Master Thesis

Agility in Production Networks

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Graz, 2015

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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Abstract

As market volatility and uncertainty is constantly rising, companies are more and more forced to prepare their business to this increasingly changing environment. The fact that predicting up- and downturns of the market and other external influences is sometimes equal to the tossing of a coin, furthermore, hampers this in any case challenging endeavour. Through this limited possibility of forecasting, the primary goal of today's companies is to ensure the ability to react quickly and appropriately at any time to these unexpected changes. The capability to proactively prepare on the one hand and the ability to react quickly on changes and thereby optimize the economic situation of the company on the other hand is seen as the agility of a company. After the conduction of excessive literature research in order to clarify the terms and present the current state of science, the agility of the production network of the Liebherr Maritime Cargo Construction Technology (MCCtec) division, is analysed in a three steps approach. First, in order to ensure transparency across the division, information about the production equipment at each production site is gathered and as a result minor inconsistencies are found. Furthermore, the current developments in production technologies are stated and finally the production capabilities at each individual site are analysed, as well as the found limitations outlined. By looking at production fluctuations of the past, the ability of managing these volatilities is analysed and as a result the best operational agility levers are presented in order to overcome these situations. In a final step a comprehensive agility analysis of the whole division including operational, strategical and organisational aspects, is conducted. Out of the results improvement potentials are outlined and ways to increase the agility level of the division are portrayed. With the provided knowledge about the current agility level and the weak points to overcome, the MCCtec division of Liebherr is capable of proactively prepare to these challenging environment and step by step improve the agility level of its production network.

Kurzfassung

Aufgrund steigender Volatilität und Unsicherheit am Markt sind Unternehmen heutzutage gefordert, sich auf diese sich rasch ändernden Bedingungen gut vorzubereiten. Die Schwierigkeit einer Vorhersage dieser Schwankungen am Markt und anderer externer Einflüsse stellt dabei eine zusätzliche Herausforderung dar. Aufgrund der nur eingeschränkt möglichen Prognose besteht das oberste Ziel darin, in der Lage zu sein, jederzeit schnell und angemessen auf diese unvorhersehbaren Entwicklungen reagieren zu können. Diese Fähigkeit der schnellen Reaktion und die aktive Vorbereitung auf diese Veränderungen, verbunden mit dem ständigen Ziel der Optimierung der wirtschaftlichen Situation des Unternehmens, wird unter dem Begriff der Agilität eines Unternehmens subsumiert. Im Zuge dieser Arbeit wird das Produktionsnetzwerk der Maritime Cargo Construction Technology Division (MCCtec) des Unternehmens Liebherr auf dessen Agilität untersucht. Dabei wird im theoretischen Teil mit Hilfe einer Literaturrecherche der aktuelle Stand der Forschung bezüglich Agilität dargelegt. Um in weiterer Folge die Agilität des Produktionsnetzwerkes der MCCtec-Division fundiert beschreiben zu können, werden in einem ersten Schritt die Begebenheiten an den einzelnen Standorten des Netzwerkes untersucht. Durch die Beschreibung der vorhandenen Produktionsmöglichkeiten und aktueller Entwicklungen in der Produktion wird hierbei die Transparenz des Netzwerkes erhöht. Über die Betrachtung historischer Produktionsdaten werden in weiterer Folge die vorhandenen Fähigkeiten des Netzwerkes, auf diverse Schwankungen zu reagieren, analysiert. Als Ergebnis dieser Untersuchung werden die besten Agilitäts-Hebel im Bereich Operations präsentiert. Abschließend wird über die Beschreibung der Agilität im Bereich Operations, Organisation und Strategie das aktuelle Agilitäts-Niveau des Produktionsnetzwerkes bestimmt. Basierend auf diesen Ergebnissen werden Handlungsempfehlungen mit dem Ziel einer weiteren Agilitätssteigerung aufgezeigt. Die Beschreibung der aktuellen Agilität sowie der Verbesserungspotentiale soll der MCCtec-Division von Liebherr ermöglichen, ihr Produktionsnetzwerk bestmöglich auf zukünftige Volatilitäten vorzubereiten und dabei das vorhandene Agilitäts-Niveau Schritt für Schritt zu erhöhen.

Acknowledgement

First of all I want to acknowledge the company Liebherr for providing me the opportunity to write my Master thesis in cooperation with them. I am very thankful to all the employees and management at the Liebherr sites in Nenzing, Rostock, Killarney and Sunderland who supported me with their valuable input. In particular I want to thank Mr Thomas Pröckl for his support during the whole project.

Furthermore, I want to thank Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer and the Production Science and Management Institute at Graz University of Technology for providing the basis and support for this research. I especially want to express my gratitude to Dipl.-Ing. Alexander Pointner, BSc for his guidance and valuable recommendations.

Lastly, I also want to thank all my friends who accompanied me through this challenging but interesting period of my life and my family for being the strongest backing one can have.

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1 Introduction

In recent years increasing competition and tough market conditions have been forcing more and more companies towards improving the efficiency of their production.[1] Lately lean tools and techniques have been seen as the perfect solution because they imply lower costs, higher quality, and major improvements in customer service. The consequent implementation of these lean practices, however, is a tricky, long lasting procedure and companies are often struggling to achieve the benefits they expected.[2] To make things even worse, lean production can nowadays no longer be seen as the one solution to solve all the upcoming problems in today's production. In fact, a blindfolded implementation of lean in every business environment is problematic as focussing too much on operational excellence can lead to rigid structures, tailored only for one viable operating point. As nowadays volatility and uncertainty of the markets are increasing, deviations from this operating point are becoming more and more daily routine.[3] The understanding of these up- and downturns, however, is complicated and predicting them is sometimes equal to the tossing of a coin.[4]

In addition to this fast changing markets, production planning itself is getting increasingly complex due to the fact that infrastructures of big organisations are seldom limited to one location. Big organisations operate in huge production networks across national borders. These extended capacities offer great opportunities and chances to cope with the volatile environment but at the same time new challenges derive.[5,6] All these facts together trigger more and more organisations to rethink their production principles. The idea is to look for the right balance between the implementation of lean practices and still ensure a certain degree of manoeuvrability in order to handle these emerging uncertain conditions. Thereby the concept of agile manufacturing can be seen as the key to success as it tackles exactly this problem.

[1] cf: Abele et al. (2011), p.1,19

[2] cf: Frost et al. (2011), p.1

[3] cf: Schurig et al. (2014), p.957

[4] cf: Naylor et al. (1999), p.108

[5] cf: Schurig et al. (2015), p.114

[6] cf: Monauni (2014), p.657

After the introduction of agile manufacturing in 1991, by the Iacocca Institute, it has been further developed over the years by many researchers. As a result of this ongoing progress the definitions have been changed from solely considering the production level towards a more comprehensive view. According to recent research today's primary need is to ensure the ability to react quickly and appropriate on unexpected changes at any time. This includes profiting from upswing as well as preventing losses in case of downturns. This capability of proactive preparation on the one hand and the ability to react quickly on changes and thereby optimize the economic situation of the company by leveraging the value chain on the other hand, is seen as the agility of a company.[7]

1.1 Initial Situation

Similar to many other organisations the Maritime Cargo Construction Technology (MCCtec) division of the Liebherr Group today is facing exactly the problems and its connected challenges mentioned above. In order to upkeep their successful business in today's changing environment, the organisation is striving for a more agile layout of its production network which consists of four sites in four different countries. In order to increase the level of agility, an evaluation of the current status and the circumstances is indispensable. In doing so weak points and improvement potentials become visible and the necessary actions can be defined more easily.[8] However, an analysis of the complete production network including all the suppliers which are involved in the production of the MCCtec products would exceed the scope of this research. Therefore, the focus is put on the four main production sites of the network. In order to hamper ambiguity from the start it is necessary to state that from now on the compound of the four companies is concerned when talking about the MCCtec division's production network. Any external suppliers will be mentioned separately.

