications of the demands of the customers.
- While too little inventory leads to losses of sale, and dissatisfaction of customers over increasing of lead time to delivery, and an over amount of inventory keeps the cost high for handling keeping track of all parts, and in the long-time spectre it leads even to obsolesce parts, components or subassemblies [18].

Inventory management models are differentiated by criteria's such as volume and size of the cargo that is stored, economic lot size and production and forecasting demands, changes of availability and prices of components stored [34].

5.6.1 Dimension of Quality

For the products that are kept as inventory the term quality should cover different aspects. Two important stakeholders that needs to be satisfied are external stakeholders like the end-user and internal stakeholders like the different parts of the MS of the company. If we are taking the five approaches to define quality: a) The transcendent definition b) product-based definition c) user-based definition d) manufacturing-based definition e) value-based definition [35]. The product-based definition, which are describing the quality as one or more precise defined and measurable quantitative variables. For the user-based definition the quality lies in the "*eyes of the beholder*". The term quality defines through the satisfaction of the customer. When it comes to the manufacturing-based definition the concern laying in engineering and manufacturing practices. Identified as "*conformance to requirements*". Where the parts are measured on the relations between invested resources and the result on a technological base. In contrast to the value-based definition where the relationship of invested resources and the result is defined on a financial base.

To be able to manage the inventory of those parts, there are done some research focusing on the efficiency of the operation regarding the number of finished products of an ATO company and the number of components stored. And the differences between one and multi-period systems [19, 23, 24, 36-38]. There is also a differentiation about different types of inventory. WIP inventory, semi-finished goods, and finished goods inventory [13, 33]. Those analysis are about the manufacturing-based and value-based aspects of keeping inventory, to analyse the Trade-off between inventory volume and service level [25]. And for all approaches of quality it is important that they are regularly reviewed since both the expectations of the customers and the technological conditions for the company are in constant development.

5.7 Customer Order

That is the point where the production changes from forecasting-based to demand-based and the production is related to the specific requirements of the customer order. All upstream activities are now pulled toward the next step in the production line. Now all forecasting is showing its qualitative potential. The evaluation of the inventory kept related to the lead time of being able to deliver the finished products as fast as possible relative to the amount invested until to this point.

The customer order is a document where all delivery terms and conditions are specified [31]. It is of crucial importance that all wishes and requirements that are agreed on with the customer are detailed noticed in the customer order, that the wishes and specifications from the customer are specified as precisely as possible. The responsibility of the company to ensure that the customer receives exactly the product that is agreed on. While the company tries to relay as much as possible on the strength of the products developed, but also tries to apply as much as possible to respond on the wishes of the customers.

5.8 Assembly

The assembly line in an ATO-MS is the place where the components/modules are put together in to finished products and as part of the core system the assembly part is where the company adds value on a daily basis. The idea of MC implies a certain variety of products, this is resulting in a need of flexibility of the assembly process. Since the product range is relatively high, related to the number of products that are produced per batch, there is a need to design assembly lines that fit to the challenges of converting the assembling for different finished products [17]. Factors which impacts the choice of the assembly line are a) annual production volume b)

number of parts in the assembly c) total number of parts to build all product styles d) product life cycle e) number of shifts per day f) assembly worker efficiency[39].

Because of the possibility of variations in the quality of the purchased products that comes from your suppliers it is necessary to ensure the quality of all parts, components and subassemblies that will all merge together in to the finished products of the company. Therefore, the quality understanding will equally merge together in to the finished products of the company. Every mistake of your suppliers will therefore from this point on, be the mistake of your company and damage reputation of the company in the market. At which point should the quality, reliability of each product be ensured, is it enough to verify the functionality during the end control of the finished product, ore should each subassembly be checked, even each part?

Also the assembling in itself carries the risk of mistakes in it, resulting from the variety of products and the amount of different components/modules needed to build all finished products. The procedures which are used to manage the assembling of all parts without offering mistakes to happen and the necessary tools who provides help and quality assurance. Even the necessity of automated assembling procedures needs to be evaluated to.

Since the assembly is part of the core MS, adding value to the finished products on a daily basis, this part needs to be made as effective as possible to save lead-time and again avoid the possibility of mistakes.

5.9 Delivery

The delivery part is where the product meets with the expectation of the customer directly. Where the first-time user experience is deciding of the real quality of the product. Where the supplier has to deliver on what is promised. The real value for the money spend. Therefore, it is the responsibility of the company to secure this experience by making sure of, that the customer is receiving the precise product which he is promised in the customer order. That during the logistics of the finished product a protection of the product is guaranteed, no damages can occur during a responsible transport. Since all the value is now added to the finished products any damage would entail high cost. To make sure the finished product is arriving at the customer unharmed, the protection needs to cover bad weather influences like cold, rain, sun and protection from normal transport stress. The delivery part also includes all the necessary papers needed of the customer are supplied. Verification that the customer specifications and the finished product are equivalent. Verification of the security of use after regulated standards.

And a detailed introduction in how to use the product so it offers the greatest amount of yield in performance on a daily basis and over a long time period.

5.10 After Sales Service

After sales service has a variety of functions, where one is the increasing of the revenue stream by selling necessary maintenance parts [40]. Another is analysing the reliability of the different components and the functions they perform and detecting improvement opportunities of the finished products. Are all components behaving like intended, or are their unusual behaviour of the modules related to unexpected problems occurring? For the customers the failure of functions of the product leads to loss of income and incurring of increased costs. The costs incurring for the customer can be divided in to two different types a) the fixed costs which comprises the costs of parts and labour for the repair and b) variable costs which comprises the eventual costs continuing for labours needed additional without the necessary service provided and the loss of income from the offered service provided [41]. Which is extremely unfortunately for both the customer and as a result for the company's reputation. The service needs to be able to provide very short led times for the service and change of necessary products/components and continues use of the product for the customer.

6 ISO 9001 and QMS

ISO 9001 is a standard that specifies the requirements of a QMS. It does not refer to a specific goal or objective that should be accomplished, rather it proposes guidelines on how to implement company processes that contain procedures, duties and roles to achieve product homogeneity and product specifications established by the customer [42]. Where customers includes both internal and external customers [43]. ISO 9001 is a compilation of good company practices that have evolved over many years [44].

Potential benefits that can be achieved by implementing a QMS in to the companies organizational structure are a) the ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements b) facilitating opportunities to enhance customer satisfaction c) addressing risks and opportunities associated with its context and objectives d) the ability to demonstrate conformity to specified quality management system requirements [45].

The seven basic QMPs that are responsible for developing and maintaining the QMS are a) customer focus b) leadership c) engagement of people d) process approach e) improvement f)

evidence-based decision making g) relationship management [46]. Depending on the nature of the organization, the ways of applying and implementing these principles may vary. The recognition of those principles will help the company to successfully implement a QMS in to the organization of the company. For large organizations it is a standard demand, that their suppliers establish and maintain QMS with accreditation to ISO9001[6].

6.1 Process Approach

Process characterization is defined as identifying elements and understanding their linkage for operations [6]. The ISO9001 standard promotes the process approach when developing, implementing and improving the effectiveness of a QMS, and as one of the QMPs. To manage the processes the PDCA cycle with an overall focus on risk-based thinking should be used. The PDCA cycle, based on ISO9001, can be applied to all process. The PDCA cycle guaranties that every process undertaken will be evaluated and verified, that the processes performed achieved the desired effects and is providing a constant improvement.

6.2 Implementation

As mentioned in the chapter before the ISO9001 standard promotes a process approach for implementing a QMS in to the organization of the company. Implementing of a QMS in to the structure of a company should be organized in a project planning management discipline and its related tools [47]. The most important step to a successful implementation of ISO 9001 in to every company is that ISO 9001 is a matter of commitment. The successful implementation starts by the management and its committing to the implementation and

While the companies implemented ISO 9001 in to the company structure for the purpose of marketing and sales beneficences, so where the experienced benefits related to the management development like a more operational efficiency [47].

6.3 ISO 9001 and Lean

The principle of lean and the principles of ISO 9001 are in concert with each other. While lean is defined as" A systematic approach to identifying and eliminating waste and none-value-added activities, trough continuous improvement, by flowing the product at the pull of the customer, and respecting and involving the employees, in pursuit of perfection." So those a QMS also

As in Lean Six Sigma so has the ISO 9001 processes that are related to management, support, operation, performance evaluations and improvements. (FMEA, statistical techniques for manufacturing, reward schemes for improving process continually, periodical reviews of customer orders to satisfy their requirements, additional controls for contract manufacturing)

7 Q A

QA is a regulative process to measure quality performance in order to compare it with standards [48]. Or in other words QA refers to the full range of practices employed to ensure that results are reliable [49]. ISO 9000 defines QA as a part of QMS focused on providing confidence that quality requirements will be fulfilled. Based on the assumption, that quality defects can occur at any part of the active MS, QA must be considered as a complete system used throughout the complete MS. Since QA is a maintaining tool for quality, meaning that QA will try to avoid failure by using technics and tools that assure the quality in a pre-defined area, well- validated methods are essential to the establishment of a good QA program [50, 51]. Its ultimate goal is to minimize the occurrence of errors. Once a QA programme is implemented, quality control activities are undertaken to confirm that the results are accurate and reliable. A god QA system allows to identify limitations, focusing on minimizing risk of errors. The implementation of a QA programme provides with an infrastructure needed to promote high performance over a long time period. In a quality study of the WHO R, Briggs defines components of QA in a laboratory environment like management, training, SOPs, laboratory facilities, equipment maintenance and calibration [49]. In higher education the use of standardization is more suitable [52].

7.1 Components

Management

> Successful implementation of a quality system is supported by the establishment of effective management [50]. Each organization determines the extent of documentation required and the media to be used. Dependent on the size and type of the organization, the complexity and interaction of processes. While the QA manager is responsible of document control and execution of QA procedures, all personnel is responsible of using the right procedures and documents.

Education

All types of training to staff members to ensure a good level of competency relevant to their work to enable good quality work [49, 50].

Standardization

Standard in its definition is defined as widely agreed on. So therefore standards needs a common understanding of the terms which the standards are regarded to and which can be agreed on.

SOP

SOPs shall contain all types of employee training records, that documents a good competency relevant to their work, All QC procedures related to internal and external control activities, use of equipment for assembling and control mechanism [49].

Continual improvement

Continual improvement of the organization's overall performance should be a permanent objective of the organization to enhance the satisfaction of customers and other interested parties [50].

Equipment and facilities

For the production and control of products or services the needed equipment shall be calibrated and maintained. All equipment needs to be supported by providing suitable facilities that ensures a proper function [49].

QC

Verification of QA system. While QA is responsible to ensure the quality in the chosen processes, so is QC activities responsible to confirm that the results are accurate and reliable. Compliance to quality assurance programme implies that whenever an error is detected, an investigation of its cause begins, and appropriate remedial actions are taken.

Documentation

Each organization determines the extent of documentation required an the media to be used [50]. The updated versions of quality system documents must be available to all the staff. The quality management manual is to be considered as the top-level document.

7.2 Quality Assurance Ability

As in the chapter before described the meaning of Quality assurance is to preserve an agreed standard of quality. When the quality of the products is extending the parameters which are predefined, then the use of Lean Six Sigma methods will be used to improve quality assurance ability, there are several Quality engineering technique applications that provide help for the different stages of a MS.

Demonstration phase	Concept phase	Engineering development phase	Production phase	After-sale service phase
QFD	Risk Analysis	Concurrent Engineering	QC seven tools	Countermeasure list
Risk Assessment	QFD	Design FSS	QC New seven tools	Customer feedback list
Trade Analysis	Analytic Hierarchy Process	Taguchi Methods	SPC	Customer Satisfaction Assessment
Cost versus benefit analysis	FMECA	DOE	Process Capability Analysis	Pie chart
Gantt chart	Quality cost management	Fault Tree Analysis	Sample Inspection	FRACAS
Network Analysis technique	QC New seven tools	life cycle cost	FRACAS	Poka-Yoke
Quality cost management		FMECA	Value Engineering	
life cycle cost		Design For X	Lean production	

Figure 5 Quality tools[53]

Process Tools	Basic Tools	Statistical Tools
Benchmarking	Data Analysis	Control Charts
ERP	Project Mgt.	Computer-aided Testing (CAT)
Focused Factory	Surveys	Computer-aided Inspection
JIT	PIT Teams	Gage R&R
Lean	Costs of Quality	
Awards	PERT	
Six Sigma	7 Basic Tools	
Failsafing	7 Managerial Tools	
DMAIC	5-S	
Supply Chain Tools	**Design Tools**	**Management Tools**
Supply Chain Management	Environmental Design	Leadership
Customer Relationship Management	Design Teams	On the job Training
Complaint Resolution	QFD	Change Management
Supplier Development	CAD	Human Resources Management
Supplier Evaluation	Concurrent Design	Systems Thinking
Customer Benefits Package	Prototyping	Contingency Theory
Single Sourcing	Quality Assurance Design	Deming
ISO 9000	FMEA	Quality Circles
SERVQUAL	DOE	PDCA
	Design for Manufacture	Crosby
	Reliability Indexes	Malcolm Baldrige Award
	Robust Design	Juran
	DMADV	Hoshin Planning

Figure 6 Quality tools[54]

8 Engineering Strategies

Each company designing and developing products which shall satisfy the needs of their customers and be able to make money out of the system, they need to establish an outstanding quality performance in every step of the MS. For each step of the MS the company need to use engineering strategies to ensure the quality performance. Those strategies need to reflect on how the company is defining the term of quality for each step and that each step is tight together with an overall quality definition.

Focusing on an SME with an ATO-MS and the idea of MC the necessity of finding engineering strategies which answers to the challenges of this combination and finding ways to mitigate the complexity of those challenges. Which engineering strategies exist, and which are applicable for this combination.

8.1 DFV

The design of products after the idea of MC which offers products that inherence the capability of serving different customers with their specific needs. The solution to these challenges is the design of products which are offering varieties in functions parameters, design parameters or operational parameters. Products that are developed to distinguish a company from competitor

companies. The global market is trying to react on fulfilling perceived needs of customers, by establishing companies in a more segmented market by conquering market niches. In that way the companies are trying to reach specific customers[55].

Other variables that are influencing those processes are shorter life time cycles of products, the emergence of new materials and new technologies. And even the needs of the customers are changing in the same speed of time. When the products of the company are able to satisfy the customers today, then attractive requirements after Kano's model will be one dimensional requirement by tomorrow and must therefore new requirements needs to be developed by the day after that. One way to keep up with those changes is the DFV. By using variation of products, it will be easier to analyse successful and not so successful changes. So, changes in the products perceives rather as continues changes then giant steps in the product development where the customers have problems to recognize the original product. And also, not all changes are equally successful. The impact of those changes shall not be essential for the whole branch, just on a product variation. When it comes to changes in new materials and new technologies, the variation of products makes it possible to play more around with those and being able to catch the reaction to those changes in a balanced way.

And especially for a company with an ATO-MS it cannot be stressed enough, how important the design phase is. Since the MS consists of mainly two parts which are responsible of adding value to the finished product. Those two are procurement and assembly.

8.1.1 Product Variety Management Strategies

Product variety is defined as the diversity of products that a MS provides to the marketplace [56]. The variety of products is not just accompanied of positive effects. In reality the customers are often confused about the differentiation among the product variants, if the differences do not stand out clearly enough. Offering more product variants incurs expenses from product design to production, inventory, selling and service [55]. It is therefore important to aligning customer's values with a specific set of product features. On the positive site's which product variety can offer, is the potential of expanding market shares and even open the market for new customers.

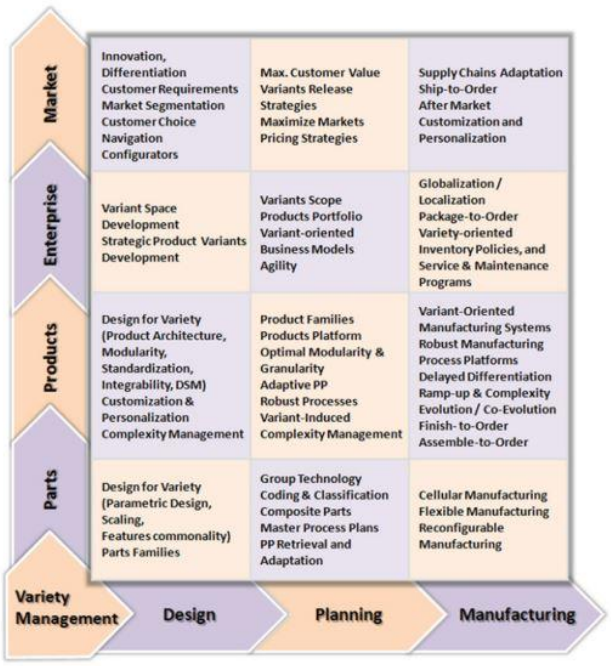

Figure 7 Variety Management Strategies [55]

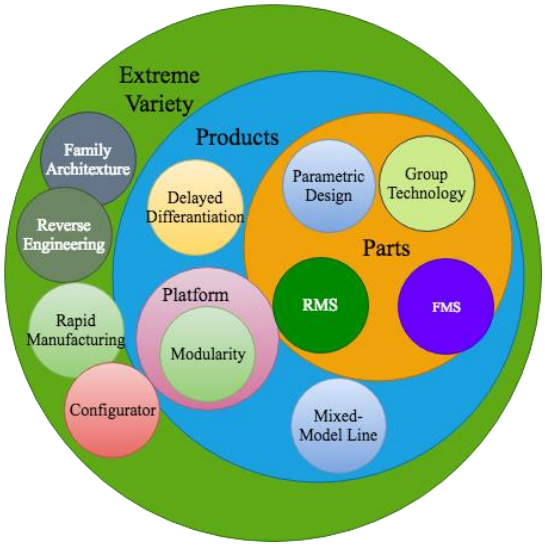

Figure 8 Variety Management Strategies[17]

8.1.2 Product Families

Designing and developing product families is recognized to be an effective method to achieve the goals of MC and product variety [56]. The core is to minimize the internal diversification of production and maximize the external diversification of product functions for customer. A product family is made up of the products which are similar in function, structure or technology [57]. A weakness with product families is that while increasing commonality may reduce costs, but at the same time it might also compromise with the performance of some of the products in the family. More generally product family strategies that occur in the design phase are a) product line positioning b) commonality, or c) the optimal configuration of design variables for each product in the family[58].

8.1.2.1 Based on Modularity

Two of the strategies to cope with the challenges of product families are to design modularization and standardization in to product families, to ensure the quality of the finished products [59]. Modular product development means that the design is trying to define all the different functions of the finished product in to sub functions. Down to the smallest reusable independent entity, that can be used for the variety of products. Each of those entities would be a module which will be implemented.as a part of the product. Most of the modules are fulfilling

a distinct function. These modules offers benefits like a) reduced lead times b) decrease assembly time c) ability and agility in supply chain management d) minimizing the level of inventory e) product postponement or DD f) flexibility of the supply chain for the purpose of delaying the production until the custom order arrived g) increasing of function alternatives h) decreasing the number of small parts g) providing the opportunity to procure modules that are developed from the supplier, and need just to be integrated in to the finished products . The process of developing a modular product gives an opportunity to mix and match all the components in to standardized modular products [60].

8.1.2.2 Based on Standardization

When the designer have managed to define the different modules necessary to provide all required functions for the variety of the products, each of the modules can be defined as a standard to use. This is another strategy in designing products after the ideas of MC and building product families. This standardized modules can be used in the product families but also across families to the complete product range. But this is just one use of standardisation. Another way to improve the efficiency of designing new products is to use standardised parts required from third parties. Where the development and all connecting required steps is done by a third party. The availability of those types of products and their advantages will be described in the next chapter.

8.1.2.3 Based on Scalability (Parametric Design)

Parameterised component families are using the same components, but with different parameters like operational, geometrical or performance parameters. The meaning with parametric design is to save development costs and time in the design phase by trying to reuse as much as possible from other parts or components which was used before and simplify the process. The simplest parameters to reuse are the geometrical variables. To change the lengths, widths or height of a part is the easiest way of parameterisation. But it is also possible to change other parameters of components like the performance parameters, if the supplier offers components with different performance parameters while keeping the geometrical parameters comparable the same, or a combination of performance and geometrical parameters. This method is very useful for an ATO-MS. It supports the idea of MC by offering more customization with less use of resources.

8.1.3 DFSS

With DFSS the focus is in preventing problems instead of fixing problems, while the same principles are used as in Six Sigma, the DFSS is going more upstream and recognizing that in the design phase the most important impact on the quality and the avoidance of problems can be done[61]. The effort invested in this phase is paying very well of during the rest of the MS. The initiative of DFSS has the goal of increasing the revenue of the investment of time and effort[62]. To balance the needs of the customers together with the needs of the company regarding to capabilities of the whole MS. To be able to design parts, components and products so they fulfil the needs of both parts will guarantee successful new-product development. In case of an ATO-MS where the main parts of the MS are the inventory and the assembly the focus of the company should be directed towards supplying parts which make it possible of decreasing the time of assembly as much as possible, and to simplify that assembly parts to the degree, that the possibility of mistakes is reduced as much as possible.

8.1.4 DFMA

The system of DFMA is developed over a very long time with help of decades of research and thousands of man hours of experience to support product design with decreasing of product development time, lower manufacturing and assembling cost and improving product quality. The idea behind DFMA is that 70% of the cost of the products is fixed at the stage of design[39].

DFMA keeps the focus on all the used components used for all products and identifying the parts of all components and defining parts which are equally used in different components. And if the number of equal parts exceeds a certain proportion, then if it is possible to combine those two components in to one more complex component and achieving the same performance just with less effort in regard of amount of parts needed[63]. This type of design responds very well to delayed product differentiation in the inventory.

8.2 Procurement

Procurement is the point of the MS where the first value is added, in form of financial investment in to procured parts, which in its fullness will be represented in the finished product. And since the value adding chain of an ATO-MS is as short as it is, all inputs in to the value chain are of the most importance.

In this chapter the focus will be on which engineering strategies can be used to ensure the best quality for the parts or components procured. Especially because those parts cover so much of

the value of the finished product. How can the fact of a global supply chain be exploited to offer a good financial and a good qualitative deal for the company?

8.2.1 Collaboration

One way of turning the challenges of a global supply chain and procuring products from suppliers in to an advantage is to collaborate with those suppliers. For an SME with limited resources when it comes to negotiate with other suppliers, the best way of collaborating is to find other SMEs where they can benefit from expertise of each other[64]. While the expertise on specific areas of those other SMEs can be used to boost the own product and give a step ahead for the overall performance of the company, so can the expertise of the own company and knowledge on problems and their solutions give positive effect on the supplier when both companies allow to tap in to the resources of each other. And for the company a bigger return on the investment. The connection between two companies and their different location can also be used to extend the sales market when the interests of both companies are aligning. Other side-effects of good collaboration are increasing of a) process efficiency b) flexibility c) business synergy d) quality and e) innovation[65]. To maximize the success of a collaboration there are strategical elements like a) technology b) business case c) intra-organisational support or d) corporate focus. And cultural elements like a) trust b) mutuality c) information exchange and d) openness and communication to be considered[66]. Miscommunication with misunderstandings is the main reason of collaboration failure[65]. Since communication is the glue which holds the supply chain together, so there for a balanced, two-way, multilevel contact is of the essence. The decision how close the collaboration should be is always dependent on the benefits which can be obtained, from an arms-length distance where the information flow will not be so extensive, until a real collaboration where the amount of profit for both companies is proportional to the information exchanged. In this case the companies share resources and commitment and intra-organisational support. Types of collaboration to be considered are a) strategic alliances b) joint ventures c) cooperative arrangements d) virtual collaborations e) vertical, horizontal and lateral integrations with advantages for both company's[67].

8.2.2 Commonality parts

Another way of trying to benefit of a global supply chain and at the same time to serve the ideas of MC is to buy parts that are produced in larger volumes[68]. Products which are used in a vast amount of different finished products. The effect which can be achieved by buying parts which are produced in a larger scale is called the economy of scale and scope. The term which

describes this type of parts best is commonality parts. Normally the term commonality is a strategy that is used for components/modules which are implemented in as many as possible products of a product family in a product design phase[69]. But this type of parts doesn't need to be limited to a product family of one company but rather be used for all different type of companies. While the idea of economy of scale and scope in the scientific research is an object of interest, when it comes to the companies using this system, so is the research of second part users of the system difficult to find. Therefore, to prove some of theories which will be stated in this chapter it will be done by using examples, experience and common sense.

8.2.2.1 Economies of Scale and Scope

The economy of scale means the relationship of the scale of use of a proper combination of all productive services of a company and the rate of output of products[70]. Very simply explained on one effect of this theory is that the fixed costs stay the same by producing more parts, while just the variable costs are increasing, and therefore the profit if the revenue stream also will increase. The optimum size of a production facility is not so easy to evaluate. While growth not continuously provides increased profit. On one point the extending of production lines and needed equipment will be followed by an increasing of fixed costs and in the end the raise of the fixed costs will even extend the profit of the extend of production. One way to mitigate this problem is by adding new technology and better production tools in the production line and using Lean Six Sigma to optimize the production system with the goal of decreasing waste and increasing the efficiency of the system with growing output and profit.

8.2.2.2 Effects for Second Users of the System

8.2.2.2.1 Resources:

Instead of using resources to develop all the parts necessary, implement in the own products, it is possible to apply many parts needed, from other suppliers or even other producers of the equivalent type of products. Which really saves the company of a big amount of resources for research and development. Here is also another idea supporting to by parts/modules rather than developing them self. It is the idea of being able to develop profound knowledge of the part of the products where the company wants to be distinguishable from their competitors. Instead of being differently in all parts, it is better to being not just good, but superior in one specific area than your competitors. Therefore, the use of commonality parts will save resources to achieve this goal

8.2.2.2.2 Quality

As mentioned in chapter 8.2.2.1 the economy of scale and scope offers the opportunity of making the production line more efficient by using the tools of Lean Six Sigma. By using those methods not just the effect of more efficiency is gained, but also the effect of better control of the output of those processes. And following of this facts, the conclusion can be made, that the quality of the products produced in that content will automatically also increase. More precisely not the quality of each product, but the quality of the overall production. The meaning of Six Sigma is to improve the reliability of the process performance so that it gives not more than 3,4 defects per million opportunities. As higher the commonality of the products purchased is an as wider the use of these parts by different companies implemented in their finished products is, than the possibility of higher quality output is given. Because of what is mentioned above there is a positive effect for second users of commonality parts. The need for quality control of purchased parts before implementing them in to the inventory of the company and finally in to the finished products is significant decreasing. When a company is buying screws for example. Than normally, SMEs are not concerned about the quality control of this type of product, they will directly be used in the assembly. Not properly working parts implemented in the finished product will entail a significant increasing of costs when detected late. Therefore, an FMEA of each part implemented is important. For commonality parts the probability of failure will decrease.

8.2.2.3 Commonality and Cannibalization

When commonality between the different models of one product family is used in a degree, where the models produced of a company makes it impossible to be able to distinguish between those products and a similarity of different products is too high in a degree that the customers will by one product instead of buying another products, then this type of choices are called cannibalization. It is important that every variation done in a product family offers a wide enough differentiation of function in the product family.

8.2.2.4 Lead Time and Prize

When the company decides to by parts, one of the most important factors for the decision of the supplier will be the price of the parts. And also, in this part the amount of produced parts will reflect on the price of the parts. As more parts are to find in different products as more parts will be available on the market, which again result in more competition from more suppliers of those parts which again will be reflecting in decreasing of the price. And with more competition and more parts available on the market the lead time from the suppliers will go

down. Which again has a positive effect, while the time period where the capital is captivated by the parts in inventory can be shortened down significantly.

8.3 Inventory

As mentioned in chapter 5.6 there are several reasons to keep inventory, and even more reasons to keep it as low as possible. For the inventory where the main capital of the company is captivated by the different components/modules purchased and stored the value of those needs to be preserved over the longest time possible. While the worth of the components/modules is deteriorating with every day going by, and in the worth case even can reach the state where they are obsolete before implemented in to the finished product. Therefor the parts, which are stored in the inventory need to meet certain quality parameters, which secures the value. Here some engineering strategies that will ensure the quality of the products stored, as long as possible and helping to keep the amount of parts as low as possible.

What all the different engineering strategies have in common is to keep the parts in the inventory as low as possible. And making every part in the inventory count. As valuable as possible.

8.3.1 Delay Product Differentiation

It is not always smart to try to allocate the procured parts towards their final use right after they are bought. When modules are sharing many parts between them, then it must be considered to by the parts and keep them undifferentiated in store and wait with the allocation towards the final use until the customer order arrives before building them in to subassemblies[13]. In this case the components are keeping their value best when they can be used in as many as possible different subassemblies.

8.3.2 Product postponement

Product postponement is a strategy which intention is to delay the allocation of the components/modules purchased as long as possible towards the final assembly. Starting in the design phase the finished products will be designed around those components which often serve specific functions in the finished products. Depending on the customers and the customer order those functions will then be added to the finished product or not. The best yield of this type of functions is achieved when they can be represented in as many as possible of the finished products.

8.3.3 Delaying of production

For some of the components which are needed for the finished products, after the idea of MC and even extended to the idea of personification of the finished products, then the delaying is comprising not just the allocation of the components but extending the delaying to the production of the components. The meaning is to provide the highest term of service to the customer regarding personification of the finished product. The possibility for the customers to be able to implement the purchased products in to the companies own product or service line.

For all those engineering strategies the responsibility for implementing the ideas is laying by engineers in the design phase of the products. The components/modules which the finished products contain needs to perform especially well in this phase of the MS.

8.4 Customer Order

The customer order is the point of the MS, where the customer and the company are describing the product and the associated functions on which both parties are agreed on. As mentioned in chapter 5.7, the importance related to the customer order is that the customer order needs to include a description of all specifications of the finished product in a very detailed manner. For the customers those specifications are related to the problems which they need to solve. And for the company it needs to relay on the core experience. If those two claims are reasonably balanced than there can be placed a customer order. The customer order also needs to include other specific information like a) a specific lead time for the delivery of the product[71] b) a detailed price information for the product and all additional services c) who is responsible for the delivering of the goods d) detailed warranty or guarantee information's e) which laws apply. And more specific agreements need to be considered for each sale. For the company the customer order is the point where all activities are now driven by customer specifications.

For the case of a quality assurance system the point of the customer order is not a part where engineering strategies are developed to support the quality. Except from being comprehensive and including detailed descriptions of important information.

8.5 Assembly

The assembly line as part of the core MS for an ATO-MS needs to be designed in a way that it can support the different variations of finished products according to idea of MC of an ATO-MS.

The first step is to define all the different products which have to be assembled with all the underlying modules/components/parts implemented in the products. Therefore, an analysis of all the components/modules contained in the finished product is required to find an economically assembly system [39]. Assembly process planning with time and cost analysis[72] and assembly line and control mechanism. In an ATO-MS the assembling is the only place where the company is adding value, and which will be represented in each finished product and therefore can be related in its fullness to each of the finished products. All costs will be reflected directly in to the finished product and therefore this part is one of the most important parts to be analysed, planned and improved continuously. But starting with an analysis of the assembling process, which components/modules are really necessary to be assembled in the finished line or which components should be pre-assembled in to modules to be implemented in to the finished product. Resulting in a decreasing of the lead time for the main assembling. At this point it can be established how strongly the cost of the assembly is connected to the design of the finished product and it's under laying components. One of the intentions of this analysis is to minimise the number of parts that needs to be assembled into the finished product to reduce the lead time for assembling. This analysis should already happen in the product development process, so also the assembly system is influencing the design phase. And not pushing problems ahead and trying to solve them, but rather try to analyse possible problems before they occur and find ways to mitigate or solve possible problems on forehand.

A normal analyses of the assembly part happens with a combination of knowledge- and intelligent methods [73]. For the ASP using knowledge- and intelligent methods needs to be combined to find the right assembly sequence[74]. The knowledge-based part of establishing an ASP can e.g. consist of an assembly-disassembly process, where a finished product first is completely assembled, and afterwards is disassembled again, and this for several times to establish the most efficient assembly sequence. While intelligent methods are related to an analysis in a 3D simulation environment. Where the design and the layout of the assembly line can be realized, manual assembly station will be ergonomic studied ore tools and fixtures needed for an reliable assembly process will be designed[72].

An assembly line and its underlying assembly sequence should be handled as a flow-orientated system[75, 76]. The normal approach to analyse the assembly system is through an ALB[75]. To be able to assess an assembly line, assembly lines needs to be seen as flow-line systems, where the amount of different finished products and allocated components/modules can be

optimized with optimization algorithm so called ALB[75, 76]. Performance analysis using the ALB and Improvement of assembly lines should happen with lean techniques. But this thesis comprises the ideas of engineering techniques for the case of quality assurance and therefore those techniques would exceed the scope of this thesis. Important for the efficiency of this part are the time but also the capability related to precision in the assembling and the reliability of the process. Mistakes in this phase will drive the costs exponential. While the different products mostly consist of the same or similarly components/modules which serve different functions, the assembly line for each finished product will be partially equal.

Another issue for the assembly line which is to be considered are the possibilities of mistakes that can occur during the assembly which have also have to be minimised. Normally the right procedure to avoiding mistakes is to establish SOPs which are a very reliable tool to decrease the possibilities of mistakes. SOPs are a very powerful tool in the quality assurance. They describe very precisely how to do certain steps in the assembly procedure.

It is necessary to ensure that the assembling of the finished products is regarding to the specifications defined in the customer order.

As shown in the figure below the assembly lines can be classified after different of the possible characteristics. The classification after the categories of a) manual assembly b) special purpose assembly machines c) robot assemblies [39] is missing in this figure. For an ATO-MS the classification after the product characteristic gives the best result related to engineering strategies for a quality assurance system.