1.2 Problem Definition

The market of maritime cranes was prospering for a long time. Therefore, the division expanded its capacities and opened up its youngest production site

[7] cf: Schurig et al. (2014), p.957

[8] cf: Schurig et al. (2015), p.114

in 2002 in order to handle the increasing demand and to benefit from the untouched potential of the market. Back then the division was constantly growing and sales were stable on a high level. In 2009 the economic crisis was affecting the division. Sales dropped and in 2010 production was without exception throttled in every production site across the whole network. However, this extraordinary decrease of production was followed by a strong increase in the year 2011. It seemed that the division was back on track. This collective trend, however, should not obscure the fact that the individual sites are still struggling with fluctuating demand.[9]

In addition to this market volatility there are other incidents challenging the individual sites lately. For example, the strategically motivated shift of whole product groups from one site to another or the occurrence of big orders are forcing the sites to improve their ability to manage change and extraordinary events in the future.[10,11]

1.3 Objectives

In a few words the goal of this thesis is to provide the reader with an overview of the current state of science in the field of agility in production and, furthermore, delineate a way of how to analyse and increase the extent of agility in a production network like the MCCtec division.

Literature research should clarify the origin of the term agility and show its development over the years. Furthermore, the presentation of clear definitions should hamper ambiguity from the start. The main goal of this part is the definition of the range of the topic and the preparation of information in order to trouble-free understand the content of this research.

The practical part of the thesis is about the agility analysis of the production network of the Liebherr MCCtec division. Focus is placed on the operational dimension of agility as a detailed analysis of all dimensions would exceed the scope of this research. However, organisational and strategic aspects are considered as well. In order to lay the foundations for a closer inspection and in-depth analysis of the network's agility level, first of all the production capabilities of the sites need to be analysed individually. Thereby increased transparency across the network is strived for. Next, based on

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[9] cf: company-internal source: Pröckl (2015), EK-Stundenentwicklung

[10] cf: Liebherr annual report (2014), p.25

[11] cf: www.liebherr.com [30-09-2015]

historical data, the best operational levers to manage fluctuations in production are looked for. The concluding part of this research includes the description of the current agility level of the network. Therefore, several circumstances the division has to deal with are described in order to identify the main factors which define the current agility level. Additionally a quantitative agility evaluation, including a comparison to the automotive supplier industry, should illustrate the derived agility level. As a result and final step, potentials and ways to increase the agility for the future, are outlined. The following research questions represent the main objectives of this thesis:

- What is the current state of science in agility in production and which enablers are most suitable to enhance the agility of a production network like the one of the maritime division of Liebherr?
- Which operational agility levers are most suitable to handle massive up- and downturns in production hours?
- Which main factors are influencing the agility of a production network and what are ways to increase the agility level in the future?

1.4 Approach

In the following section the approach of this thesis as well as the arrangement of the chapters and their content is explained.

An introduction to the thesis is provided in chapter 1. First the initial situation at the Liebherr MCCtec division is explained briefly. It is followed by the problem definition, the objectives of the thesis and its approach.

In chapter 2 the Liebherr Group is introduced and its maritime cranes division, the MCCtec is described in detail. Furthermore, current issues, which are challenging the division lately, are outlined.

In chapter 3 the results from the conducted literature research regarding agility in production are provided. They include definitions in order to clarify the terms and hamper ambiguity from the start. Furthermore, the current state of research in this field is discussed. As there are countless approaches this thesis follows mainly the agility understanding of Graz University of Technology. In addition within this chapter, the reader gets all the background information which is necessary to trouble-free understand the further content of the practical study.

In chapter 4 the empirical part of this thesis is presented. It can be subdivided into three parts. While the first one is about the analysis of the individual production sites of the MCCtec division concerning their equipment, current developments and production capabilities, the second one deals with production fluctuations at the individual sites and the ability of them and the whole network to handle those by the application of agility levers. Thereby several levers are described in detail. In the concluding part the overall agility evaluation of the production network is concerned. The current agility level of the network across several categories is described and the subsequently conducted quantitative evaluation is explained.

In chapter 5 the results of the thesis are presented in a compact form. First of all the most suitable agility enablers to an organisation like the MCCtec division of Liebherr are described. Subsequently the findings of the analysis of the individual production sites and the agility lever study are presented. In the end of the chapter the current agility level of the MCCtec division is determined and recommendations in order to increase this level are given.

In chapter 6 a brief summary of the whole research concludes the thesis. Additionally an outlook is provided.

2 About the company

In order to link the subsequent literature research to the actual situation at the company Liebherr, the necessary background information is provided beforehand. More precisely the four companies which form the production network of the Maritime Cargo Construction Technology division, in short MCCtec, of the Liebherr Group is described in detail. After a short introduction of the whole group, the MCCtec and its four production sites are introduced.

2.1 About the Liebherr Group

History:

The company Liebherr was founded in 1949 by Mr. Hans Liebherr. With the invention of the first mobile tower crane he turned the small construction firm of his parents into a construction machinery manufacturer (see Figure 1). As it was the time after the Second World War in Germany, there was a rising demand for tools and machinery to rebuild industry and other destroyed facilities. Among others this fact ensured the fast growth of the company in the first years. Besides, Mr. Liebherr soon recognised a rising demand in other sectors and expanded his business into fields like domestic appliances and aerospace technologies.[12]

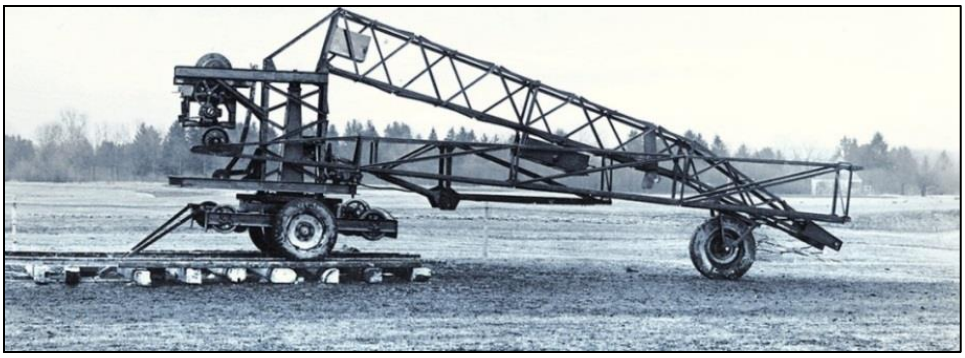

Figure 1: First Liebherr tower crane TK 3.6 in 1949 [13]

[12] cf: www.liebherr.com [28-07-2015]a

[13] www.liebherr.com [28-07-2015]a

Over the years the company Liebherr had been growing steadily and soon started to expand into new countries all over the world. Today the Liebherr Group consists of more than 130 companies worldwide and employs around 41.000 people. The annual turnover is currently around 9 billion euro.[14]

Company structure:

The organisation of the Liebherr Group is decentralised. From Bulle, in French-speaking part of Switzerland, the central holding company Liebherr-International AG is directing, coordinating and monitoring the eleven autonomously operating product divisions. The board of shareholders consists exclusively of Liebherr family members. They are responsible and empowered to decide on all fundamental matters concerning the company. Recently the independent family-run business fulfilled the alternation of 2nd to 3rd generation and will, therefore, also in the near future be solely led by the Liebherr family.[15]

Philosophy of Liebherr:

As already mentioned the Liebherr Group is entirely family-owned. This independence ensures that decisions can be taken rapidly and without too much influence from outside. The Liebherr Group fosters long-time relationships with their business partners built on consistency and trust. Furthermore, the commitment to production locations and the people working there should be mentioned in this respect. So far not a single production site of Liebherr was shut down again. One example for social engagement and commitment to a region is the “Liebherr-Akademie” in Rostock where people who are either unemployed or looking for re-education get trained. This helps on the one hand the company because future staff can be equipped with exactly the skills needed at Liebherr. On the other hand it ensures employment in the region and enables prosperity for the people living there. In conclusion it can be said that the Liebherr Group is investing a lot in its employees and sites all around the world.[16,17]

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[14] cf: www.liebherr.com [30-07-2015]c

[15] cf: www.liebherr.com [28-07-2015]b

[16] cf: www.liebherr.com [29-07-2015]a

[17] cf: www.liebherr.com [29-07-2015]b

Product mix:

Nowadays besides construction machinery there are several other products produced by the Liebherr Group. In total it can be distinguished between eleven divisions with products ranging from crawler cranes which can lift up to 3.000 tons to refrigeration and freezing equipment for domestic use (see Table 1). Due to this product diversification the risk of volatile markets and unstable economic conditions is wide spread and the fluctuations are smoothed.[18,19]

Divisions of the Liebherr Group
Earthmoving
Mining
Mobile cranes
Tower cranes
Concrete technology
Maritime cranes
Aerospace and transportation systems
Machine tools and automation systems
Domestic appliances
Components
Hotels

Table 1: Divisions of the Liebherr Group [20]

2.2 About the MCCtec division

One of these just mentioned eleven divisions is the MCCtec GmbH. It consists of four production sites which are located in four different countries. The locations are Nenzing/Austria, Rostock/Germany, Sunderland/United Kingdom and Killarney/Ireland. The headquarters of the division is located in Nenzing.[21]

[18] cf: www.liebherr.com [04-08-2015]

[19] cf: www.liebherr.com [30-07-2015]b

[20] www.liebherr.com [04-08-2015]

[21] cf: www.liebherr.com [30-10-2015]a

2.2.1 Members of the division

In the following paragraphs the individual production sites of the MCCtec division are introduced and described briefly. In addition the abbreviations of the sites, used in the following chapters of this research, are explained.