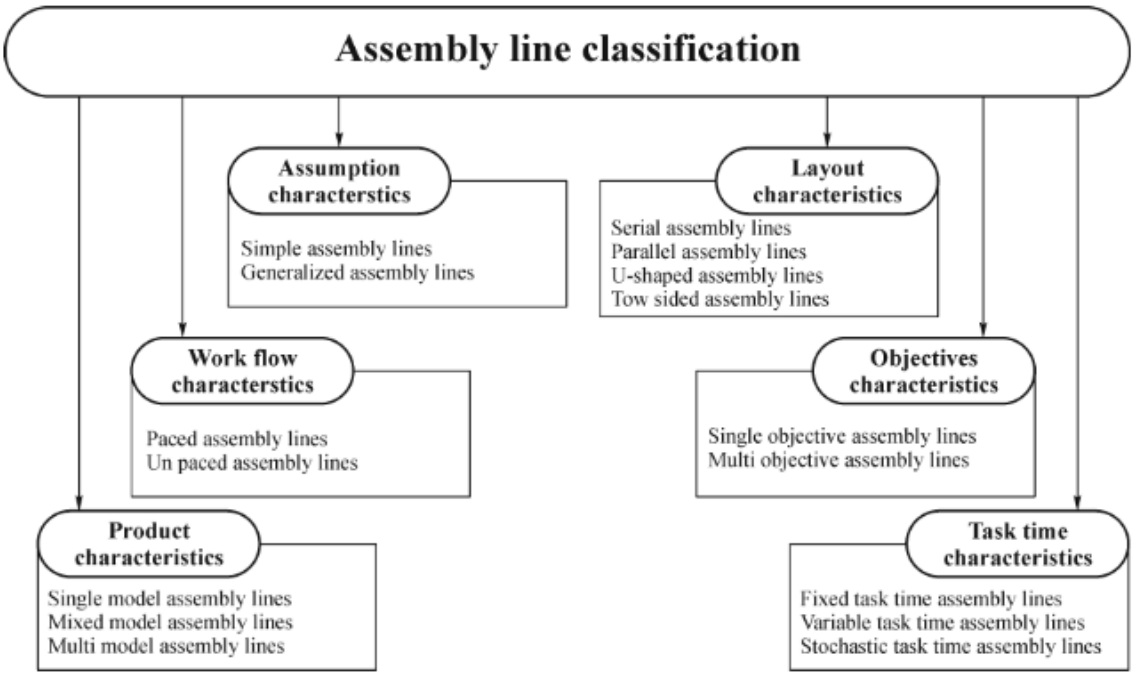

Figure 9 assembly lines [77]

8.5.1 Single Model Assembly Line

In a single model assembly line, where there is just one single product model which is assembled. The single model assembly line is the least complex assembly line. Every consideration for this type of assembly line is to increase the efficiency and securing the reliability of each step of the assembly. The challenges with the system are related to the time used on each station, while processing times alternate between all stations, from high processing time to lower processing time. As mentioned before the different steps will be treated like a flow-system and using the bottleneck management to optimize the system[76]. A negative site with the single model assembly line is the amount of investment when a new model needs to be added. Therefor the numbers of output of each model needs to be relatively high in relations to the investment for the assembly line.

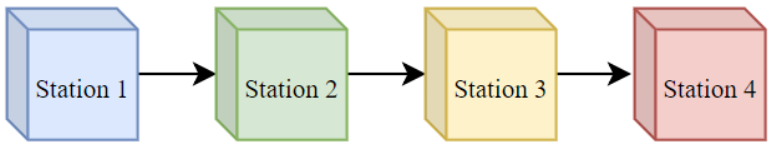

Figure 10 Single Model Assembly Line

8.5.2 Mixed Model Assembly Line

A mixed model assembly line is a line which is designed to assembly the same models of a product family. The products are sharing the same parent's modules/components and different functions are added to the parent's product. The challenges for this assembly line is that the process time for each station is different and the combination of all of them. While each station can, but must not, be part of the line, the problematic of ALB is increasing potentially with each station that is needs to be part of the assembly line. Another challenge of this assembly line is the sequence planning for all the different models. While the combination of all assembling stations for each of the models may contradict other models. Meaning that for one model the best solution might be that station three should be done after station two and before station four, while for another model station four needs to be executed before station two. The mixed model assembly line is not suitable for assembling of more than one product family. While the combination than makes it impossible to provide an efficient assembly line.

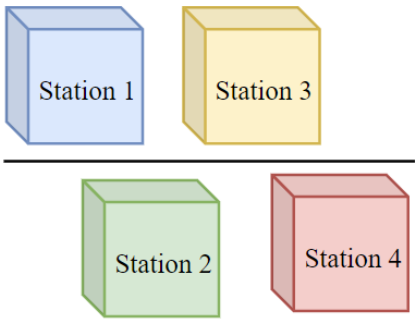

Figure 11 Mixed Model Assembly Line

8.5.3 Multi Model Assembly Line

The multi model assembly line needs to provide the capability of simultaneously assembling different product model types[78]. Where every station of the assembling line always has to be operational. The best way to provide this is the cellular organization of the assembling line. Using batches where the flow of the assembly line is controlled by the stations which needs to be executed and providing an efficient flow of products through the assembling process. The challenge for this type of assembly line is to provide a constant flow of the line and avoiding bottleneck problems. To mitigate those problems, some of the stations can provide flexible assembly tasks for resolving bottleneck problems.

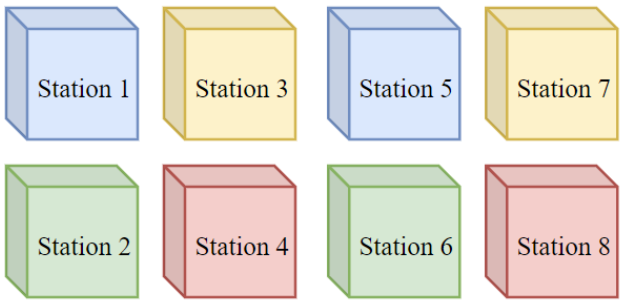

Figure 12 Multi Model Assembly Line

8.6 Delivery to the Customer

The part of the MS where the finished product is arriving at the customer can maybe defined in to two parts. Starting with the most important thing, that the customer is receiving the product in the same condition as it left the factory. The first-time experience of the customer with his new product needs to be conserved towards the best positive experience possible. For smaller product even that can be used as an advantage. The company will provide packaging, which can achieve different goals as a) protecting from stress under transport and possible damages b) the way to pack the product can be used for brand building with the design of packages that supports product recognition [79], and c) contributing the overall first time experience, while it is always fun to unpack a new product and there are the sight and the touch sense involved. Opening a package with a new product is always releasing the new product smell which also contributes to a first-time user experience. Designing the package after an idea of prolonging the unpacking process in a way that opening the new product needs additional time to extend the experience a bit longer. This part also comprises the important part that the customer is receiving a product which was ordered precisely defined in the customer order. As defined in Chapter 8.4 There are specified functions which the finished product needs to fulfil. Those functions are in detail described in the customer order and therefore needs to be according the customer order. There is always a possibility of circumstances arising which delay the point of delivery ahead in time. Which is a difficult part while when the product is in transport, even the responsibility is declared in the customer order, the product in itself need to be able to resist more difficult conditions during storing, without changing characteristics in functions or appearance. Unfortunately, this part of the MS provides little research and engineering strategies.

The second part that the delivery must cover is the paper part. When the customer receives the finished product he also needs a detailed introduction to all the functions of the product, and how to use them properly and how the customer can ensure a long product life cycle. Additional getting warnings of how not to misuse the product by showing explicit the limits in which the product is operating and in which the product will lose the capability of well-functioning. It needs additional a detailed packaging list with all parts that follows the delivery. Other papers that might be necessary are a certificate of origin when the product is being exported in to other countries. And a CoC which states that the product is meeting a minimum set of regulatory, technical and safety requirements.

8.7 After Sales Service

As mentioned in chapter 5.10 after sales service offers a variation of functions which the company can profit of. From increasing the revenue stream to a source of valuable information for continues improvement of the products regarding quality and reliability. After sales service can also offer a main competitive differentiator[80]. The building of seller buyer relations to connect the customer to the company for long time periods with mutual benefits for the company and their customers[81]. Where the customer benefit with increased reliability of product functionality and in case of malfunctioning with short repair lead times. For the company after sales service offers increasing of the revenue stream which can be divided in to three sub parts as a) sales of spare maintenance parts, which are parts that have a specified life time cycle and therefore are designed to be easily replaced, b) periodically maintenance which is happening periodically dependent on the time in action and c) accessories where the company offers products that are useful to add to the product like protect covers or adding new functions[40]. The importance of after sales service has been acknowledged in times where the competition of suppliers is globalized.

The decision regarding on how to build after sales service is closely connected to the cost of a product failure happening for the customer. The cost again can be divided in to two types which are a) fixed costs which mainly are the cost of repairing the malfunction and b) variable costs which comprises the continuing costs like the labours needed additionally for the job and even the costs of loss of income from the service the company’s customer provides to their customers.

c

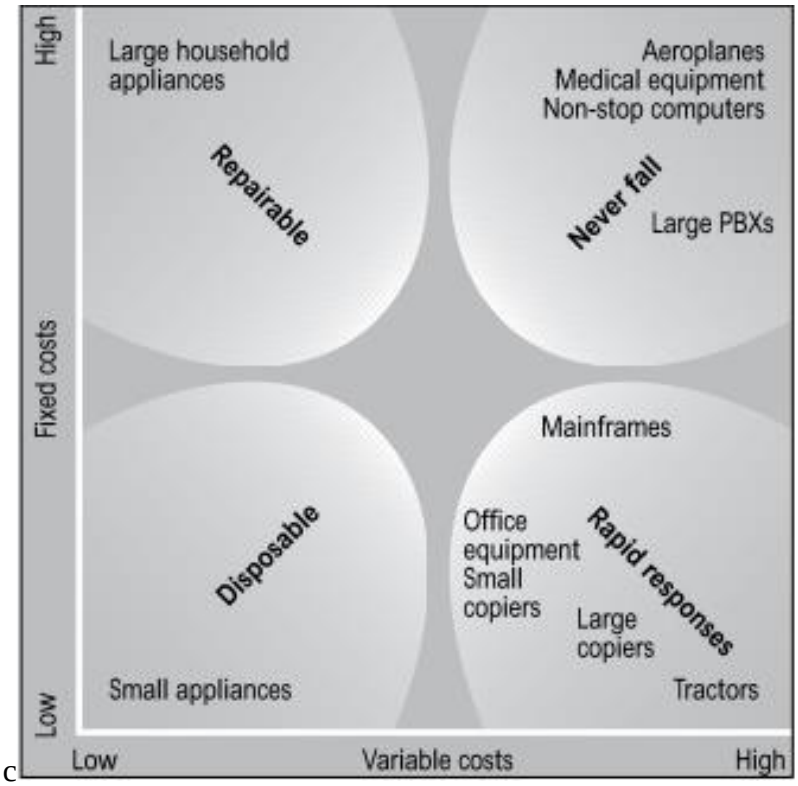

Figure 13 Relationship Service-Design[41]

As shown in figure 13 the two types of cost because of a malfunction of the product has an impact on the decision on how to react to a malfunction. While the variable costs are connected to the function that the product must fulfil, so are the fixed costs very close related to the design of the product. When the cost of both the variable and the fixed cost is very low, then the question of repairing the malfunction at all is current. Depending on the costs of the finished product the question is relevant to even replacing the product. For more expensive products the design of the product needs to allow to change malfunctioning parts. And then depending on the price of the part a decision can be made of to dispose or repair the part. Which in itself then has to be designed to be repairable. When generally the product is worth to be repaired the design is mostly done with module based design which makes it possible that the service easily attribute the failure to one specific module, which then should be relatively ease to change called module swap out[41]. In case of high variable costs related to a malfunction of the product, the company needs to be able to offer very short lead times for service and repairing the malfunction. Normally the service should be able to repair on site while having a variation of parts with them. The lead time for the service needs to be as short as possible. This is only possible when the company has a knowledge of their products and an updated database of parts which are more error prone then others. For modules/parts which have both high variable and

fixed costs the design of the product need to be able to offer continues monitoring or a built in redundancy for specific components/modules[41].

8.8 Cross-connections

After going through all the different steps of the MS and the engineering strategies which are found in the research for this paper, one point revealing is that there are cross connections between the different engineering strategies from the different steps of the MS. When a part is designed in the context of a standardisation, than in the step of procurement the strategy of supplying commonality parts is supplemented by this strategy. Standardized parts are also supporting the strategies of delay of product differentiation thinking smaller parts in the step of inventory. For the step of after sales service, the strategy of rapid response is supported from the inventory strategy of product postponement, while as longer as the parts are not implemented in to the finished parts, those parts are still available for repair of malfunctioning finished products and not . Those cross connections between the strategies and the steps of the MS, are visualized in Figure 14. Those cross connections of supporting the engineering strategies in between different steps is another value added to support the quality of the finished products. And as more connections which can be made, that makes the complete model stronger. This affinity diagram shows very good the strong connections of all steps of the MS and the underlying engineering strategies. The strongest connections are from the design part, where each strategy easily can supplement the other strategies trough each step of the MS.

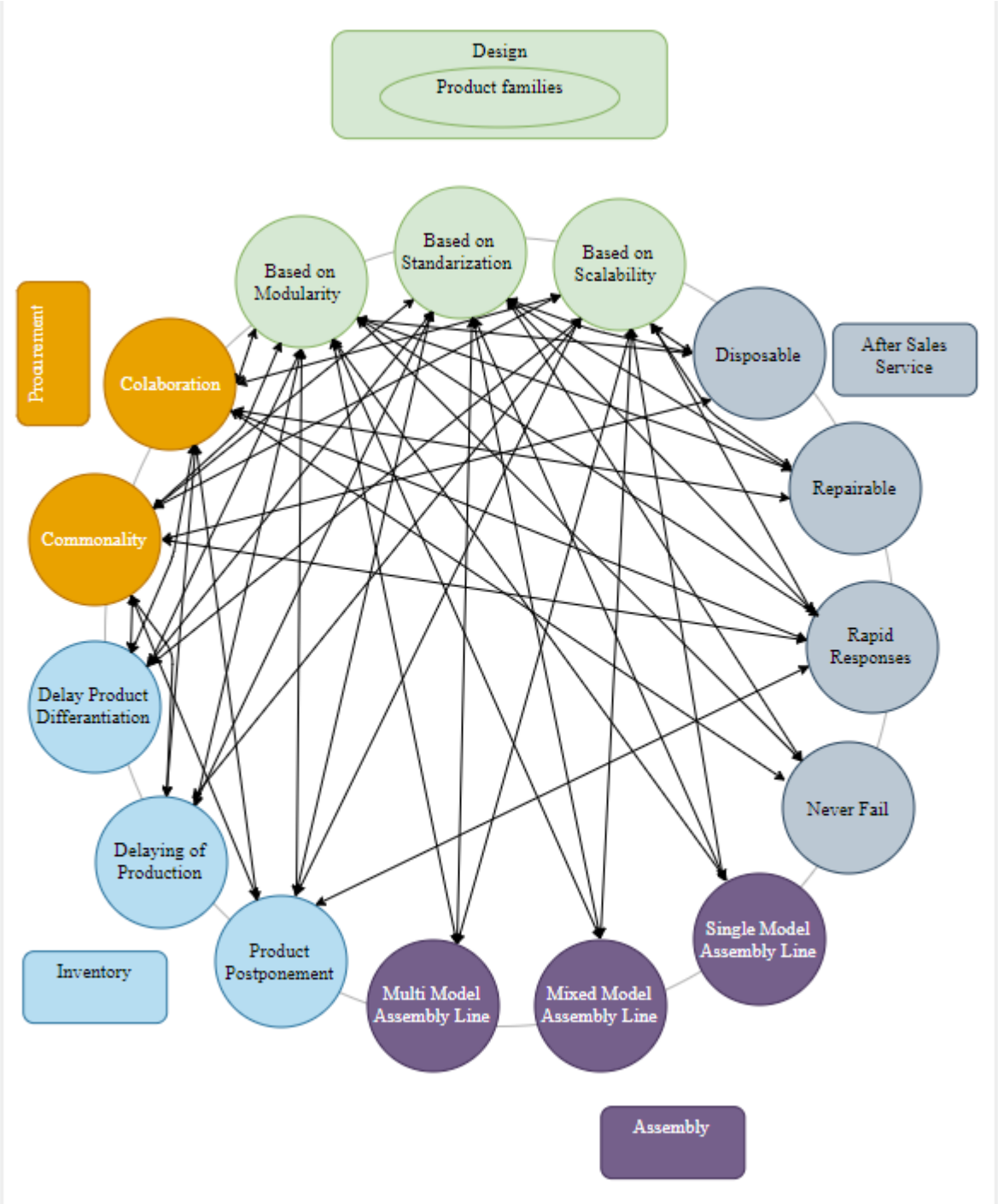

Figure 14 Affinity Diagram

8.9 Summary

For the case of an ATO-MS relaying on a global supply chain there were found o profound amount of engineering strategies for each step of the MS. In specific the design phase has to offer different reliable solutions which will have positive impacts to the other steps of the MS

and seems to be the most important part, and it is therefore no surprise that the most specific strategies for an ATO-MS where found for this part, while for the rest of the MS the strategies are more generally independently of the MS. The study of the available engineering strategies shows, that the only advantage for SMEs in comparison to big companies is to collaborate with other SMEs and try to exploit the specialized knowledge of another SME.

Two points which are sticking out are the Customer order and the delivery of the product to the customer where there could not be reviled engineering strategies which are supporting the quality of those steps of the MS.

9 Quality Tools

Working in a predesign phase the intention is to find a specific quality tools which can provide a method to evaluate the quality impact of the parts which will be procured and needs to perform in all steps of the MS represented by the engineering strategies. The preferences which the quality tools need to be able to supply are an overall assessment of different type of parts which are used in different type of products, regarding the idea of MC. And all those parts needs to perform against the products and the engineering strategies in each step of the MS. And again, thinking from the perspective of a predesign phase, therefore the complete MS. Concentrating on the design phase there are not so many tools which can supply this type of evaluation. Tools like SIPOC in its one-dimensional system evaluating one process at the time, and FMEA can offer additional information for an evaluation. To be able to digest all those inputs needed QFD seems to be the best tool. It is a comprehensive tool which allows to be fed with a vast amount of input and digesting the information to an applicable result. QFD mainly used in the design phase where the product development is the task, QFD are used in different type of analysis than just product development with examples like risk management analysis [82] or service QFD[83], this tool should not be limited to the product development, but rather be used after is capabilities.

9.1 QFD

The QFD developed as a product design and development tool that is responsive to customer needs throughout each stage of the production [84]. The QFD is a multi-attribute decision-making tool [62, 82]. While the life time cycles of the products are getting shorter, the developing of new products must happen in a shorter time period than before. And the production line of those new products needs to be able to deliver higher quality from the first day on [85].

Instead of analysing which causes that are contribute to undesirable outputs using the cause and effect diagram (fishbone-diagram), the HOQ was developed where the causes of positive quality was identified [61, 84]. Those analysis grew completely in to the HOQ with large projects.

Areas that are using the QFD are transportation and communication, electronics and electrical utilities, software systems, manufacturing, services, education and research and other industries. With functional fields like product development, quality management, customer needs analysis, product design, planning, engineering, decision making, management, teamwork, timing costing and other fields [86]. There is a real value in QFD when it is so widely used. The main principle benefit of using the QFD is that all persons in the MS are starting thinking together in the same direction[87].

9.1.1 The VOC and Kano's Model

One of the most important areas that the QFD has an impact on is the voice of customer [85, 88]. In times with a global supply chain and MC there is increasing competition in the market. The need of finding competitive advantages with in specific market segments where the core competence of the company can be exploited As a result of this customer satisfaction strategies are becoming more important. [89]. To understand the needs of the customer it is important to know both the spoken and the unspoken needs. Kano in his model of Quality distinct between three different types of requirements that are important for customer satisfaction. While the one-dimensional requirements are those that the customers mostly answer while be asked for their wishes, like a good design or all the functions that are expected to be there, those requirements can impact in both a positive or negative way, while those expectations are fulfilled or not. When it comes to must be requirements like the perfect functioning of all features will just impact the experience of the product in a disappointing way, when not met. Nobody will take it as a bonus when it works. But when it is not working as supposed, then the customers will be dissatisfied. When it comes to attractive requirements, those are requirements that the customer didn't even know that they where needed before the customers experienced the functionality of those functions. Functions that are showing that the producers know more about the real value of the product than even the customers that will stand out of the products of competitors. And they will create only positive satisfactions while they are fulfilled [90].

But listen to the VOC might be not so easy, while at first just listen is not good enough, when the meaning of it is not understood. To understand deeply the characteristics of the VOC and

then obtain the useful information [91]. In practice first when the use of the VOC and the QFD gives results in increasing sales numbers, then the VOC is really understood. To obtain the right information, which provides you with a competitive advantage, from the VOC it is necessary to ask the right questions.

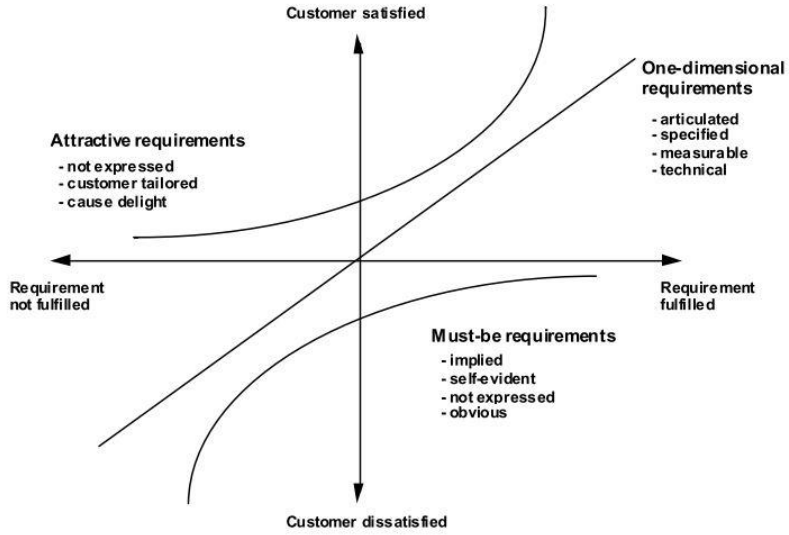

Figure 15 Kano's Model of Quality[90]

9.1.2 The HOQ

The HOQ is a complex matrix, which can be divided in to several steps to organize different inputs like the VOC, the engineering parameters and the competitor comparison for an overall analysis. In the start phase of a product development the HOQ converts the needs of the customers in to technical specifications on how the products need to perform to the needs, e.g. a customer need for a cup of coffee needs to include a technical specification on the size of the coffee, translated in to volume, and how important this measurement is.

9.1.2.1 Part one

Different type of customers

Starting by defining the different type of customers for the product. In general, the customers are differentiated in three different types. The internal customers, the intermediate customers and the final customers[87]. Internal customers are shareholders, management and the

employees. The intermediate customers are more like retailers and businesses that will be responsible for serving finish customers. And the main focus in every evaluation must be the end customers which are the final users of the product and where the products needs to perform after their wishes, since they are paying for the product and therefor need to perform after expectations.

The needs of the customers

For the end user of the product, the importance is not just that the products perform after the expectations, but as we learned from the Kano's model, the product needs to perform in all three types of expectations. For the users of the products a distinction after Kano's model should be used. Which leads to step two, establishing the VOC in the what's which represents the needs of the customers. To learn the skill of listening to and collecting the VOC, which can be challenging, it needs a lot of practice. The VOC is about the quality of the data that you are collecting, meaning that you receive the information that you really need. As shown in chapter 9.1.1 the VOC is a complex matter, with expectations that the customers are aware of, but also expectations that the customers are not aware of. To find the right needs for the customers is a process that can be divided in to these 4 steps (gather the VOC, analyse the VOC, define customer prioritized needs, validate customer needs, begin the HOQ work). This is to be filled in to the left side of the HOQ [62].

The relatively importance

In the third step the needs which are established in the second step receive a relatively importance score which relates to the different needs to each of the customers, while not all needs are equally important to all customers. It will be therefore a distinguishing with importance graduation. Represented in numbers from zero to ten. And then the percentage distribution of all scores.

9.1.2.2 Part two

Converting the needs of the customers in to engineering parameters

The fourth step is to convert the VOC in to engineering parameters which needs to be measurable parameters. How can the developers respond to the VOC by using engineering parameters that relates to the needs? That's why this part is called the how's. How can the needs be converted in to engineering parameters?

The correlation of the engineering parameters

The roof of the HOQ to adding the correlation matrix which shows the different correlations between the engineering parameters. Which again adds more important information to the HOQ. When there are done changes done to one engineering parameter, then often those changes have impact to other parameters, and this will again change the outcome of the product.

9.1.2.3 Part three

The main body

The sixth step is, where the relationships between the VOC and the engineering parameters is evaluated in the main body, mostly done by fuzzy numbers. Where the relations are evaluated by stating the strength of the relations by a spectre between one and ten.

9.1.2.4 Part four

Evaluation of the competitors

On the right hand side of the HOQ the evaluation of the competitors found their space. Developing new products should always be done with the focus on the competitors. The evaluation will show the equality, or the differences of the products, related to the products of the competitors. Which gives the opportunities of the own product to distinguish from the products of the competitors.

9.1.2.5 Part five

The technical matrix

In the last step the relative importance of all engineering parameters related to the VOC is evaluated in the base of the HOQ, which indicates the importance. The part of the HOQ where some of the results of the evaluation is visible. The results to see in this matrix are a combination of the what`s, the importance of the what`s for each customers and the connection to the how`s. Which resolves in a matrix that contains a ranking of the best how`s and where to focus in the development.

9.1.2.6 An overview on a typical HOQ

Under is a figure of an HOQ, which visualises all the different parameters which are established in the different steps.

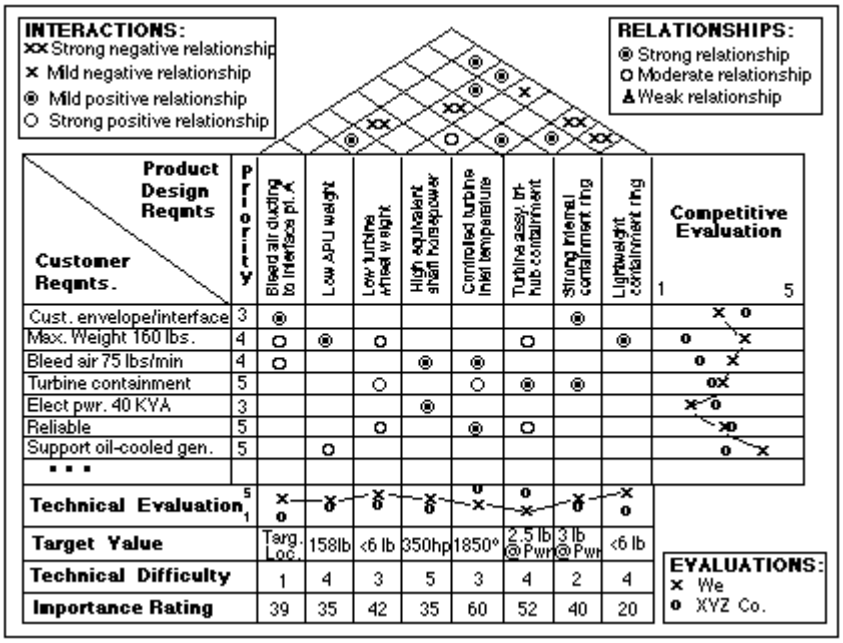

Figure 16 The House of Quality [62]

9.1.3 The Four Phases of Product Development

In figure 17 it is shown how the QFD can be used in the development of new products, not just as a single event tool, but a tool that can be used for the four phases of a product development. Starting with the product definition, then the product development, than the process development and in the end the process quality control [87].

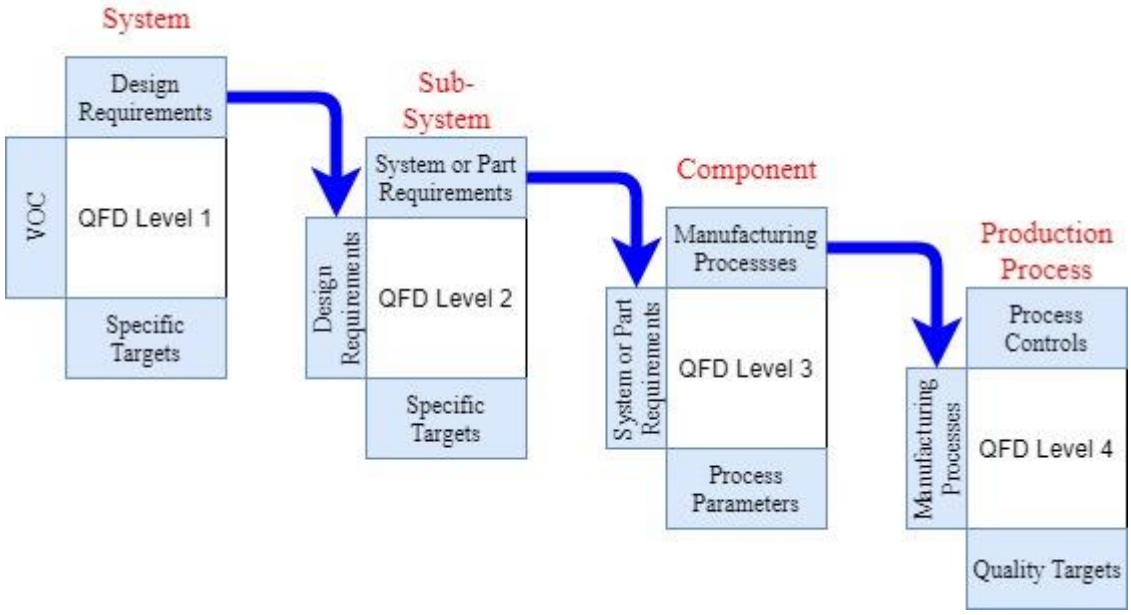

Figure 17 QFD Total System Analysis [92]

10 Summary

For the evaluation of the quality impact of the engineering strategies the HOQ offers a wide spectre of opportunities to compare different type of inputs and evaluating the outcomes. Very convincing tool because of the brought spectre of inputs possible and the analysis toward a result matrix, and with an appendix to allow analyses of competitor products.

11 The Case of a Variety of LED Illumination Products for Vehicles

To test the QAS with the engineering strategies and the quality assessment tool, there will be a theoretical case established. The company first considered as a collaboration partner where not able to offer the time needed to support this project. The time it took to establish that the company in mind could not offer collaboration made it necessary to establish a fictive case, keeping the time of delivery for this project in mind. A case which can provide products that can be served from an ATO-MS, products which are needed in the arctic region, and products which can be produced in variations to satisfy the ideas of MC. Regarding the main challenges of the arctic region which are the long arctic winters, where the sun is not reaching over the horizon for several weeks, and being relatively dark over months. The sun is, during that period, not available to offer the light necessary for the human eyes, to secure the work done by the people. While the amount of work which needs to be done anyway is equal, meaning the same as in the time with enough light. Therefore a case is chosen which offers the necessary light needed. For a vehicle the consumption of electricity is directly related to the size of the battery and the power which it provides. That makes the use of LEDs as a means of illumination an interesting case, when it comes to looking for efficient and power saving methods for lighting up the vehicles and its surrounding areas. LED lights contain different components/modules, which can be bought from a global supply chain and be assembled together in a facility in the arctic region.

The case will be a company which produces LED illumination products for vehicles that are used in a commercial content. LED light products consist of some different components/modules which can be analysed of the ability of how the different engineering strategies have an impact through all the steps of the ATO-MS. How can modified versions of the main product offer more than just one usability to satisfy different customers? Where the product can be modified after customer specifications. To produce LED illumination products the company is depending on a global supply chain with low customer service, when it comes to the requirements from the company. Every customer who will by LED products has their

own preferences, why they need to find a product to solve a specific problem. For vehicles used in a commercial content light is an important thing, for different circumstances like driving, work insight and around the vehicle, securing the visibility for the vehicles when the vehicle is parked in or close to the traffic flow while needed stationary service is provided. This company will offer a connection between the different illumination products for their customers. As it is now, most customers by each product separately and install them. So there is no connection between those different products needed, and no product will work together with the other products.

12 LED Lights

LED light has been around for over 5 decades. The invention of the practical LED is attributed to Nick Holonyak in 1962[93]. Used frequently over many decades in status indication applications for the industry. LEDs in the early stages had not the potential to be used as illumination devices, while the output of light was too low. Then in the last decade, when the improvements made, allowed the amount of light output to be significantly increased. The use of LED for illumination was growing strongly and refunding other sources of illumination devices like traditional types of bulbs, halogen or CFL bulbs. The use of LED has several advantages over other light sources. LEDs offering better results in cost safety quality and reliability compared to other methods. LEDs offering a power saving of at least 50% compared to the other methods. While offering extent life cycles the maintenance is also significant decreasing. And LEDs offering the mitigation of safety risks, as a solid state device it is extremely resistant against shock and vibration, has a low environmental impact during the production and a low risk of ignition in areas where this can be dangerous[94].

Today's LEDs are working with 160lm/W but this is increasing, which makes them as nearly 70 % more energy efficient as other illumination technologies[94]. Other advantages of LEDs are the instant on-off capabilities and their capability of working in extreme temperature environments both hot and cold. The approximately life time expectancy of a LED is 100000hr.

12.1 LED Circuits

Depending of the voltage which the power supply is serving to the circuit LEDs as any other electrical material can be used in both serial and parallel circuits.

12.1.1 Serial Circuit

In a serial circuit the positive connection of the first LED is connected to the negative connection of the following LED and then the positive connection from this LED will be connected with the negative connection of the next and so on. Until on the last LED the opposite connection as the first can be connected to the power supply to close the circuit. When LEDs are connected in serial then the Voltage of every LED needs to be added when calculating the required power supply. For each LED counting 3V, times 4 gives a necessary Voltage from the power supply of 12 V. LEDs are designed to operate between 2 and 4 V, which means that the voltage of every LED is not equal for all LEDs. Normally the Voltage for each LED is counted with 3V. Disadvantage is that if one LED is failing the circuit is broken for the current flow and all the other LEDs will stop lighting unless a bypass is built in and allows the current to flow around the failing LED.

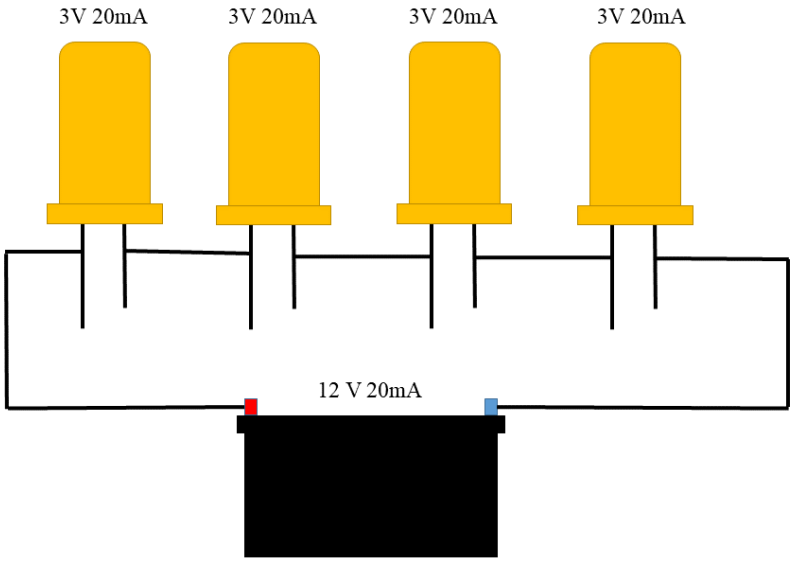

Figure 18 LEDs in Serial Circuit

12.1.1.1 Parallel Circuit

The parallel coupling of the LEDs in a circuit means, that the positive connection of the power supply is connected to all positive connections of the LEDs. Which means that the power supply needs to supply a Voltage of 3V and current flow of up to, number of LEDs times 20mA. The parallel circuit has the advantage of, that if one of the LEDs is failing then the rest of the LEDs

will still be working, and even the stress of the remaining LEDs will increase because of the increasing of the current flow. This type of circuit is good for the intent of increasing the amount of Lumen output and by that increasing the amount of light.