Liebherr-Werk Nenzing GmbH (Austria):
The Liebherr-Werk Nenzing GmbH (LWN) was founded back in 1976. In the beginning ship cranes, offshore cranes and duty cycle crawler cranes were produced. Today there are around 1540 people in the fields of design, research and development, production, sales and after sales service working at the plant. The total area of the production site adds up to around 254.000m² of which 98.000m² are built-up area. To get a feeling about the size of the site a photo is provided in Figure 2.[22]

Figure 2: Production site Liebherr-Werk Nenzing GmbH [23]

Currently there is a shift of product groups between the recently founded production site in Rostock and the site in Nenzing going on. Although Liebherr in Nenzing has been producing ship cranes, offshore cranes since 1977 and mobile harbour cranes since 1986, in the future, the production of these product groups will be managed in Rostock. The reasons for this shift and its challenges will be analysed in detail in 2.2.3. In the future the focus in Nenzing will be placed on the further development and production of continental product groups like duty cycle crawler cranes, crawler cranes and piling and drilling rigs. Crawler cranes and piling and drilling rigs have been

[22] cf: www.liebherr.com [29-07-2015] c

[23] www.liebherr.com [29-07-2015]c

produced in Nenzing since around the last turn of the century (detailed information on the products is given in section 2.2.2).[24,25]

Liebherr-MCCtec Rostock GmbH (Germany):

Founded in 2002 the Liebherr-MCCtec Rostock GmbH (MCR) is the newest site of the MCCtec division. It is located in Rostock in northern Germany. The direct access to the Baltic Sea is a big advantage compared to the other sites. In the last years the plant has been rapidly growing and today around 1360 people are working there. In Rostock mainly ship cranes, offshore cranes and mobile harbour cranes are built. With a total area of more than 437.000m² and a built-up area of 136.000m² the site is by far the largest of the network. The latest enlargement of the site through simply banking up solid ground towards the sea is shown on Figure 3.[26]

Furthermore, worth mentioning is that MCR has a branch located in Lubmin which is located approximately 100km east from Rostock. The branch offers additional space and production capabilities.[27]

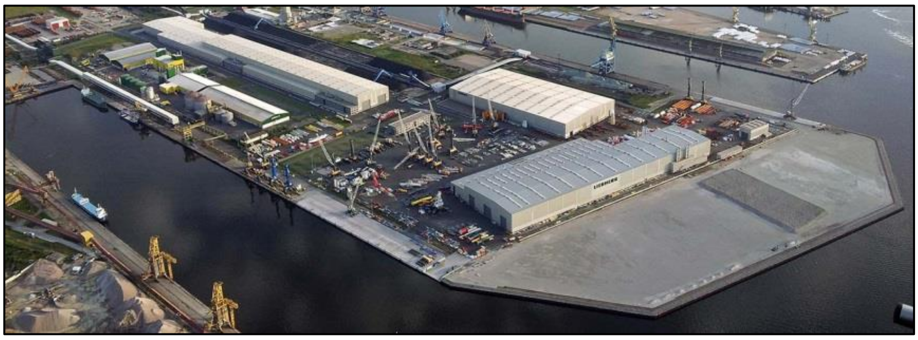

Figure 3: Production site Liebherr-MCCtec Rostock GmbH [28]

Liebherr Sunderland Works Ltd. (U.K.):

With a total size of 70.500m² the Liebherr Sunderland Works Ltd. (LSW) is the smallest site of the MCCtec division. It was founded in 1989 and nowadays around 190 people are working there. Besides the primarily produced products like ship-, offshore and special cranes, recently the

[24] cf: Liebherr annual report (2014), p.25

[25] cf: company-internal source: Fact-sheet: Liebherr-MCCtec GmbH (2014), p.2

[26] cf: www.liebherr.com [30-07-2015]a

[27] cf: company-internal source: Werksführer MCR (2014), p.11

[28] www.liebherr.com [30-07-2015]a

construction of the new Reachstacker, an application for container handling, has been arranged.[29]

As space is limited the acquisition of the neighbour area can be seen as a future chance for the site to further expand. Another issue is the sanding up of the River Wear next to the site (see Figure 4) which makes water transportation to the mouth of it more and more difficult. These two issues will be discussed among others in 4.4.

Figure 4: Liebherr Sunderland Works Ltd. [30]

Liebherr Container Cranes Ltd. (Ireland):

The Liebherr Container Cranes Ltd. (LCC) in Killarney was established in 1958. It was the first production site of Liebherr located outside of Germany. Besides, it was one of the first establishments of a European industrial company in Ireland. Because of its long history as a reliable employer and the ongoing commitment to the region, Liebherr is highly regarded among the people living in the area around Killarney.[31]

Today the workforce of around 770 people is producing port equipment like ship-to-shore container cranes, rubber-tyred or rail-mounted stacker cranes for container handling. Once the cranes are built and checked at the plant their components are transported via trucks to the port of Fenit which is approximately 40km away. From there they are shipped into ports all over the world. With a size of around 190.000m² the production site is the

[29] cf: company-internal source: Fact-sheet: Liebherr-MCCtec GmbH (2014), p.2

[30] www.thenorthernecho.co.uk [30-07-2015]

[31] cf: www.liebherr.com [03-08-2015]

third largest in the division of MCCtec. Regarding space, further expansion of the site is possible. For example the production hall on the left side of Figure 5 was built recently.[32]

Figure 5: Liebherr Container Cranes Ltd. Killarney [33]

Unless stated otherwise, the abbreviations of the individual production sites will be used throughout the following thesis.

2.2.2 Product portfolio of the division

Due to the fact that a detailed description of all MCCtec products would exceed the scope of this thesis, only a compact overview will be presented. Product groups which are analysed in detail in the course of the agility study will be introduced in detail in the associated chapters. In general there are two big groups which can be distinguished. On the one hand there is the maritime sector which includes for example port equipment, ship cranes and offshore cranes. On the other hand there is the continental sector, containing all different kinds of construction machines.[34]

While sales of ship-, and offshore-cranes are facing troubles in the last years, the cargo handling sector, including mobile harbour cranes, gantry cranes or ship-to-shore cranes, has been rapidly growing. In the product group of mobile harbour cranes Liebherr is already world leader with more

[32] cf: company-internal source: Fact-sheet: Liebherr-MCCtec GmbH (2014), p.2

[33] cf: company-internal source: Liebherr MCCtec presentation (2014), slide 21

[34] cf: company-internal source: Fact-sheet: Liebherr-MCCtec GmbH (2014), p.2

than 70% market share.[35,36] The following table shows maritime and continental sectors with their corresponding product groups:

Maritime Products	Continental Products
Ship cranes	Crawler cranes
Offshore cranes	Duty cycle crawler cranes
Mobile harbour cranes	Piling and drilling rigs
Reachstackers	
Rail-mounted ship-to-shore container cranes	
Rail-mounted container stacking cranes	
Rubber tyre gantry cranes	
Straddle carriers	

Table 2: Product groups of the MCCtec GmbH [37]

For examples to each product group see Table 25 in the appendix of this thesis.

2.2.3 Shift of product groups

One of the biggest challenges of the MCCtec division in recent years was for sure the strategic reorientation of the production sites in Rostock (MCR) and Nenzing (LWN). Since its start of production in 2005 MCR has been growing at rapid pace. With the exception of 2010 where the whole division struggled due to decreasing market demands and a small knit in 2013's statistics, the production hours at MCR have been constantly rising. The favoured location of the production site with its direct access to the Baltic Sea and its large halls which offer plenty of space, are the major benefits of MCR. Rising demands combined with a tendency towards bigger machines triggered the management of the group towards a reorientation of the two sites. In the past the size of the produced cranes was especially crucial as special transports

[35] cf: Liebherr annual report (2014), p.86-87

[36] cf: Liebherr annual report (2014), p.23

[37] company-internal source: Fact-sheet: Liebherr-MCCtec GmbH (2014), p.2

from Nenzing towards the coast in northern Germany were everyday business. A detailed analysis of the transport problem is provided in 4.4.

While in the past LWN was responsible for the production of mobile harbour cranes, offshore cranes and ship cranes, nowadays this responsibility lies at MCR. The focus at LWN in the future will be the production of construction machinery like duty cycle crawler cranes or foundation equipment. This change is not only challenging the individual sites, it is also a challenge to the whole group. The most important and crucial part is the know-how transfer between the responsible employees. Currently at LWN 114 employees from MCR are getting trained in order to be able to carry out their new jobs in Rostock. Additionally affected from the shift is the site in Sunderland. In the past LWN was responsible for the planning of the production at LSW. Due to the fact that in Sunderland solely maritime cranes are produced, in the future the site in Rostock will be responsible for the planning of the production there.[38]

As mentioned before the major task of the site in Nenzing for the future will be the further development of the construction machinery sector. This switch from project oriented orders like it is common in the offshore business towards a more series manufacturing oriented production of construction machinery will be challenging and indicates a major change to LWN's production.

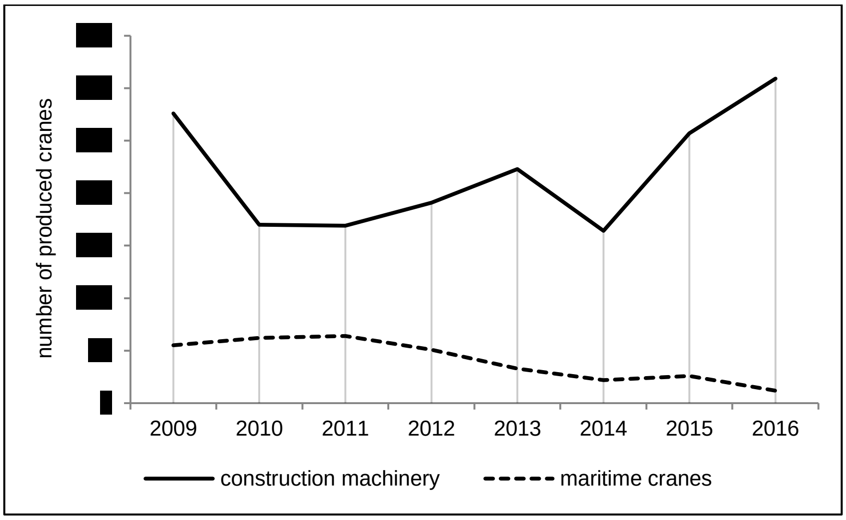

Figure 6: Composition of production at LWN since 2009 [39]

[38] based on e-mail communication with A. Nigsch, human resources LWN [07-10-2015]

[39] company-internal source: Production figures, Liebherr Nenzing Intranet [19-10-2015]

Figure 6 shows the development of the production composition at LWN in the last years. Thereby at the maritime sector a certain decline is evident. Furthermore, an increasing production of construction machinery can be recognized.

2.2.4 Market shares

Related to this shift of product groups and the reorientation of the site in Nenzing is the dependence on market opportunities in the continental machinery sector. Although a detailed analysis of the market shares would exceed the scope of this thesis, a brief presentation about the current situation at LWN is conducted due to its strategic importance to the MCCtec division. The following paragraphs assess the current situation of the construction machinery sector market in order to give an outlook of the upcoming challenges LWN will be facing.

As one can see out of Figure 7 and Figure 8 the market share of Liebherr in the product groups of duty cycle crawler cranes, crawler cranes and foundation equipment is expandable. A share of [redacted] at LR and HS cranes and [redacted] at FE products of the global market in 2014 indicates remaining latitude.[40]

[redacted]

Figure 7: Market shares LR & HS cranes LWN in 2014 [41]

While the LR and HS market is more equally distributed, in the segment of foundation equipment there are bigger and smaller players evident.

[40] based on e-mail communication with I. Haltmeier, strategic marketing LWN [19-10-2015]

[41] ibidem

[redacted]

Figure 8: Market shares FE cranes LWN in 2014 [42]

The challenge of the site in Nenzing in the future will be to adapt its production to the new focus on continental machinery. Furthermore, a lot of innovation and ongoing development of the current products will be indispensable. The goal should be to increase market shares in the fields and seize the opportunities the market provides.

[42] based on e-mail communication with I. Haltmeier, strategic marketing LWN [19-10-2015]

3 Literature review

In order to provide the necessary backdrop for the results of the empirical study, extensive literature research concerning agility in production networks and its associated fields is conducted. The outcome, a comprehensive overview of the current state of science, is provided. To hamper ambiguity from the beginning great emphasis is placed on the definitions and delimitations of the important terms.

3.1 Definitions of agility

In recent years the term agility has become more and more indispensable for every successful, up-to-date manufacturing enterprise. The following sections deal with the origin of the term, various definitions and interpretations, as well as the importance of agility in today's manufacturing environment. To especially point out the emerged shift towards a more comprehensive view of agility the last couple of years, the research and its corresponding definitions are presented in chronological order. One can see that the latest definitions of agility include not only the area of manufacturing but also enterprise-wide strategic considerations. To ensure a better understanding of the complexity and versatility of this quite young field of research, different definitions are discussed in the following sub-chapters.

3.1.1 Early definitions of agile manufacturing

Triggered by the ongoing loss of influence of the American manufacturing industry Nagel et al. (1991) coin the term agile manufacturing in the early 1990s. In their report the transition from the mass production systems to agile manufacturing as a onetime opportunity for the U.S. industry to regain hegemony, which was lost in the previous two decades, is presented.[43]

In summary Nagel et al. (1991) see a rising demand of customized, high quality products and state that the agile manufacturing system with its smaller scale, modular product facilities and increased cooperation with other enterprises is the ideal way to meet these emerging customer needs in the future. The ability to react instantly and effectively to changes of these needs

[43] cf: Nagel et al. (1991), foreword

and in general on changing market situations is seen as an important prerequisite of agile enterprises.[44]

The work of Nagel et al. (1991) can be seen as the starting point of the agile manufacturing era. Since the early 1990s their definition of agile manufacturing has been used as a basis for further research by many authors. The derived definitions differ from ones that emphasize flexibility and customer service to others which focus on the requirement of virtual organisations and the exploitation of rapidly changing markets.[45]

In 1994 Kidd stated that according to common dictionaries agility is defined as quick moving, nimble and active. Thereby to him, the difference to flexibility in manufacturing, which means adaptability and versatility, gets evident. Kidd (1994) is of the opinion that flexibility is a necessary condition to compete in volatile markets, but flexibility itself does not include agility.[46] In his work the characteristics of an agile enterprise in Table 3, as they are defined by the Iacocca Institute, are summarized.