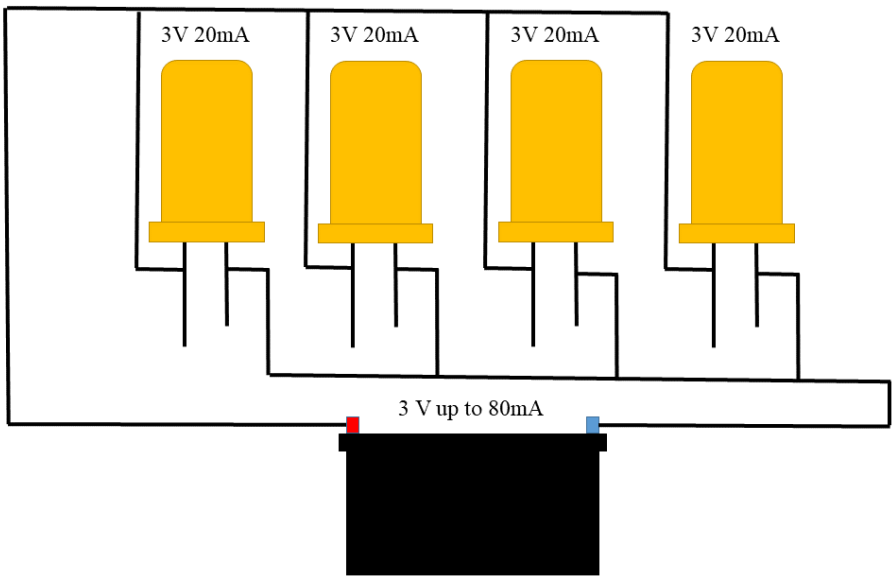

Figure 19 Parallel Circuit

12.1.1.2 Combining Serial and Parallel Circuits

The best solution for to build up the LEDs is to use a combination of serial and parallel coupled circuits. While the serial circuit is used to respond to the amount of power provided by the power supply, so can the parallel circuit respond to the needed Light output by adding an amount of equally serial circuits in parallel.

12.2 LED

As mentioned before, LED light-emitting diodes are generally operating with a forward voltage of 2-4V and a forward current ranging from 10 to 30 mA which is relatively low compared to traditional light sources. The amount of voltage in which the LED is operating is also depending on the emitting of the wavelength. Those values are varying depending on the semiconductors used. Depending on the semiconductors not only the value of the voltage but also the wavelength of the light and corresponding to that the colour of the light. LEDs are manufactured in different sizes and shapes. LEDs contain no harmful materials. Working with low energy output

SEMICONDUCTOR MATERIALS	LED EMISSION
Aluminum gallium arsenide (AlGaAs)	Red and infrared
Aluminum gallium phosphide (AlGaP)	Green
Aluminum gallium indium phosphide (AlGaInP)	Bright orange red, orange, yellow
Aluminum gallium nitrate (AlGaN)	Near to far ultraviolet
Aluminum nitrate (AlN)	Near to far ultraviolet
Diamond (C)	Ultraviolet
Gallium arsenide phosphide (GaAsP)	Red, orange and red, orange, yellow
Gallium phosphide (GaP)	Red, yellow, green
Gallium nitrate (GaN)	Green, emerald green
Gallium nitrate (GaN) with AlGan quantum barrier	Blue, white
Indium gallium nitrate (InGaN)	Bluish green, blue, near ultraviolet
Sapphire (Al_2O_3) as substrate	Blue
Silicon (Si) as substrate	Blue (under development)
Silicon carbide (SiC)	Blue
Zinc selenide (ZnSe)	Blue

Figure 20 Semiconductors[93]

12.2.1 Colour Variations

With LEDs it is possible to combine different Semiconductors which emmits light of different wavelenghts resulting in different colours. When combining two colours in one LED by adding one additional annode, then this LED can actually provide three colors when both colours are activated in the same time for example red and green to obtaine yellow which makes it a tricolour LED. For a RGB (red, green, blue) LEDs is one mor anode necessary to sypply the third colour.

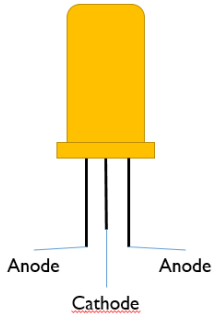

Figure 21 Tricoloured LEDs

12.2.2 COB

COBs are LEDs which are, as the name says, already installed LEDs to a circuit board, wired in serial or parallel circuit depending on the specifications that the COB is designed for.

Driverless COBs are circuits of installed LEDs that have drivers directly built inn directly in to the circuits which ensure a constant current flow. The characteristics of the COBS are the same as by the LEDs just with different values. The intention of COBs is to provide enough light output for different specifications in one object without soldering all LEDs.

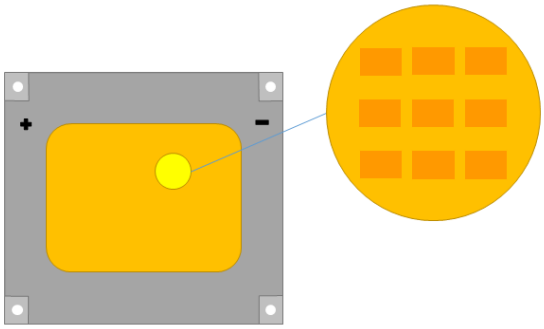

Figure 22 COB

12.2.3 Lumen, Candela, Lux

Three different expressions which are used to state the number of light photons which is generated by the LED. Lumen is the best way to describe the efficiency of a LED, since it is the number of light photons produced by the LED related to the electric power that is provided as input. Going out from a candle which produces 1 lumen. Light efficiency of an LED is 160lm/W [94]. But this value is temporary, because of the continues development of LEDs. Lux is measured by lumen/m^2. That means the amount of light on one area of one square metre. For a candela the definition is the luminous intensity on a given point and a given angel from the light source.

12.2.4 Parameters

- Watt
- Lumen
- Efficiency (Relation between power input and lumen output)

12.3 Power Supply/Driver

Since LEDs in its nature are fluctuating in the production process, meaning that LEDs are never equally regarding both the forward voltage and the current needed for the LEDs to work. That there is a need to respond to those challenges. In figure 23 the relationship between the Voltage and the corresponding current flow is visualized. That for a LED starting with a needed forward

Voltage to work, the change of the amount of the current flow is very high related to a small change of forward voltage. Therefore, for LEDs a stabile current flow is important to work in an optimal environment and securing a long-life cycle.

A driver in generally is a control circuitry that provides an output which is equally to the characteristics of the LED to supply, and controls the flow of current in specified parameters[93]. Different type of drivers are responding to different type of voltages which are supplied in the power grid over the world, or from different types of voltage supplied by batteries and always keeping in mind to provide a current flow in specific parameters. The power supply is also responsible for converting the supplied voltage from the grid or the batteries in to a voltage which replies to the circuit in which the LEDs are connected[95, 96].

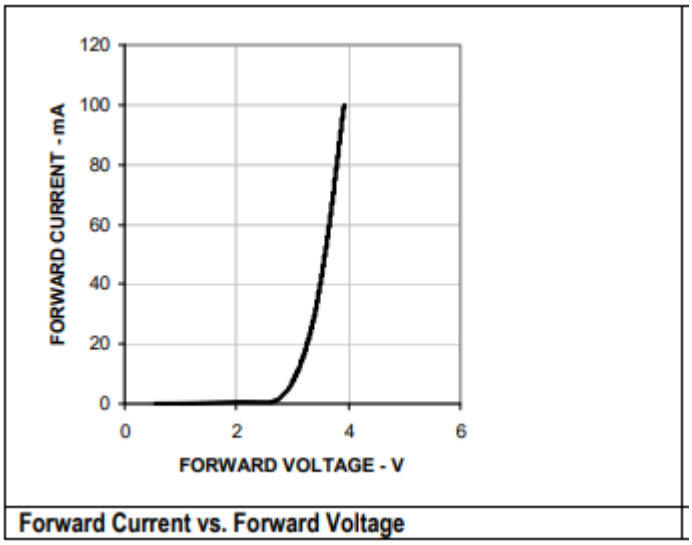

Figure 23 Relationship Forward Voltage and Current[97]

12.3.1 Parameters

- Voltage
- Current
- Environment
- Power Grid or battery

12.4 Heatsink

The effect of producing light photons always includes also the production of heat. Therefore a thermal management is needed[95]. Normally used are aluminium or aluminium alloy material

to distribute the heat away from the LEDs/COBs since the thermal conductivity of aluminium is one of the best when we consider metals. Generally, metals have the best values of conductivity of all materials. Better thermal conductivity behaviour then aluminium (237 W/m K, in its purest form and right under 200W/m K as an alloy) has only copper (around 400 W/m K) and gold (around 300(W/m K))[98]. The idea is to provide the highest surface area on a relatively small perimeter of the heatsink. The thermal management can be done by active or passive heat distribution. Passive heat distribution is only using normal heat exchange between the heatsink and in to the air surrounding the heatsink. Another method is active heat distribution, where the heat exchange between the material and the air is supported by e.g. a fan increasing the amount of air, which transport the heat away, or water cooling, which also supports the amount of heat transport.

12.4.1 Parameters

- Amount of area needed to distribute the produced heat
- Active/passive heat distribution
- Air or even water cooled

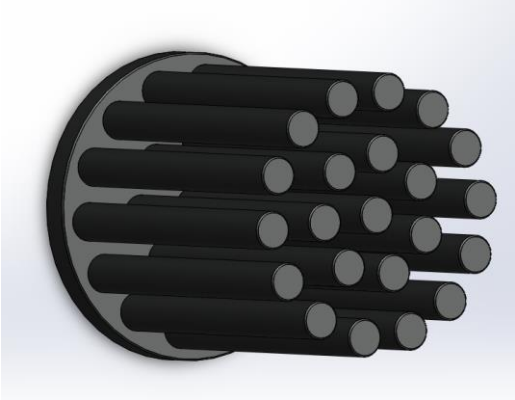

Figure 24 Heatsink

12.5 Reflector

The reflector is used to increase the yield of the provided light from the LED/COB towards a specific direction. Maybe not necessary when lighting up a room, since the intention is to generate light equally over the whole room. While flash lights or lights used on vehicles want to generate the light in a forward direction from the light source and the person behind the light source. The reflector will bundle the light and focus it in a specific direction.

12.5.1 Parameters

- Size
- Material
- Reflect capability
- Capability of heat resistance
- Live cycle

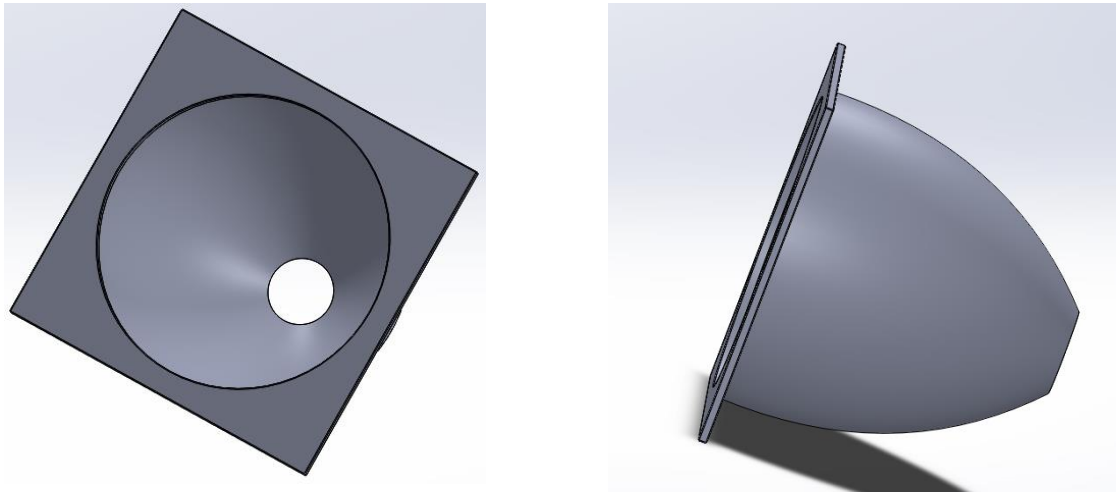

Figure 25 Reflector

12.6 Housing

The Purpose of the housing is to provide the entity an enclosure which protects all the parts necessary against the impact of the environment. The housing of an LED lamp is always very different depending of the different requirements which are important for this specific light. Starting with the amount of parts which the light entails, this will be important for the size of the housing.

For the materiel used in the housing there are some different considerations. The most important is the environment in which the lighting device will be used. While the material needs to provide a protection against the environment. Another consideration to be done is the possibility of saving parts. In case where the housing is also taken over the role of the Heatsink in one function, the housing needs to provide a degree of heat conductivity regarding the heat produced from the LEDs. That will save material and assembly time. The houses also need to answer for the requirements of mounting the light. If it is a head light the capability of combining the light

with headbands. For stationary and headlights, the capability of connecting it to the vehicle with mounting brackets.

12.6.1 Lenses

Lenses are a part of the enclosure which will allow the light photons to travel out of the enclosure and provide the area around with light. The material used for lenses LED products is e.g. PDSM. Polymer lenses possess a variety of benefits e.g. low cost, high optical property, flexible shaping and high mechanical resilience[99]. For the lenses the same criteria's are relevant as for the housing to reply on the environmental challenges.

12.6.2 Sealing

For the connection of the different parts which the enclosure entails and the breakthroughs needed for different functions, those needs to be protected against breaches. To do this using gaskets, which are securing against hazardous intrusion of humidity, dust or other particles.

Table 1 Enclosure Gasket[100]

	Temperature in °C	Restriction	Comment
Polyurethane	-40 to 70	Good compression set resistance	Easy to create irregular shape
Neoprene	-55 to 120	Offers excellent chemical, abrasion and tear resistance. Waterproof	Most common material used
Nitrile	-40 to 121	Excellence compression set resistance	Poor resistance to ozone
Silicone	-40 to 232	Excellence compression, weather and temperature resistance	More expensive than many other materials

Viton	-28 to 204	Good chemical resistance	More expensive than many other materials

12.6.3 IP Classifications

IP is the degree of protection which an enclosure offers against hazardous parts witch can breach the barrier of the enclosure[101]. The classification is regarding from the protection against water and solid foreign objects like dust particles. Starting with an IP 20 classification where the degree of protection against foreign objects is 2 and the degree of protection against water ingress is 0. So that this product should be used inside the house. While an IP 68 describes the highest degree of enclosure of foreign objects and the highest degree of water protection.

12.6.4 Parameters

- Ability to contain and protect all parts
- Capable of being easy extendable to more lights if needed
- Customizable
- Being the face of the company, needs an recognizable design
- Environment
- IP classification

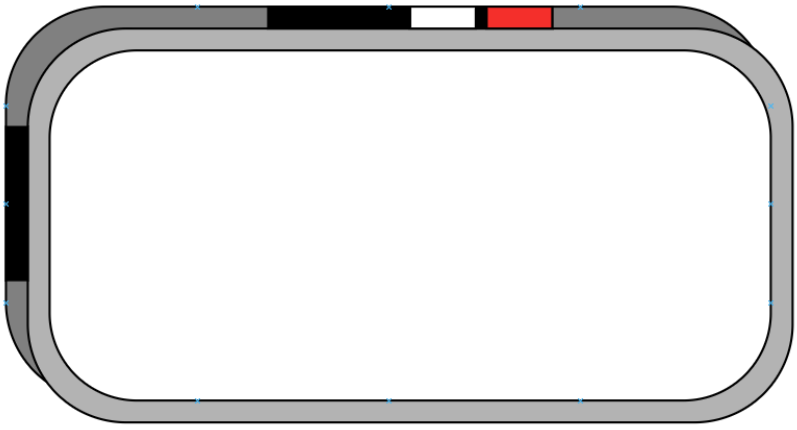

Figure 26 House

12.7 Control Units

Control units are a mean to provide increased user-friendliness to the product. For LED products there are different types of controlling mechanism possible supporting the functionality of the LEDs. Starting with a mandatory On-Off switch that starts and stops the

function of the light. In the case of an LED product the demands to resist electrical voltage and the flow of current is relatively low since LEDs don't need the big amounts. Depending of course on the amounts of LEDs which shall be controlled by the switch. Always depending on the environment in which the product is used there will be additionally control mechanisms provided. When the switch is not located close to the LED, than a control light which makes the state of the light more visible might be considered.

12.7.1 Parameters

- Easy to read
- Easy to understand
- Easy to use
- Durability
- Withstands the challenges form the environment

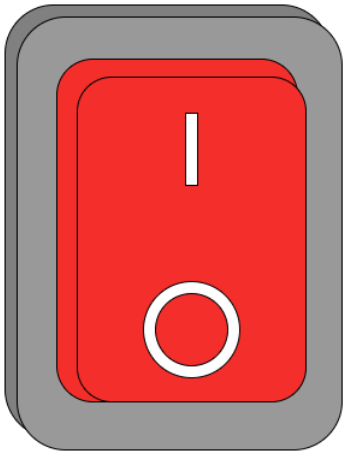

Figure 27 On-Off Switch

13 Product development

To provide LED based illumination products implemented in vehicles which are used in profession, there needs to be done an analysis of the different possible customers for this kind of service. A provider of a complete illumination solution needs to take care of the needs from a variety of customers, since there are a big difference of the needs of those customers always keeping in mind the ideas of MC. The products which are provided should be treated like an additive service to the existing functions of the vehicles and will not interfere with the installed system of the vehicle. For the case of the alternator there might be some limitations when the

amount of LED products exceeds the capability of the power supplied. If we are considering the low power consumption of the products this should really not be a problem.

13.1 Customer Evaluation

Based on the customer analysis for the development of new products there are the three different types of customer's, the internal -, intermediate – and external customers. The intention for this thesis is to establish a case which provides information on how the engineering strategies are contributing for a quality assurance system, therefore the development of the theoretical case is important for the evaluation of the needed products and their underlying parts, and from there the relationship of those parts to the engineering strategies and how their interaction contributes to the quality assurance. Since the value of this Thesis is directed to the quality assurance system for a company with an ATO-MS, the product evaluation will not be a comprehensive evaluation with questionaries' of probably customers. The evaluation of the customers will be based on logic observation on normal traffic in the every day.

13.1.1 Internal Customers

The Internal customers for LED illumination products are represented by the different steps of the MS. To secure the quality of the finished products in the best way possible, the products and the underlying parts which are injected in to the MS needs to satisfy different quality standards for each step of the MS, visualized in Figure 4. Those quality standards are represented by the different engineering strategies for each step.

13.1.2 Intermediate Customers

Intermediate customers might be e.g. retailers, which sell vehicles to end customers and try to offer a better service to their customers by offering special service to customize the vehicles even more to the requirements of their customers. This type of products can be used as a competition advantage. But using a third part suppliers, the retailers are very interested to drop the price for this service as much as possible. So, for the producer of the LED illumination products, a collaboration could be considered. The advantages for the intermediate customers would be a better service to their customers, and for the company the retailer could be an important source for the expectations of the end users, since they have a big customer base. For the intermediate customers the same criteria's are important as the criteria's for the end customers.

13.1.3 External Customers

Those are customers which have bought a vehicle and are using it in commercial business and whom experience a lack of service of light. A generally surveillance on vehicles which are observed on the street on a daily basis shows different type of vehicles. Vehicles which are providing services to the local area, they whom are servicing on the roads as connecting lines between local areas, and vehicles which provide emergency help to different customers in different context. What they all have in common is that they need to be able to see things, since the Human eye needs light to see things. While a vehicle delivered from the manufacture normally is not providing a good lightning system which serve the need sufficient. The vehicle producing company is always trying to balance the service of between the requirements from regulations, the wishes of the customers and the price. Mostly other functions are more prioritized then sufficient light.

13.2 Product analysis

While internal- and intermediate customer's interests are more centred towards technology and costs, for the development of the products and parts the vast majority of the need's lays by the external customers. Therefore, it will be done an analysis of the needs of the different products regarding the external customers.

Table 2 Customer needs

	Needs
<u>Service to the local area</u> Carpenter, Plumber, Electricians, Cleaning service, Post, Care service for older people and more.	• Improving the visibility of the road for the drivers and the surrounding areas between the service points. • Improving the visibility in the vehicles for the equipment necessary to provide the services. • For the remote area of the arctic region sometimes it is necessary to stop direct on, or so close the roads that the vehicle is interacting with the ongoing traffic and therefore the vehicle needs to be visible for the other road users.

	• The need of controlling the lights is strong connected to the existing system of the vehicle. Therefore, the control of high beams might be connected to the existing control system. • Transportable light useable independent from and outsight of the vehicle for unforeseen events.
<u>Servicing the roads and connecting the local areas</u> Road maintenance, Goods transport, Snow Plowing and more.	• Very important that the visibility of the road for the drivers and the surrounding areas is improved, because of the standard of the roads in the arctic region with winding roads and the length of the transport routs, almost no other light sources than the lights on the vehicle. • Related to other road users, those vehicles often have special needs of visibility since the service those type of vehicles are providing for the roads, often interacts with the ongoing traffic. • The services those type of vehicles provides are mostly implemented in the vehicles as e.g. the snowplow ,so that the drivers needs to be able to oversight the correct working of the functions • Transportable light useable independent from and outsight of the vehicle for unforeseen events.
<u>Emergency</u> Fire trucks, Medical Emergency, Police cars Car rescue and more.	• For emergency vehicles the most important factors are see and be seen. As time is of the most important essence for those vehicles. The time for the transport to the service point needs to be minimized as much as possible.

	• When this type of vehicles needs to travel on the roads, then they need to travel fast. Therefore, to be able to see any participant who is directly or indirectly interfering with the traffic flow is important to secure that the vehicle is arriving save at the service point. • When those vehicles are arriving at the service point the capability of illuminating the functions of the vehicle and the surrounding area to be able to provide the best service they are called for to do. • And also, this type will need to stop on or close to the road, interacting with the ongoing traffic on the road and being a potential danger, and therefore to be visible for other road users is also very important. • Also, for this type of customers as for the others easy control of all the illumination products from both the vehicles seat and from outside the vehicle is fundamental. Outside the vehicle direct on the point of interest two solutions are possible. Number one a remote control or number two extern switches. • Transportable light useable independent from and outsight of the vehicle for unforeseen events.

Throughout the analyses of the different categories of customers using vehicles, there are different type of products which can be provided.

Product one - head light high beam

For all type of vehicles, the visibility of the roads and the surrounding areas is one of the main challenges when driving. While driving the long distances between villages in the extended dark winters, on winding roads that are twisting trough the natural profile of the area. But there are not just other road users which interact with the traffic on the roads, also wildlife e.g. mouse and reindeers, which are interacting with the traffic and often are cause dangerous situations when observed too late. Therefore, a light which improves the visibility ahead of the vehicle when driving

Product two - working lights

Working lights which are serving two purposes. One is to observe the correct working of a function e.g. snow plowing, and the second is to provide illumination while working stationary, when the vehicle is parked, the surrounding area needs to be illuminated to provide secure and controlled service.

Product three – room lights

To provide the intended services to customers it is sometimes necessary to keep equipment stored in the cars like tools or parts required, or transport goods from one service point to the next. To keep control of the equipment or goods which are stored in the inside of the vehicles, a sufficient illumination can save time, increase the quality of the service by providing better working conditions.

Product four – warning lights

To secure the traffic flow on the roads the vehicles needs a high visibility rate to other road users to avoid dangerous situations when those vehicles needs to stop on or close to the roads, still interacting with the traffic flow. To improve the visibility to other road users a light which attracts the attention of the other road users.

Product five – hand light

It is not always possible to mount light sources which reaches all areas, at and around the car sufficiently. A hand light which is easy to transport, and which can shed light on any possible point and from any possible angle which is needed.

Product six – head light

In a lot of situations, the drivers of the vehicles need to assure illumination, while to be able to simultaneously use both hands and move around. A headlight would be able to provide this function. For this type of product a accessory to

Product seven – advertising light

Promoting the own company is for every business a necessity to keep and improve the number of customers. To be able to provide a service which makes other road users e.g. people walking around the villages aware of the company and which service they are providing an easy investment.

Using the advantage of the fact that LED illumination products are using less power by providing more of the light needed without draining the on-board batteries to its limits.

For all this different type of products there needs to be variations of each of the products since there are not only one type of vehicle used. Those variations need to provide differentiations in sizes, light output and others.

Product eight – Main Control Unit

One additional product which the company can offer is a central control unit, by the number of different type of products which the company can offer one element that are providing additional information and better control of the functionality is a central control unit.

13.3 Parts development

Because of the analysis of the different products and because their needs to be variations of all products, and because of the analysis of the parts needed for LED illumination products, the next step is to develop the parts needed for those products and their variations. Not all products can use the same type of parts, therefore, the different products then needs variations of the parts.

Table 3 LED Product

	LEDs/COBs RGBs	Driver	Heatsink	Reflector	Housing with lenses and sealing	Control unit	Accessories

Front-beam light	White	12V/24 V power supply DC-DC converter	Necessary and depending on the number of LEDs	The light should be directed towards a moving direction	Protection against environmentally impact	Automatically with the vehicles implemented high beams	Mounting brackets
Working light	White	12V/24 V power supply DC-DC converter	Necessary and depending on the number of LEDs	Not necessary since the intention is to light up as much as possible of the working area around	Protection against environmentally impact	On-Off switch Depending on the use of the light located close to the light or on a main control panel	Mounting brackets
Room light	White	12V/24 V power supply DC-DC converter	Necessary and depending on the number of LEDs	Not necessary since the intention is to light up as much as possible of the working area around	Protection against environmentally impact	On-Off switch Depending on the use of the light located close to the light or on a main control panel or by remote control	Mounting brackets
Warning light	RGB	12V/24 V power supply DC-DC converter	Necessary and depending on the number of LEDs	Not necessary since the intention is to draw attention from the surrounding area	Protection against environmentally impact	On-Off switch located on a main control panel or	Mounting brackets

Hand light	White	Implemented battery DC-DC converter	Necessary and depending on the number of LEDs	To increase the amount of light from the power supply	Protection against environmentally impact	On-Off switch battery control charging status on the front panel	
Head light	White	Implemented battery DC-DC converter	Implemented in the housing	To increase the amount of light from the power supply	Protection against environmentally impact	On-Off switch battery control charging status on the front panel	Headbands
Advertising light	RGB	12V/24V power supply DC-DC converter	Necessary and depending on the number of LEDs	N/A	Protection against environmentally impact	To increase the attention toward the light extra light effects like wandering light	Mounting brackets
Main Control Unit	White and RGB	Non-specific driver necessary	N/A	N/A	Cover all parts		Installation

13.3.1 LEDs

There are two different type of LEDs necessary two satisfy the different finished products. LEDs which are providing white light to illuminate a specified working area and RGBs which are providing coloured light to attract attention to the vehicle. For the white LEDs the possibility of using COBs which are providing improved light output by saving time and space of installing more LEDs in circuits which can be designed for defined voltage output. For the vehicle

interesting for this case this is either 12v or 24V. For the warning light there will be used RGB LEDs which provide coloured light. There are two reasons for that. One is that the vehicle is parked in a way that interacts with the traffic flow as an obstacle while executing a service, and the other is that the vehicle is moving in the traffic serving a function which also interacts with the float of the traffic as an obstacle. The circuit connection of the LEDs should be designed regarding the 12V/24V power supply from the on-board system, then adding parallel circuits to reply to the needs of the amount of light.

13.3.2 Driver

The power supply is strongly related to the on-board power supply of the vehicle which is based on a 12V or 24V system. The driver for the LED lights needs to be designed to regulate the current flow regarding the number of LEDs used in the product. Since the amount of current is so important for the durability of the products, depending on the number of LEDs used to provide the right amount of light needed. To reply to the different type of products the drivers need to be designed exactly after the requirements of the different products. In the case where the amount of current flow needed is exceeding the capability of the area of the wires, then converting the output to a higher voltage is a possibility.

13.3.3 Heatsink

The heatsink of the light needs to respond to the amount of heat produced by the LEDs from the different illumination products. For each LED which needs a particular area that can transfer the produced heat of the LEDs. And when the LED is no longer working, then the effect on the other LEDs in the circuit is increased, and therefore the output of heat is increasing. The best answer regarding the amount of heat which needs to be distributed is the amount of energy distributed in to the system when all the LEDs are no longer working. For the different products and their underlying variations, the heatsink needs to be designed regarding to the amount of heat produced from the LEDs.

13.3.4 Reflector

Reflectors for this type of products are designed in size and shape regarding to the type of LEDs used. As lower the amount of variations of LEDs used in the finished products is, as lower the variations of reflectors needs to be.

13.3.5 Housing

The most important thing to think of when to design the housing is, that the housing will be the face of the company. Therefore, the design of the houses is extremely important to contribute in to the success of selling the products. Buying most of the parts from a global supply chain exploiting the possibility of cheap parts while produced in high volume, the houses are a totally different case. The amount of resources invested in to this product needs to reply on the importance of this product. It needs to be absolutely perfect. For each of the products and their variations, the houses need to provide the capability of protecting all the parts needed and to be able to provide the capability of an amount of personification of the finished product. This could mean special colours which are defining the customer, or personified sticker which are covering wide areas of the housing, again to make the product interesting for the customer. For the case of protecting the parts needed, the complexity of the design of the housing is strongly connected to the amount of each of the different models and their underlying parts. Personification of the finished product is also given when the customer can choose between different functions which are built in to the finished products. Not all functions are equally important for all customers.

13.3.6 Control Units

The most essential control unit for illumination products is the On-Off switch, which provides the control of when the on-board power system is draining the batteries. The On-Off switch of the different lights can consist different switches situated on different places e.g. close to the light and at the main control panel close to the driver seat. In certain occasions it can be an advantage when those switches provide the capability of remote control or are dimmer able. To report the status of the light an On-Off switch might not be sufficient enough to provide needed information. Extended with a control light which shows visible if the light is in an on or of position draining the battery or not. Often lights which are forgotten to turn off are the main reason for drained batteries. Maybe adding a sound control stating that one product still is draining the battery after turned off the main engine switch and opening the door of the vehicle to leave it.

Always important is the status of the battery, if it is the battery of the product or the battery implemented in the vehicles electrical system. How much power is left for the consumers to drain? A battery control system protects from bad surprises by providing information’s of the status of the battery. The battery control system shall consist of a status report on the charge left in the battery, and a control function of how the status of the temporary charge to the battery

is. For the case of illumination devices that are operating off grid, where the power is provided from a battery and considering the arctic region with its partly hostel weather conditions with temperatures fare down below in minus degrees, do not underestimate the importance.

Combining all this control functions of the different lights in a central control unit situated close to the driver seat and providing all the necessary information's needed to empower the user to provide the service intended to the customers and keeping full control, so that there will as few as possible bad surprises as possible. The variations of the control units to each of the product should be limited.

13.3.7 Accessories

To secure the capability of implementing all variations of the different products to the specific customer vehicles, every product needs the capability of flexible mounting. For this their needs to be developed mounting brackets. The brackets needs to be designed to support a flexible mounting of the products to almost each point of the vehicle to secure the best output of light supporting the overview, control of different.

For the headlights there needs to be required headbands for the lights which should be capable of allowing a high level of personification for the customers.

Both the hand light and the headlight with their own implemented batteries, which allows a high rate of independency from the vehicles system, they need to be supplied with power and therefore need a charging station. This station should be implemented in to the vehicles system and be located inside the vehicle not too far from the driver seats to guaranty an ease of use.

Related to the ideas of industry 4.0 to implement the control ability of all products in to a company control system, which provides information that can be used for maintenance and allows the company to improve and evaluate continuously the products. This type of products will not be discussed in this thesis, because that exceeds the scope of the thesis.

14 Evaluation of the Case

A company, which is providing LED based illumination products for vehicles used in professional context seems a good case to evaluation the impact of engineering strategies to establish a quality assurance system. LED products entails a few parts needed. The need to provide variations of products to respond to the idea of MC has an effect on the parts needed for the products. For the LEDs the need of variations is relatively small. Using the capability

which COBs offer. The driver are limited to the on board 12V system and need mostly reply to the amount of LEDs. In relation to the LEDs/COBs the variations needed for the heatsink is also relatively limited. Reflectors are not needed in all finished products. Also, here not a lot of variances needed. The houses needed for all the different products and their variations requires the most capability to variation. Those houses protecting all the parts, needs the highest capability of variations to provide the intended functions. The control units are probably the best way to provide advantage from other suppliers of those type of products.

15 Using the QFD

The intention of using the QFD in this study is to provide information about the impact of using engineering strategies as a main to build a system for high quality products for a SME with an ATO-MS. As the most important building blocks for an ATO-MS system is the input to the MS represented by the parts procured from the global supply chain. The QFD will be built up around those parts. The customers for those parts are the products with their underlying variations. For the practical part of the HOQ a template is used which were available on the internet [102].

15.1 Part one

The customers in this case are represented by the different products developed in chapter13.2, placed on top of the left side of the HOQ, and their underlying variations. Each of those products need the parts developed in chapter13.3. The parts are provided with a colour differentiation, dependent on what the parts are used for. E.g. battery control, On-Off switch, On-Off control lights are all from the category control units and are therefore indicated with the same colour. When it comes to the evaluation of the parts regarding to the finished products the system used is by numbers, where a 5 represents a must have situation and the number three represents a possible to use situation. The reasons for that are explained in chapter 13.