Concurrency in all activities	Skilled and knowledgeable employees
Continuing education for all employees	Open systems architectures
Customer responsiveness	Right first time designs
Dynamic multi-venturing capabilities	Total quality philosophy
Employees valued as vital assets	Short cycle times
Empowered individuals working in teams	Technology awareness and leadership
Environmental concern and proactive approach	Enterprise integration
Accessible and usable information	Vision based management

Table 3: Characteristics of an agile manufacturing enterprise [47]

Kidd (1994) himself describes agile manufacturing as a structure which enables companies to develop their own business strategies and products. It consists of three primary resources and an underlying basis (see Figure 9).[48]

[44] cf: Nagel et al. (1991), p.1-2

[45] cf: Narasimhan et al. (2006), p.441

[46] cf: Kidd (1994),p.9

[47] Kidd (1994),p.12

[48] cf: Kidd (1994),p.10

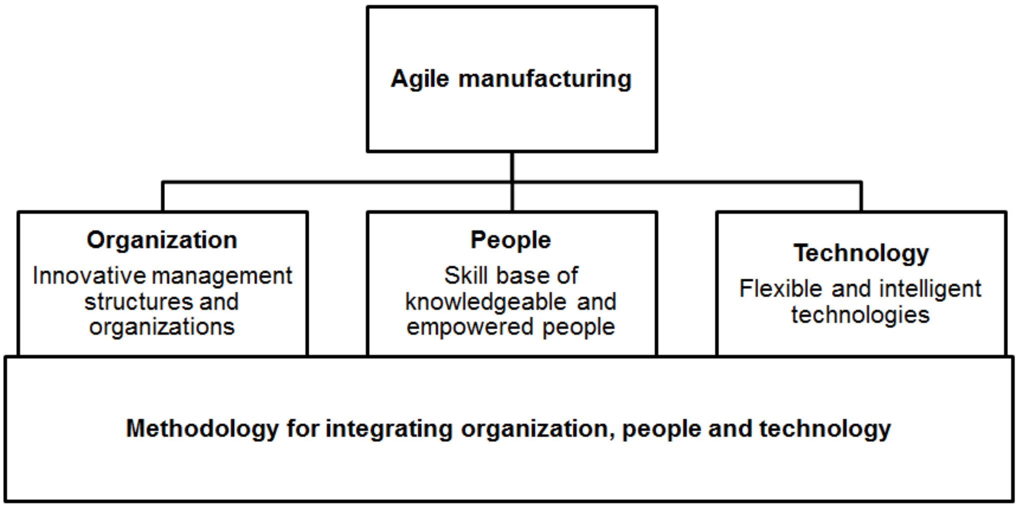

Figure 9: The structure of agile manufacturing enterprises [49]

Agile manufacturing is defined by Kidd (1994) as:

> *"…agile manufacturing can be considered as the integration of technologies, to achieve cooperation and innovation in response to the need to supply our customers with high quality customized products."* [50]

Besides the already mentioned necessary characteristics, the implementation of new information and communication technologies into the tools of manufacturing are as well described as crucial for the transformation process towards an agile manufacturing system already in the early 1990s.[51]

In their work Cho et al. (1996) are dealing with this fact. The beginning of their research outlines the changing environmental conditions and the mass production system, which is no longer enough to boost the economy. According to Cho et al. (1996) the shortened product life cycles, the demand for high quality products, the diversified and global markets and the unexpected changes are the major upcoming challenges. Therefore, a need for three things is outlined: first a quicker and cheaper product development is mentioned, followed by a need for the development of production facilities.

[49] Kidd (1994), p.11

[50] Kidd (1994), p.10

[51] cf: Nagel et al. (1991), p.2

And third, supporting software which also provides functions like design, process planning or shop floor control is described as crucial to stay successful. A special focus of Cho et al. (1996) is put on agile manufacturing enabling technologies like the electronical exchange of product data or shop floor control systems as well as communication infrastructure.[52]

Furthermore, Cho et al. (1996) point out that the increased use of computers in the early 1990s leveraged systems like Computer-Integrated Manufacturing (CIM) or Material Requirements Planning (MRP) to primary manufacturing paradigms. Due to reasons like the rising volatility of the markets and the more rapidly changing customer demands these systems alone are no longer sufficient to compete in this complex environment and need to be further developed and are more seen as components of new manufacturing paradigms. Besides well-known targets like high productivity, high quality and reduced costs, the ability to react quickly to changes is seen as the new big upcoming challenge for the future.[53] The following definition of Cho et al. (1996) emphasizes this fact:

> *"Agile manufacturing can be defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services."* [54]

However, it is also mentioned that it is not only about changes in markets. Adaptability to changes in technology in production or information technology is another necessary characteristic to sustainably operate successful. Additionally Cho et al. (1996) outline that the supremacy of large and strong enterprises is declining and in the future speedy enterprises will be more successful than slow and negligent ones.[55]

According to Gunasekaran (1998) technologies like CIM and MRP or concepts like Just in Time (JIT) and Total Quality Management (TQM) should be utilized to implement agile manufacturing.[56] Furthermore, he states that

[52] cf: Cho (1996), p.323-324

[53] cf: Cho (1996), p.323

[54] ibidem

[55] cf: ibidem

[56] cf: Gunasekaran (1998), p.1245

an enterprise which is aiming for an agile manufacturing strategy should consider the following three directions:[57]

- Cooperation between small and medium enterprises in order to bundle their capabilities and execute mutually profitable projects.
- Organisation of companies as teams in order to take advantage of market opportunities.
- Installation of effective communication with partner firms and the realization of their integration.

Through this list it becomes evident that the focus of Gunasekaran (1998) is put on the need for increased collaboration between companies. The formation of virtual enterprises and its connected enhanced competitiveness is presented as the key enabler of agile manufacturing.[58] This need for increased cooperation gets also evident in the following statement of Gunasekaran (1999).

> *“Agile manufacturing requires to meet the changing market requirements by suitable alliances based on core-competencies, organizing to manage change and uncertainty, and leveraging people and information.”* [59]

In the supply chain strategy related definition of agility of Naylor et al. (1999), virtual corporation is as well considered as crucial to the establishment of an agile production.

> *“Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place.”* [60]

In this definition market knowledge and virtual corporation are seen as the keys to operate profitably in volatile markets. As one can see agility in manufacturing is described more as an opportunity to gain profit than as a must to compete.

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[57] cf: Gunasekaran (1998), p.1243

[58] cf: Gunasekaran (1998), p.1223

[59] Gunasekaran (1999), p.88

[60] Naylor et al. (1999), p.108

Rating the importance of different characteristics of leanness and agility		
Keyword	Lean	Agile
Use of market knowledge	○ ○ ○	○ ○ ○
Virtual corporation/Value stream/ Integrated supply chain	○ ○ ○	○ ○ ○
Lead time compression	○ ○ ○	○ ○ ○
Eliminate muda	○ ○ ○	○ ○
Rapid reconfiguration	○ ○	○ ○ ○
Robustness	○	○ ○ ○
Smooth demand/Level scheduling	○ ○ ○	○

Note: ○ ○ ○ = essential. ○ ○ = desirable. ○ = arbitrary.

Table 4: Importance of different characteristics of leanness and agility [61]

As a basis for this emerged definition and derived from the analysis presented in Table 4 Naylor et al. (1999) state the following five characteristics of agile manufacturing:[62]

- *The use of market knowledge*
- *Working together in virtual corporation*
- *Shortening of lead time*
- *Ability for rapid reconfiguration of the production*
- *Robustness*

While the first two characteristics are already mentioned in the definition above, three additional ones are presented. These five characteristics together can be seen as prerequisite for a successful implementation of agile manufacturing.[63]

Naylor et al. (1999) focus their research on the relation of lean and agile manufacturing and describe the delimitations and commonalities of the two manufacturing paradigms. Although some experts see these two

[61] Naylor et al. (1999), p.109

[62] Naylor et al. (1999), p.109-112

[63] cf: ibidem

paradigms separated from each other and more in a successive than related way, Naylor et al. (1999) state that this is a too narrow view and that also their combination is definitely possible. In their work this statement gets verified by an example of a successful concurrent implementation of lean and agile principles. According to their research results, the suitability for leanness and agility depends on the market and, therefore, on the whole supply chain strategy.[64] As leanness and agility are essential parts of this thesis, their relation gets explained in detail in section 3.2.[65]

3.1.2 Broadening the scope of agile manufacturing

Around the turn of the century Gunasekaran (1999) widens the view of agile manufacturing towards an enterprise-wide perspective. It is stated that the key to a successful implementation of agile manufacturing is the right combination of culture, business practices and technologies all over the whole enterprise. Business practices in this respect should always be customer-supplier oriented from product design, over manufacturing and marketing to support services.[66] Besides this customer-supplier orientation, the cooperation with competitors is also seen as an indispensable part of acting agile.[67]

According to Yusuf et al. (1999) at the end of the 1990s no enterprise is truly acting agile in terms of following all the theory guidelines emerged from research in this field. Agility and especially its drivers, concepts and attributes are still described as a visionary concept which requires a lot of further research.[68] To support this process a comprehensive definition of agility is presented by Yusuf et al. (1999).