Row #	Weight Chart	Relative Weight	Front-Beamlight	Working Light	Cargo Space Romm Light	Warning Light	Handlight	Headlight	Advertising Light	Main Control Unit	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)
1		12 %	5	5	5		5	5	3	3	9	**LEDs/COBs white**
2		7 %				5	3	3	3	3	9	**RGB**
3		14 %	5	5	5	5	5	5	5		9	**Driver**
4		8 %	5	5	3	3		5			9	**Heatsink**
5		7 %	5	3			5	5			9	**Reflector**
6		14 %	5	5	3	5	5	5	5	3	9	**House**
7		6 %					5	5		5	9	**Battery control**
8		13 %	3	5	5	5	5	5	3	3	9	**ON-OFF Switch**
9		2 %								5	9	**On-Off Control light**
10		2 %								5	9	**Battery charging control**
13		2 %						5			9	**Headband**
14		10 %	5	5	3	5			5	3	9	**Mounting Bracket**
15		4 %					5	5			9	**Charging Station**

Figure 28 HOQ part one

This part of the evaluation worked out relatively well since each of the products needs parts to build a LED light. And for all of the products the parts described to build a LED light are similarly for all products, as the LEDs the driver and an On-Off switch. While some parts are just needed for a few until down to one specific product like the headband for the headlight. The distribution of all parts is relatively good for all products, visualized in the weight chart in Figure 28. Except from the main control unit which is conceived for another purpose, which is improvement of control, and therefore uses mostly specific parts just for this product. So the design of LED illumination products provides parts with a high degree of recurrence.

15.2 Part two

For the second part of the evaluation, using the HOQ, the main part for this thesis comes in to play. The different engineering strategies which are found in this thesis are filled in to the ceiling of the house. On top, the roof is represented by the correlations between the different steps of the MS and the related engineering strategies are stated. From a strong correlation signed with a plus sign to a negative correlation signed with a minus sign. When no direct correlation could be stated than the place is not signed at all. Each step of the MS are defined with a specific colour code. The different steps of the MS are directly connected to the engineering strategy and described together with them. In between the ceiling and the roof the intentions of which of the engineering strategies should be improved or which of them the impact rather should be decreased.

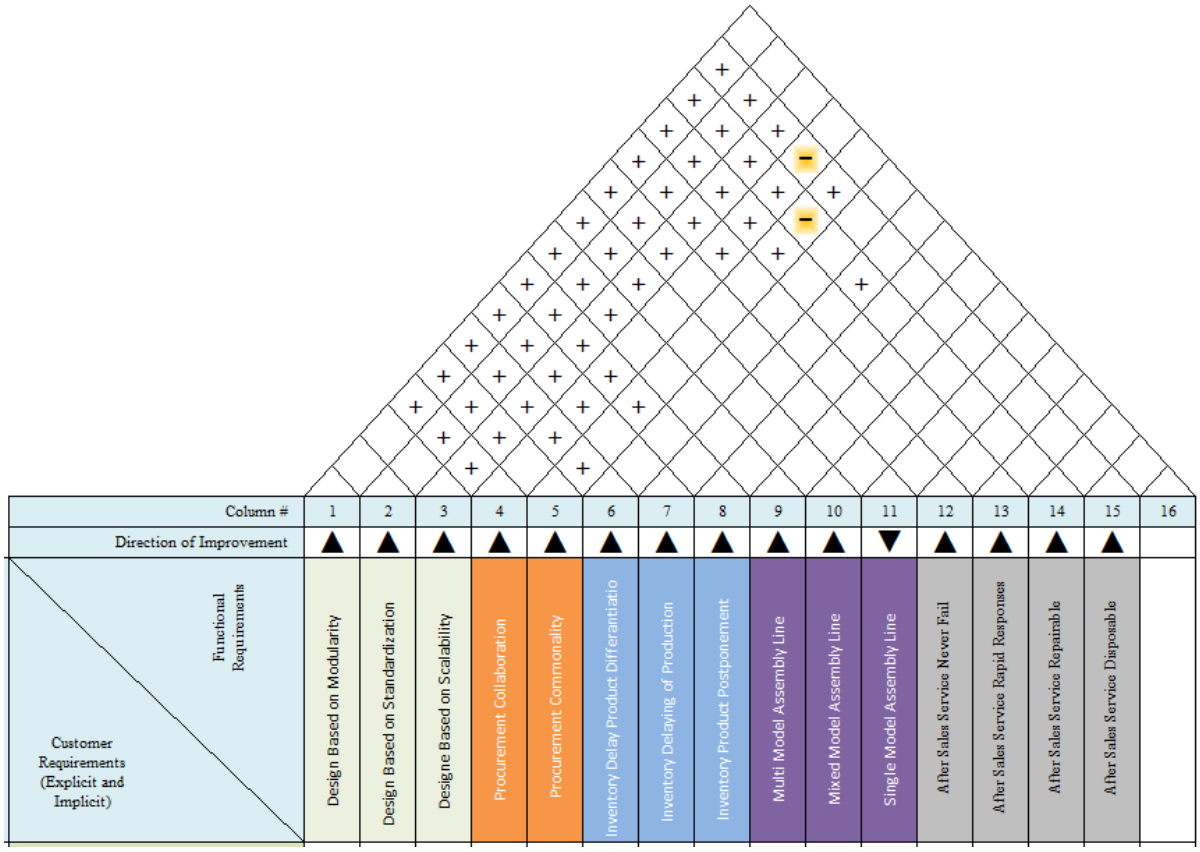

Figure 29 HOQ part two

For the analysis of this part of the HOQ please look to chapter 8.8 where an analyses of the strong relations between the different engineering strategies of each step of the MS is done.

15.3 Part three

The different engineering strategies which are found in this thesis are now to be tested against the parts and the connecting products from part one of the HOQ. The meaning is to show how the parts and the engineering strategies are working together, and how they can tribute to the quality of the parts. To state the relationships between the parts and the engineering strategies a system is used where a dark point state a strong relationship while a white point state a moderate relationship and a white triangle state a weak relationship.

Functional Requirements / Customer Requirements (Explicit and Implicit)	Design Based on Modularity	Design Based on Standardization	Designe Based on Scalability	Procurement Collaboration	Procurement Commonality	Inventory Delay Product Differantiation	Inventory Delaying of Production	Inventory Product Postponement	Multi Model Assembly Line	Mixed Model Assembly Line	Single Model Assembly Line	After Sales Service Never Fail	After Sales Service Rapid Responses	After Sales Service Repairable	After Sales Service Disposable
LEDs/COBs white	▽	●	●	▽	●	▽	▽	●	○	○	○	▽	○	▽	●
RGB	▽	●	●	▽	●	▽	▽	○	○	○	○	▽	○	▽	●
Driver	○	●	▽	○	○	○	○	●	○	○	○	○	●	▽	○
Heatsink	▽	●	●	▽	●	▽	▽	●	○	○	○	▽	▽	▽	●
Reflector	▽	●	●	▽	●	▽	▽	●	○	○	○	▽	▽	▽	●
House	●	▽	○	●	▽	▽	●	○	○	○	○	●	○	▽	○
Battery control	○	●	▽	▽	●	▽	▽	●	○	○	○	▽	○	▽	●
ON-OFF Switch	▽	●	○	▽	●	▽	▽	●	○	○	○	▽	○	▽	●
On-Off Control light	▽	●	▽	▽	●	▽	▽	●	○	○	○	▽	○	▽	●
Battery charging control	○	●	▽	▽	●	▽	▽	●	○	○	○	○	▽	○	●
Headband	○	●	▽	▽	●	▽	▽	○	○	○	○	○	○	▽	●
Mounting Bracket	○	○	●	●	○	●	▽	●	○	○	○	○	●	▽	●
Charging Station	●	●	▽	▽	●	▽	▽	●	○	○	○	○	▽	●	▽

Figure 30 HOQ part three

This part of the evaluation shows that for each part used in this case there is at least on equivalent engineering strategy in each step of the MS. Except for the assembly, where it could not be stated that the parts would be able to work closely together with one of the engineering strategies, which actually came as a surprise. In case for the assembly line the relationship is not directly stated by the parts, but by an indirect relationship represented by the different products and their variations. Which is not visible in this HOQ, what is a weakness using this tool. For the rest of the parts and the relations to the engineering strategies shows that they work

well together. After reviewing the evaluation that is done in this part it shows clearly that some of the choices done could be done differently by other people with other background or experience with good reasons.

15.4 Part four

For this thesis the part of evaluating the value of the own product against the products of the competitors is not conducted, since there are no different quality systems which need to be compared. Not as the writer knows of. For the future an evaluation of different measure systems for the term quality is absolute something to think of. But this thesis is does not provide a research on this topic.

15.5 Part five

The results of this HOQ, the technical matrix. All results in this part are a result of the connections between the parts, the different defined products as the customers, as well as the evaluation of those two in relationship to the engineering strategies. The results of this matrix is done by the sum of the strength of the relationship of each part to each engineering strategy times the weight chart of the evaluation of part one of the HOQ.

Target	Design Based on Modularity	Design Based on Standardization	Designe Based on Scalability	Procurement Collaboration	Procurement Commonality	Inventory Delay Product Differantiatio	Inventory Delaying of Production	Inventory Product Postponement	Multi Model Assembly Line	Mixed Model Assembly Line	Single Model Assembly Line	After Sales Service Never Fail	After Sales Service Rapid Responses	After Sales Service Repairable	After Sales Service Disposable	
Max Relationship	9	9	9	9	9	9	9	9	3	3	3	9	9	9	9	
Technical Importance Rating	309,3	727,9	504,7	319,4	646,5	207,8	238,8	765,1	300	300	300	274,4	400	134,9	703,9	
Relative Weight	5 %	12 %	8 %	5 %	11 %	3 %	4 %	12 %	5 %	5 %	5 %	4 %	7 %	2 %	11 %	
Weight Chart																

Figure 31 HOQ part five

Starting with the design phase the best result shows for the design based on standardization. Since the parts are relatively simple parts almost 50% of all parts have this design type as the best method. This is well as it can be expected. As a result of this and to again support the cross connections of the different strategies in the procurement step, the best result is attained by the procurement from commonality parts. For the step of inventory since most of the parts are using the product postponement strategy, when thinking of the evaluation of part one of the HOQ where most parts are related to most products, than this result is easy to explain. Since the parts

are not directly responsible for the choice of the best type of assembly line just indirectly, explained in part three of the HOQ, the results here are inconclusive. And to state one more time the cross connection of all the strategies used, in the after sales service step the strategy of disposable parts is showing the best result. Good to explain by small parts bought from the shell of other suppliers.

15.6 Evaluation of the HOQ

The evaluation, using the HOQ with the parts, as points of interest, and the engineering strategies, as a method to provide high quality parts, as an input to an ATO-MS, shows a good capability to provide information needed, to decide how a design phase should handle the design of those parts to supply high quality products to their customers. It can be stated, that for each of the parts one or more engineering strategy for each step of the MS was found, is it than to courage's to state that also for other parts needed there could be found at least one engineering strategy for each step of the MS. Which in the end could be defined as that all the engineering strategies are offering quality improvement to the parts.

One point discovered by during the work with the HOQ is the lack of experience of doing this type of evaluation. The times each step and each evaluation needed to be done and redone was because of the lack of experience not surprising. By going deeper and deeper in to the matter new points to consider showed up all the time which resulted in a new version.

16 Conclusion

This thesis has three different parts which are separately important for the wholeness of finding and proofing engineering strategies which assure the quality for the products of a SME with an ATO-MS, and the impact of the quality. Starting with the engineering strategies for each step of the MS. The first thing revealed was how difficult the research was for this kind of problem. It was not possible to find research with the same or even comparable content. The topic of a quality assurance system using engineering strategies for a complete MS seemed not to exist, or at least could not be found. When going step by step for the MS, than it was visible that the design, the assembly and other steps where topics of the research. For two steps of the MS it was not possible to find research on the use of engineering strategies to improve the quality. The customer order and the delivery of the products to the customers, where there was just sporadically research found. Research done on specific content in this two parts, not for the whole step of the MS. Such as how to design the cover of a product, to support the brand. For the part of the delivery of the products to the customer no research of substantial content was

found. Also this facts supports the discovery that there exist no complete research on securing an overall quality by using engineering strategies for a complete MS, always from the perspective of an engineer trying to design high quality parts. And even the design phase offered no engineering strategies to support the quality of the parts when using standardized parts and the supporting effects of this strategy. For more information on this context see chapter 8.2.2.

But now to the results of this thesis. In this thesis the use of engineering strategies for each step of the MS to assure the quality of the parts procured from a global supply chain for the products of an ATO-MS is described. The intention is to look in to a general understanding of how to combine the supply of products for a remote region with an ATO-MS and the dependency on a global supply chain. Which strategies can be used to insure that the idea of developing and supplying products can be make true.

For an ATO-MS there where found a variety of engineering strategies for a lot of the steps of the MS except the ones mentioned before in this chapter. The engineering strategies found seemed absolute capable to support quality improvement for the step of the MS. The strategies found are explained in this thesis and when it comes to the proof of quality improvement than the discovery of the cross connections between the different engineering strategies and the different steps of the MS is very profound.

To prove the impact of the engineering strategies a case was established of a illumination products, which provided capable parts to be used in this thesis. The parts where relatively simple parts but still able to provide liable results. The most important part for the prove of the different engineering strategies found was that the parts not just responded to a specific part of the strategies but responding to the complete variety of strategies. And the parts could deliver on this part of the evaluation too, even if not so strong.

The third part of this theses was the quality tool, where the HOQ was used to make the connections between the engineering strategies and the parts to prove the impact of the engineering strategies to the improvement to quality of the parts. Despite the problems with the direct and indirect relations in the HOQ, which might be resolved in using the HOQ for different levels, the use of engineering strategies is considered as a success. And particular the visibility of the results and the capability of this tool to understand the connections between the different strategies and why it is important to improve the parts with regards to some of the engineering strategies.

One point of this thesis was the fact that the company in mind is a SME. For this type of companies the advantages of the engineering strategies are, as in opposite to big companies where the part of collaboration with their suppliers is in a higher degree possible, the SME can use the part of purchasing commonality parts can be increased. Where a global supply chain can be used as an advantage, with their bigger markets and wider product variety produced for a global market, so that those not necessary mean a decreasing of quality. Global markets also incurring increasing of customer base and increase of production volumes. So in recognizing and using the different engineering strategies also a SME can find solutions to supply high quality products which correspond to their needs.

The usefulness of this thesis is to understand the connection of all steps of the MS for an ATO-MS system and how important especially the design phase is. For each engineer who will design parts, capable to the idea of DFSS, should make themselves known to each of the engineering strategies down to its core, and the responding cross-connections between them. This will contemplate to prevent designers from making mistakes.

References

[1] M. F. Zaeh, *Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013), Munich, Germany, October 6th-9th, 2013*, 2014 ed. Cham: Cham: Springer International Publishing, 2014.

[2] W. Lehmacher, *The Global Supply Chain: How Technology and Circular Thinking Transform Our Future* (Management for Professionals). Cham: Cham: Springer International Publishing, 2017.

[3] S. Chopra and P. Meindl, *Supply chain management : strategy, planning, and operation*, 5th ed. ed. (Always learning). Boston: Pearson, 2013.

[4] B. M. Beamon, "Measuring supply chain performance," vol. 19, no. 3, pp. 275-292, 1999.

[5] A. Gunasekaran, C. Patel, and R. E. McGaughey, "A framework for supply chain performance measurement," *International Journal of Production Economics,* vol. 87, no. 3, pp. 333-347, 2004/02/18/ 2004.

[6] D. Natarajan, *ISO 9001 Quality Management Systems* (Management and Industrial Engineering). Cham: Springer International Publishing, Cham, 2017.

[7] P. M. P. Joseph Geunes, H. Edwin Romeijn, *Supply Chain Management: Models, Applications, and Research Directions* (Applied Optimization). Boston, MA: Springer US, Boston, MA, 2005.

[8] M. Szymczak, *Managing Towards Supply Chain Maturity : Business Process Outsourcing and Offshoring*, London: Palgrave Macmillan UK : Imprint: Palgrave Macmillan, 2013.

[9] R. A. Lancioni, M. F. Smith, and T. A. Oliva, "The Role of the Internet in Supply Chain Management," *Industrial Marketing Management,* vol. 29, no. 1, pp. 45-56, 2000.

[10] J.-P. Rodrigue and T. E. Notteboom, "Containerization, Box Logistics and Global Supply Chains: The Integration of Ports and Liner Shipping Networks," in *Port Management*, H. E. Haralambides, Ed. London: Palgrave Macmillan UK, 2015, pp. 5-28.

[11] J.-P. Rodrigue and T. Notteboom, "The geography of containerization: half a century of revolution, adaptation and diffusion," *GeoJournal,* vol. 74, no. 1, pp. 1-5, 2009.