> *"Agility is the successful exploration of competitive bases (speed, flexibility, innovation proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment."* [69]

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[64] cf: Naylor et al. (1999), p.107

[65] cf: Naylor et al. (1999), p.108

[66] cf: Gunasekaran (1999), p.87-88

[67] cf: Gunasekaran (2002), p.1357

[68] cf: Yusuf et al. (1999), p.33

[69] Yusuf et al. (1999), p.37

Compared with former definitions of agility, broader scope and the systematic approach of this definition should be highlighted. There is a clear line between input, mechanism and desired output. Regarding the scope, this definition can be divided into three levels. It can be distinguished between the elementary level, which represents the resources of each enterprise and the micro level which is about the successful combination of them within the company. The macro level represents the inter-enterprise cooperation regarding agility. Among other things the definition above is based on four core concepts shown in Figure 10.[70]

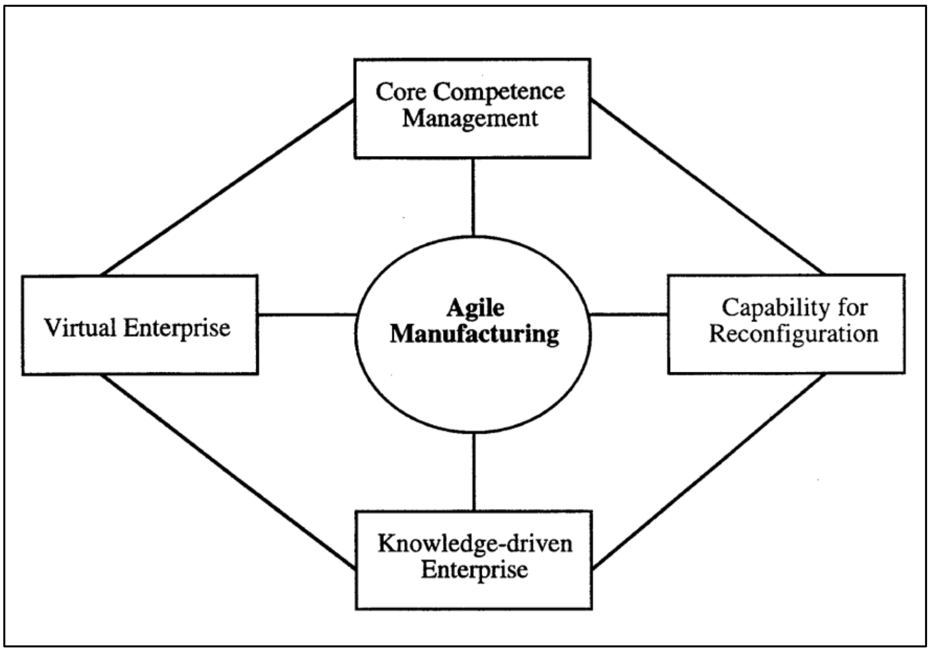

Figure 10: The core concepts of agility [71]

Virtual enterprise formation is about organisations working together on corporate and operational levels across company borders. Together with the capability of rapid reconfiguration it is also part of the prerequisite characteristics for agility by Naylor et al. (1999) mentioned above. The concept of core competence management is about the steering of the organisation, the individual and enterprise-wide workforce and the product potential. Additionally the knowledge of the employees is considered as crucial. Well trained staff is seen as the critical resource for success.

[70] cf: Yusuf et al. (1999), p.37

[71] Yusuf et al. (1999), p.38

Therefore, it is emphasized that knowledge-driven enterprises should ensure to implement the knowledge and experiences of the people in their strategies.[72] In line with this it is stated by Yusuf et al. (1999) that an organisation can only be successful if it is able to incorporate knowledge and skills of the people working there into its solutions.[73]

Besides further research on the delimitation of lean and agile manufacturing, another comprehensive definition of agility is derived by Christopher (2000). The broadened scope of agility is outlined by this definition because agility is delineated as a business-wide capability which includes lots of different sectors. One of the key characteristics and also the origin of the concept is flexibility in the manufacturing system. In summary, agility is defined as the increased urgency to be able to respond rapidly to volatile and unpredictable demands, in terms of volume and variety.[74]

Sanchez et al. (2001) agree with the above mentioned definition given by Christopher (2000) and state that while lean is just a collection of operational techniques which focusses on productivity, agility can be seen as an overall strategy which pursues the target of thriving in an unpredictable environment.[75]

A slightly different interpretation of flexibility in the context of agile enterprises comes from Zobel (2005). According to him the ability to act agile can be seen as insurance to unexpected changes. Reacting adequately to predicted changes on the other hand is enabled through flexibility of the manufacturing system. Therefore, Zobel (2005) defines agility as the ability to react adequately to unpredicted and unexpected changes and even profit from them. Furthermore, the option of the ability to prepare proactive to these changes is described as a characteristic of agile enterprises.[76] The analysis of these proactive preparation possibilities will be an essential part of this research paper.

Finally in the work of Wiendahl et al. (2007) agility is described in a large, strategic context as highest and most extensive changeability is

[72] cf: Yusuf et al. (1999), p.37-40

[73] cf: Yusuf et al. (1999), p.39-40

[74] cf: Christopher (2000), p.38

[75] cf: Sanchez (2001), p.3562

[76] cf: Zobel (2005), p.158-159

assigned to it.[77] Wiendahl et al. (2007) provide a classification of agility respective changeability classes. It is stated that it is not reasonable to use the term flexibility among all levels of an organisation. With the consideration of the product dimension a hierarchy, which shows the definition of five changeability types, is presented. The higher types of changeability include characteristics of the types below.[78] In general it can be said that throughout agility literature, different interpretations of adaptability, flexibility and agility are existing. Therefore, the differentiation of these terms is sometimes difficult.[79] Figure 11 outlines the classes of factory changeability by Wiendahl et al. (2007).

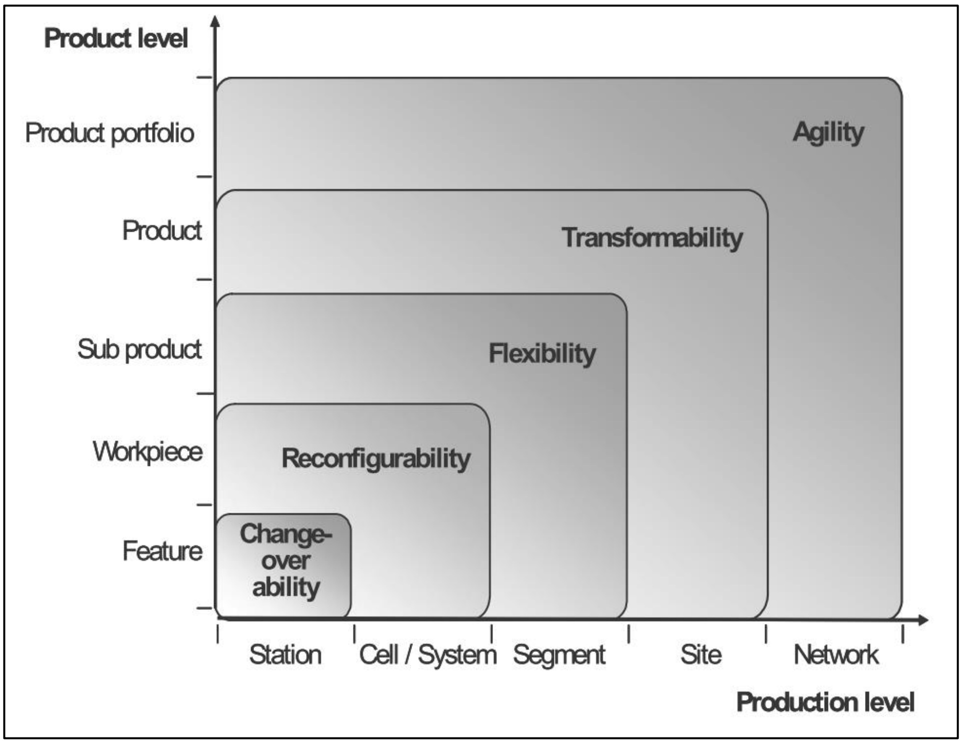

Figure 11: Classes of Factory Changeability [80]