[12] J. Groocock, "The impact of powerful and weak customers on quality assurance systems and quality improvement programs," *The TQM Magazine,* vol. 12, no. 6, pp. 372-388, 2000.
[13] D. Gupta and S. Benjaafar, "Make-to-order, make-to-stock, or delay product differentiation? A common framework for modeling and analysis," *IIE Transactions,* vol. 36, no. 6, pp. 529-546, 2004/06/01 2004.
[14] Y. Günalay, "Efficient management of production-inventory system in a multi-item manufacturing facility: MTS vs. MTO," *The International Journal of Advanced Manufacturing Technology,* journal article vol. 54, no. 9, pp. 1179-1186, June 01 2011.
[15] C. Chandra and J. Grabis, *Methodology for Supply Chain Configuration*. Boston, MA: Boston, MA: Springer US, 2007, pp. 101-128.
[16] G. Da Silveira, D. Borenstein, and F. S. Fogliatto, "Mass customization: Literature review and research directions," *International Journal of Production Economics,* vol. 72, no. 1, pp. 1-13, 2001.
[17] H. A. Elmaraghy, *Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2011), Montreal, Canada, 2-5 October 2011*, 2012 ed. Berlin, Heidelberg: Berlin, Heidelberg: Springer Berlin Heidelberg, 2012.
[18] V. G. Cannas, M. Pero, T. Rossi, and J. Gosling, "Integrate Customer Order Decoupling Point and Mass Customisation Concepts: A Literature Review," Cham, 2018: Springer International Publishing, pp. 495-517.
[19] J.-S. Song and P. Zipkin, "Supply Chain Operations: Assemble-to-Order Systems," *Handbooks in Operations Research and Management Science,* vol. 11, no. C, pp. 561-596, 2003.
[20] T. G. de Kok and J. C. Fransoo, "Planning Supply Chain Operations: Definition and Comparison of Planning Concepts," in *Handbooks in Operations Research and Management Science*, vol. 11: Elsevier, 2003, pp. 597-675.
[21] W. H. Liu, R. Z. Wu, Z. C. Liang, and D. L. Zhu, "Decision model for the customer order decoupling point considering order insertion scheduling with capacity and time constraints in logistics service supply chain," (in English), *Appl. Math. Model.,* Article vol. 54, pp. 112-135, Feb 2018.
[22] Y.-y. Li and B. Huang, "Product Quality Management in ATO Supply Chain Based on Quality Tracing," London, 2013: Springer London, pp. 535-542.
[23] Z. Atan, T. Ahmadi, C. Stegehuis, T. d. Kok, and I. Adan, "Assemble-to-order systems: A review," *European Journal of Operational Research,* vol. 261, no. 3, pp. 866-879, 2017.
[24] E. Benjaafar, "Production and Inventory Control of a Single Product Assemble-to-Order System with Multiple Customer Classes," *Management Science,* vol. 52, no. 12, pp. 1896-1912, 2006.
[25] S. Geier and B. Fleischmann, "Demand Fulfillment in an Assemble-to-Order Production System," Cham, 2014: Springer International Publishing, pp. 137-143.
[26] D. A. Garvin, "Product quality: An important strategic weapon," *Business Horizons,* vol. 27, no. 3, pp. 40-43, 1984/05/01/ 1984.
[27] C. J. Robinson and M. K. Malhotra, "Defining the concept of supply chain quality management and its relevance to academic and industrial practice," *International Journal of Production Economics,* vol. 96, no. 3, pp. 315-337, 2005/06/18/ 2005.
[28] S. Davrajh, G. Bright, and S. Davrajh, "Advanced quality management system for product families in mass customization and reconfigurable manufacturing," *Assembly Automation,* vol. 33, no. 2, pp. 127-138, 2013.
[29] D. Blanchard, *Supply Chain Management Best Practices : Best Practices*. New York: New York: John Wiley & Sons, Incorporated, 2010.
[30] R. Villanueva-Ponce, J. Romero-González, and G. Alor-Hernández, "Supplier Selection in a Manufacturing Environment," in *Lean Manufacturing in the Developing World: Methodology, Case Studies and Trends from Latin America*, J. L. García-Alcaraz, A. A. Maldonado-Macías, and G. Cortes-Robles, Eds. Cham: Springer International Publishing, 2014, pp. 233-252.

[31] V. Modrák, "On Aggregative Methods of Supplier Assessment," in *Advances in Industrial Engineering and Operations Research*, A. H. S. Chan and S.-I. Ao, Eds. Boston, MA: Springer US, 2008, pp. 111-125.
[32] K. Mukherjee, B. Sarkar, and A. Bhattacharjya, "Supplier's selection strategy for mass customization," in *2009 International Conference on Computers & Industrial Engineering*, 2009, pp. 892-895.
[33] J. R. T. Arnold, S. N. Chapman, and L. M. Clive, *Introduction to materials management*, 8th ed. ed. Harlow: Pearson, 2017.
[34] R. Paulo Cesar Chagas and O. Oliveira José de, "ENGINEERING-TO-ORDER VERSUS MAKE-TO-STOCK STRATEGY: AN ANALYSIS AT TWO PRINTING COMPANIES," *Independent Journal of Management & Production,* vol. 1, no. 1, pp. 1-23, 2010.
[35] D. Garvin, *What Does "Product Quality" Really Mean?* 1984, pp. 25-43.
[36] T. C. E. Cheng, C. Gao, and H. Shen, "Production planning and inventory allocation of a single-product assemble-to-order system with failure-prone machines," *International Journal of Production Economics,* vol. 131, no. 2, pp. 604-617, 2011/06/01/ 2011.
[37] M. Elhafsi, J. Fang, and H. Camus, "Optimal control of a continuous-time W-configuration assemble-to-order system," *European Journal of Operational Research,* vol. 267, no. 3, pp. 917-932, 2018.
[38] N. Sahebjamnia, F. Jolai, S. A. Torabi, and M. Aghabeiglo, "A novel fuzzy stochastic multi-objective linear programming for multi-level capacitated lot-sizing problem: a real case study of a furniture company," *The International Journal of Advanced Manufacturing Technology,* journal article vol. 84, no. 1, pp. 749-767, April 01 2016.
[39] I. Bettles, "Design for manufacture & assembly (DFMA)-the Boothroyd & Dewhurst approach," in *1992 Third International Conference on Factory 2000, 'Competitive Performance Through Advanced Technology'*, 1992, pp. 316-321.
[40] U. Dombrowski and C. Malorny, "Process Identification for Customer Service in the field of the After Sales Service as a Basis for "Lean After Sales Service"," *Procedia CIRP,* vol. 47, pp. 246-251, 2016/01/01/ 2016.
[41] M. M. Lele, "After-sales service - necessary evil or strategic opportunity?," vol. 7, no. 3, pp. 141-145, 1997.
[42] I. Heras-Saizarbitoria and O. Boiral, "ISO 9001 and ISO 14001: Towards a Research Agenda on Management System Standards*," *International Journal of Management Reviews,* vol. 15, no. 1, pp. 47-65, 2013.
[43] S. Sumaedi and T. Rakhmawati, "The effect of system design type on ISO 9001 implementation outcome: a proposed conceptual framework and future research agenda," *International Journal of System Assurance Engineering and Management,* journal article vol. 8, no. 1, pp. 219-229, January 01 2017.
[44] M. Micklewright, *Lean ISO 9001: Adding Spark to your ISO 9001 QMS and Sustainability to your Lean Efforts*. United States: Asq - American Society For Quality, 2010.
[45] *ISO 9001:2015*, 2015.
[46] Organisation Internationale de Normalisation (ISO). (2015). *Quality managemant principles* [Online]. Available: https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/pub100080.pdf.
[47] H. T. Ingason, "Best Project Management Practices in the Implementation of an ISO 9001 Quality Management System," *Procedia - Social and Behavioral Sciences,* vol. 194, pp. 192-200, 2015/07/02/ 2015.
[48] P. Levi, "Quality assurance and machine vision for inspection," Berlin, Heidelberg, 1984: Springer Berlin Heidelberg, pp. 329-377.
[49] (1996). *Analytic Quality Assurance*. [Online] Available: https://www.who.int/water_sanitation_health/resourcesquality/wqmchap9.pdf
[50] C. Coleman, *Quality Assurance: Analysis, Methods and Outcomes*. Hauppauge: Hauppauge: Nova Science Publishers, Incorporated, 2016.

[51] R. Schmitt, "Quality Assurance," in *CIRP Encyclopedia of Production Engineering*, L. Laperrière and G. Reinhart, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 1021-1024.
[52] (2015). *Standards and Guidlines for Quality Assurance in the European Higher Education Area (ESA). (2015) Brussels, Belgium*. [Online] Available: https://enqa.eu/wp-content/uploads/2015/11/ESG_2015.pdf
[53] Y. Miao and S. Lin, "Enhancing the application of quality engineering technique to improve quality assurance ability," in *2009 8th International Conference on Reliability, Maintainability and Safety*, 2009, pp. 1348-1351.
[54] S. T. Foster, C. Wallin, and J. Ogden, "Towards a better understanding of supply chain quality management practices," *International Journal of Production Research,* vol. 49, no. 8, pp. 2285-2300, 2011/04/15 2011.
[55] H. ElMaraghy *et al.*, "Product variety management," *CIRP Annals,* vol. 62, no. 2, pp. 629-652, 2013/01/01/ 2013.
[56] J. Jiao, T. W. Simpson, and Z. Siddique, "Product family design and platform-based product development: a state-of-the-art review," *Journal of Intelligent Manufacturing,* journal article vol. 18, no. 1, pp. 5-29, February 01 2007.
[57] Z. Wang and F. Ning, "Study on Supply Chain Management for Product Family in Mass Customization," in *2007 IEEE International Conference on Automation and Logistics*, 2007, pp. 1515-1519.
[58] W. Chen, C. Hoyle, and H. J. Wassenaar, "A Decision-Based Design Approach to Product Family Design," in *Decision-Based Design: Integrating Consumer Preferences into Engineering Design*. London: Springer London, 2013, pp. 287-317.
[59] F. Salvador, C. Forza, and M. Rungtusanatham, "Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions," *Journal of Operations Management,* vol. 20, no. 5, pp. 549-575, 2002/09/01/ 2002.
[60] A. Shamsuzzoha, S. Piya, M. Al-Kindi, and N. Al-Hinai, "Metrics of product modularity: lessons learned from case companies," *Journal of Modelling in Management,* vol. 13, no. 2, pp. 331-350, 2018.
[61] G. H. M. Charles Huber, "QFD and design for six sigma."
[62] L. C. Joseph P. Ficalora, "QUALITY FUNCTION DEPLOYMENT AND SIX SIGMA: A QFD HANDBOOK, 2ND EDITION," *Chemical Engineering Progress,* vol. 106, no. 11, p. 32, 2010.
[63] D. J. Gerhardt, W. R. Hutchinson, and D. K. Mistry, "Design for manufacture and assembly: Case studies in its implementation," *The International Journal of Advanced Manufacturing Technology,* journal article vol. 6, no. 2, pp. 131-140, May 01 1991.
[64] E. N. Tan, G. Smith, and M. Saad, "Managing the global supply chain:a SME perspective," *Production Planning & Control,* vol. 17, no. 3, pp. 238-246, 2006/04/01 2006.
[65] M. Cao and Q. Zhang, "Supply chain collaboration: Impact on collaborative advantage and firm performance," *Journal of Operations Management,* vol. 29, no. 3, pp. 163-180, 2011/03/01/ 2011.
[66] M. Barratt, "Understanding the meaning of collaboration in the supply chain," *Supply Chain Management: An International Journal,* vol. 9, no. 1, pp. 30-42, 2004.
[67] C. A. Soosay, P. W. Hyland, and M. Ferrer, "Supply chain collaboration: capabilities for continuous innovation," *Supply Chain Management: An International Journal,* vol. 13, no. 2, pp. 160-169, 2008.
[68] M. Pasche and M. Sköld, "Potential drawbacks of component commonality in product platform development," *International Journal of Automotive Technology and Management,* vol. 12, no. 1, pp. 92-108, 2012.
[69] K. Kim and D. Chhajed, "Commonality in product design: Cost saving, valuation change and cannibalization," *European Journal of Operational Research,* vol. 125, no. 3, pp. 602-621, 2000/09/16/ 2000.
[70] G. J. Stigler, "The Economies of Scale," vol. 1, pp. 54-71, 1958.
[71] R. Hariharan and P. Zipkin, "Customer-Order Information, Leadtimes, and Inventories," vol. 41, no. 10, pp. 1599-1607, 1995.

[72] G. Reinhart and R. Cuiper, "Assembly Process and Assembly Control Development – A Holistic and Consistent Approach," *CIRP Annals,* vol. 48, no. 1, pp. 25-28, 1999/01/01/ 1999.
[73] S. Li, Y. Liu, J. Wang, and H. Zeng, "An intelligent interactive approach for assembly process planning based on hierarchical classification of parts," *The International Journal of Advanced Manufacturing Technology,* journal article vol. 70, no. 9, pp. 1903-1914, February 01 2014.
[74] N. Boysen, M. Fliedner, and A. Scholl, "Sequencing mixed-model assembly lines: Survey, classification and model critique," *European Journal of Operational Research,* vol. 192, no. 2, pp. 349-373, 2009/01/16/ 2009.
[75] N. Boysen, M. Fliedner, and A. Scholl, "Assembly line balancing: Which model to use when?," *International Journal of Production Economics,* vol. 111, no. 2, pp. 509-528, 2008/02/01/ 2008.
[76] A. B. Rane, D. S. S. Sudhakar, V. k. Sunnapwar, and S. Rane, "Improving the performance of assembly line: Review with case study," in *2015 International Conference on Nascent Technologies in the Engineering Field (ICNTE)*, 2015, pp. 1-14.
[77] U. Saif, Z. Guan, M. Jahanzaib, and B. Wang, *Survey of Assembly Lines and its Types*. 2014.
[78] J. Li and J. Gao, "Balancing manual mixed-model assembly lines using overtime work in a demand variation environment," *International Journal of Production Research,* vol. 52, no. 12, pp. 3552-3567, 2014/06/18 2014.
[79] B. Rundh, "Packaging design: creating competitive advantage with product packaging," vol. 111, no. 9, pp. 988-1002, 2009.
[80] H. Kurata and S.-H. Nam, "After-sales service competition in a supply chain: Optimization of customer satisfaction level or profit or both?," *International Journal of Production Economics,* vol. 127, no. 1, pp. 136-146, 2010/09/01/ 2010.
[81] A. Parasuraman, L. L. Berry, and V. A. J. S. m. r. Zeithaml, "Understanding customer expectations of service," vol. 32, no. 3, pp. 39-48, 1991.
[82] J. L. García-Alcaraz, G. Alor-Hernández, A. A. Maldonado-Macías, and C. Sanchez-Ramirez, *New Perspectives on Applied Industrial Tools and Techniques*, Cham: Springer International Publishing : Imprint: Springer, 2018.
[83] S. M.-C. J. T. σ.-. Yeung, "Using Six Sigma-SIPOC for customer satisfaction," p. 351, 2008.
[84] G. Mazur, "Quality Function Deployment: Voice of Customer Meets Voice of Process," *The Journal for Quality and Participation,* vol. 37, no. 4, pp. 24-29, 2015.
[85] C. K. Kwong and H. Bai, "A fuzzy AHP approach to the determination of importance weights of customer requirements in quality function deployment," *Journal of Intelligent Manufacturing,* journal article vol. 13, no. 5, pp. 367-377, October 01 2002.
[86] L.-K. Chan and M.-L. Wu, "Quality function deployment: A literature review," *European Journal of Operational Research,* vol. 143, no. 3, pp. 463-497, 2002/12/16/ 2002.
[87] L.-K. Chan and M.-L. Wu, "Quality Function Deployment: A Comprehensive Review of Its Concepts and Methods," *Quality Engineering,* vol. 15, no. 1, pp. 23-35, 2002/09/24 2002.
[88] Y. Wu, B. Luo, and M. Li, "Application of Quality Function Deployment for Environment in product eco-design," in *2009 IEEE International Symposium on Assembly and Manufacturing*, 2009, pp. 254-257.
[89] K. Matzler and H. H. Hinterhuber, "How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment," *Technovation,* vol. 18, no. 1, pp. 25-38, 1998/01/01/ 1998.
[90] E. Sauerwein, F. Bailom, K. Matzler, and H. H. Hinterhuber, "The Kano model: How to delight your customers," in *International Working Seminar on Production Economics*, 1996, vol. 1, no. 4, pp. 313-327.
[91] K. C. Tan and X. X. Shen, "Integrating Kano's model in the planning matrix of quality function deployment," *Total Quality Management,* vol. 11, no. 8, pp. 1141-1151, 2000/12/01 2000.
[92] (2018). *QFD (Quality function deployment): Illustration with practical example* [Online]. Available: https://www.youtube.com/watch?v=X1KONQw02H8.

[93] G. Held, *Introduction to light emitting diode technology and applications*, Boca Raton: CRC Press, 2009.
[94] M. Schratz, C. Gupta, T. J. Struhs, and K. Gray, "A New Way to See the Light: Improving Light Quality with Cost-Effective LED Technology," *IEEE Industry Applications Magazine,* vol. 22, no. 4, pp. 55-62, 2016.
[95] Y. K. Cheng and K. W. E. Cheng, "General Study for using LED to replace traditional lighting devices," in *2006 2nd International Conference on Power Electronics Systems and Applications*, 2006, pp. 173-177.
[96] L. Yu and J. Yang, "The topologies of white LED lamps' power drivers," in *2009 3rd International Conference on Power Electronics Systems and Applications (PESA)*, 2009, pp. 1-6.
[97] Farnell. (2019). *ASMT-CW20 - LED, White, SMD, 5 mA, 3 V, 180 mcd Datasheet* [Online]. Available: http://www.farnell.com/datasheets/1648321.pdf?_ga=2.131862089.734542606.1557740478-2083988542.1557740478.
[98] G. Jiang, L. Diao, and K. Kuang, *Advanced thermal management materials*, New York: Springer, 2013.
[99] W. M. Lee, A. Upadhya, P. J. Reece, and T. G. Phan, "Fabricating low cost and high performance elastomer lenses using hanging droplets," *Biomed. Opt. Express,* vol. 5, no. 5, pp. 1626-1635, 2014/05/01 2014.
[100] Hoffman. (2010). *How to select the ideal enclosure gasket* [Online]. Available: https://www.automation.com/pdf_articles/IdealEnclosureGasket.pdf.
[101] D. Jenkins and A. Bhargava, "LED Lighting: Maximizing the Reliability, Safety, and Efficiency of Light Fixtures in Hazardous Environments," *IEEE Industry Applications Magazine,* vol. 21, no. 1, pp. 64-67, 2015.
[102] C. Battles. (2011). *House of Quality Template* [Online]. Available: www.uw-s.com/wp-content/uploads/2014/.../Full_HOQ_0.9.xlsx.