In the matrix of Figure 11 the product level is divided in an overall product portfolio, an individual product, an associated sub product, a workpiece and one of its features. Combined with the production level axis, which starts at a

[77] cf: Wiendahl (2007), p.786

[78] cf: ibidem

[79] cf: Sherehiy (2007), p.459

[80] Wiendahl (2007), p.786

single work station and ends at a production network, several interfaces arise. The relevant level of this thesis is the last one which describes the changeability of a whole product portfolio within a production network. This interface is described by agility.[81] Subsequently the following definition of agility is provided by Wiendahl et al. (2007):

> *"Agility means the strategic ability of an entire company to open up new markets, to develop the requisite products and services, and to build up necessary manufacturing capacity."* [82]

In the course of describing the factory of the future, Schenk et al. (2014) describe agility as the momentum of the organisation of a factory to autonomously initiate and consequently execute change processes. Furthermore, according to Schenk et al. (2014) agility is a prerequisite to the development ability of a factory.[83]

3.1.3 Recent comprehensive definition of agility

In order to complete the previous chronological sequence of more and more broadening agility definitions emerged over the years, the latest one from Graz University of Technology, which represents the theoretical basis of this thesis, needs to be mentioned. Recent research of Schurig et al. (2014) at the Institute of Industrial Management and Innovation Research in Graz has led to the following comprehensive definition of agility affecting the whole company:

> *"Agility of a company is the capability to prepare proactively for uncertainties and to react quickly on changes to optimize the economic situation (e.g., EBIT, market share, ROI) of a company by leveraging the value chain."* [84]

The proactive preparation of the value chain involving measures and levers, which can be put into place quickly, if necessary, marks one of the central points of this definition. This proactivity can either mean an active scanning of

[81] cf: Wiendahl (2007), p.786

[82] ibidem

[83] cf: Schenk et al. (2014), p.42

[84] Schurig et al. (2014), p.957

the enterprise environment at any time or performing simulations of certain scenarios to see possible outcomes.[85]

Furthermore, Schurig et al. (2014) point out that agility means being able to handle upswing to the same extent as downturn of sales. This means on the one hand benefiting from rising demand in form of additional contribution margin. On the other hand prevent losses in case of dropping demand.[86] These incidents and additionally the remarkable difference of the variation limits between manufacturing flexibility and agility are especially highlighted in Figure 12.

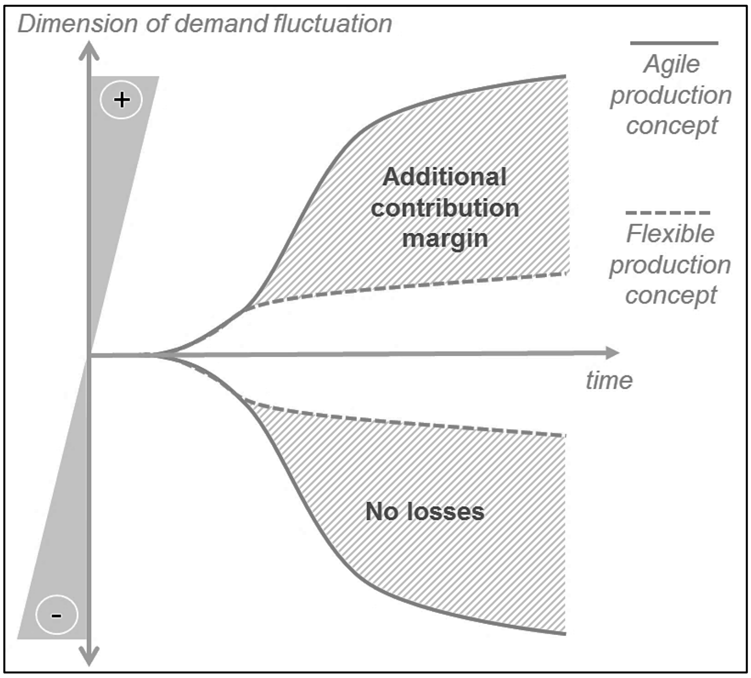

Figure 12: Agility vs. Flexibility in manufacturing [87]

As one can see, plenty of different definitions of agility have been derived over the years. To prevent misunderstandings the following chapters of this thesis will be based on the agility understanding of the Institute of Industrial Management and Innovation Research (IBL) at Graz University of Technology and the associated works of Schurig et al. (2014).

[85] cf: Schurig et al. (2014), p.957

[86] cf: ibidem

[87] ibidem

3.2 Lean vs. agile production

As leanness and agility are two of the most important terms in modern manufacturing industry, many authors like for example Naylor et al. (1999), Christopher (2000) or Narasimhan (2006) have been intensively working on their commonalities and differences.[88,89,90]

Agility in production is still quite a young field of research and has, therefore, not yet received comparable development as lean manufacturing.[91] While the following section should ensure a clear delimitation of the two terms, it is also pointed out that there are some commonalities between them. Implementing the best practices out of both paradigms, while considering contradictions between them into ones production strategy, may be advantageous.

In the beginning two representative definitions from Narasimhan et al. (2006) and Naylor et al. (1999) of lean production and leanness in the supply chain strategy should prevent vagueness:

> *"Production is lean if it is accomplished with minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations."* [92]

> *"Leanness means developing a value stream to eliminate all waste, including time, and to ensure a level schedule."* [93]

As one can see from the definitions lean principles are primarily aiming on the elimination of all kind of waste. Waste in this respect describes all activities which do not add value from the customer's perspective.[94]

The term waste includes on the one hand overproduction which leads to unnecessary inventory. Inventories themselves then are often used to hide other problems and inefficiencies. On the other hand non-value adding waiting time between the production steps and unnecessary transportation of

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[88] cf: Naylor et al. (1999)

[89] cf: Christopher (2000)

[90] cf: Narasimhan et al. (2006)

[91] cf: Narasimhan et al. (2006), p.443

[92] ibidem

[93] Naylor et al. (1999), p.108

[94] cf: Rachna et al. (2003), p.129

material is considered as waste too. The further included points are unnecessary motion of people, overprocessing, inventories and all kind of defects.[95]

Besides the main idea of eliminating all these kinds of waste in production, several lean tools to improve one's manufacturing environment, like for example kaizen, 5S, pokayoke or standardized work are common.[96] A detailed description of those would, however, exceed the scope of this thesis and is, therefore, omitted.

Concerning the relationship of lean and agile production, agility is often seen as the successor of leanness. Thereby the implementation of agility in production also includes the application of plenty of lean practices, like for example continuous improvement or waste reduction. [97,98] In literature slightly different views of the relationship of agile and lean production exist. On the one hand Gunasekaran et al. (2002) represent the vision of agile manufacturing as the natural development of the concept of lean manufacturing. Due to the fact of frequent changes in demand, agile manufacturing primarily aims for the ability to react quickly to new market opportunities. This need for flexibility with its associated risks to costs, speed and quality are described as shift backwards to the time before the coming up of the lean philosophy.[99] On the other hand Naylor et al. (1999) have another perception of the relation. They argue that seeing agility simply as the subsequent paradigm to leanness is a too simplistic view. The need for either one of the two paradigms depends upon the whole supply chain strategy and often a combination of them is the right way to go. In particular, agile manufacturing suits more volatile markets and changing demands while lean manufacturing works best with smooth demands and little fluctuations.[100]

Furthermore, the positioning of the decoupling point, which is the point at where a product gets associated to a customer, is seen as crucial when deciding between lean or agile manufacturing. Closely connected to the

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[95] cf: Frost et al. (2011), p.4

[96] cf: Pavnaskar et al. (2003), p.3076-3077

[97] cf: Gunasekaran (2002), p.1358

[98] cf: Christopher (2000), p.38, 40

[99] cf: Gunasekaran (2002), p.1358

[100] cf: Naylor et al. (1999), p.107

decoupling point is the issue of postponement. Postponing connotes shifting product differentiation, the so called decoupling point, more towards the end of the process. This reduces the risk of unnecessary inventories and ensures a short reaction time to changes in customer demands.[101]

Hence it is stated that the lean philosophy is rather suitable for processes which happen before an appropriate positioned decoupling point. Through the balancing effect of stock held at this point, the demand for production of standard products should be smooth and stable. In contrast to that, agility is the ideal way to manage the increased demand of variety, after product differentiation. This derived combination of leanness and agility is named “leagility”.[102]

Christopher (2000) emphasizes that leanness alone cannot provide fast and accurate satisfaction of changing customer needs. According to him there are only limited conditions where lean is the right way to go. Low variety, high volume and predictable demand are the main prerequisites for a successful implementation of the lean principles. Hardly surprising these were exactly the conditions when Toyota back then developed the philosophy of lean. Christopher (2000), furthermore, outlines that many firms adopted the lean principles although the conditions were not suitable. For example the Western automobile industry which is facing the demand of customized cars. This customization leads to a high variety of products and as a consequence the volume of these different products is rather low. However, he states that at earlier points of the production process lean can sometimes be an element of an agile strategy. Therefore, a similar approach to the one from Naylor et al. (1999) of combining lean and agile principles is suggested. The combination of the two paradigms, however, is named “hybrid strategies” by Christopher (2000).[103]

In the research of Agarwal et al. (2006) leanness is likewise the previous opinions described as an element of agility under certain conditions. However, according to Agarwal et al. (2006) leanness will not enable an organisation to react faster on changing customer needs.[104]

[101] cf: Naylor et al. (1999), p.108

[102] cf: Naylor et al. (1999), p.114, 117

[103] cf: Christopher (2000), p.38, 40

[104] cf: Agarwal et al. (2006), p.212

To illustrate the preferred environmental conditions and the best suitable application of each of the two paradigms Figure 13 provides a good overview. Variety, variability and volume of demand determine whether agile or lean is more suitable to the situation.

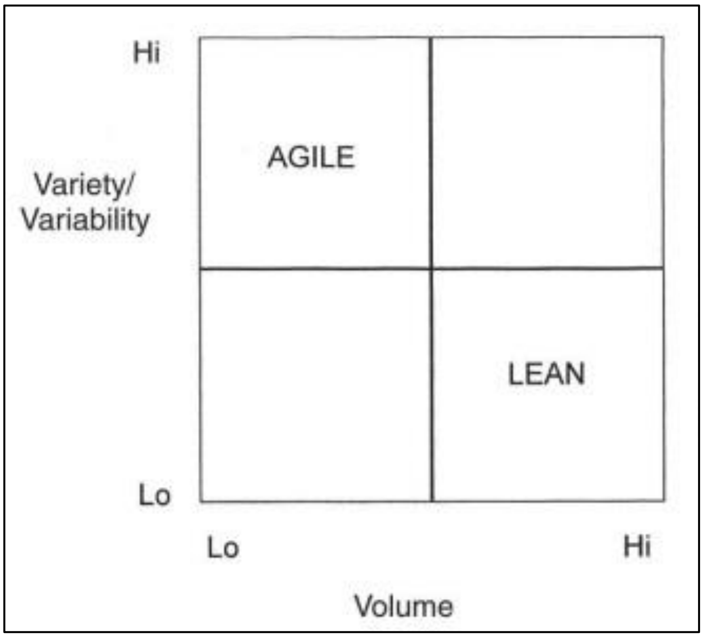

Figure 13: Lean or agile [105]

From Figure 13, one can see that agility suits best to volatile environments such as a demand with high variability and low volume. In contrast lean requires stable conditions for example a demand of low variety and high volume.[106]

Regarding the characteristics of leanness and agility certain overlaps are described by Hallgren et al. (2009). For instance waste elimination, setup time reduction, continuous improvement, 5S and other quality improvement tools can be associated with both of the paradigms.[107]

In conclusion, lean fits best to make-to-stock operations, while agility is recommended for make-to-order operations. This also implies the fact that lean should be applied in forecast-driven operations before the decoupling point and agility in this respect in order-driven downstream processes.[108]

[105] Christopher (2000), p.39

[106] cf: ibidem

[107] cf: ibidem

[108] cf: ibidem

3.3 Dimensions of corporate agility

After clarifying the relation of lean and agile principles, in this section the dimensions of the corporate agility of an enterprise get explained in detail. Therefore, the knowledge of the IBL Institute at Graz University of Technology is followed. The IBL Institute’s focus lies in the strategic and operational agility category. This thesis especially deals with the agile and efficient operations of an agile enterprise although influences of other dimensions are considered in the practical part too. In Figure 14 an overview of the categories of an agile enterprise is provided.

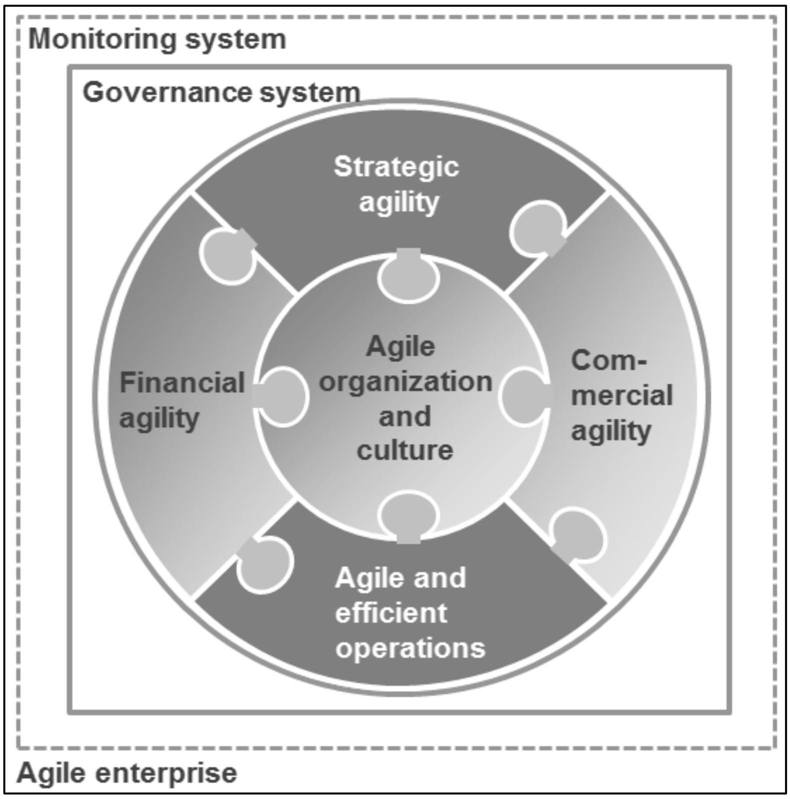

Figure 14: Agility dimensions [109]

Embedded in an overall necessary monitoring and governance system the main parts of the corporate agility are the strategic, commercial, operational, financial and organisational dimensions. In the following the individual dimensions are described and their major parts outlined.[110]

[109] based on papers and research of the IBL Institute at Graz University of Technology

[110] ibidem

3.3.1 Operational agility

Operational agility plays a main role in this thesis. Generally spoken, operational agility is about the fast adaption of production to changing market demands. This means it is about the increase of production capacities in times of upswing as well as the downscaling of production when demand is falling. In other words the operational agility of a company is the guarantee of the supply to the customer at any time. Thereby several factors like the right location of production, the quantity of produced products and their mix have to be considered carefully. However, these factors are not only about one's own production line. It is also about ensuring the supply from the upstream network and the match of the production capacities. As a consequence, also measures which ensure supply continuity in case of disruptive events like natural disasters or trade barriers are part of the operational agility.[111,112]

To achieve these goals operational agility includes further measures from the shop floor level in order to level out the capacities. These measures are for example the exchange of workers between the departments or the production sites, the adjustment of the number of workers, especially all temporary employed workers, as well as the flexibility of working hours in production.[113] A detailed description of these levers and their application will be provided in section 4.3.

Furthermore, the assets and processes at the individual sites are taken into consideration when talking about operational agility. Besides the options of subcontracting and the connected possibility of shifting production whose application is also discussed in 4.3, other aspects like the continuous tracking of the latest agile production technology and an agility conducive production layout are important components.[114]

Another crucial part of this sub-category, which is an important prerequisite of efficient intra-firm cooperation within a production network, is the degree of standardization in production. A standardized production environment facilitates on the one hand the shift of production between the sites. On the other hand the exchange of workers is simplified as learning

[111] based on papers and research of the IBL Institute at Graz University of Technology

[112] cf: Rabitsch et al. (2015), p.46

[113] based on papers and research of the IBL Institute at Graz University of Technology

[114] ibidem

curves are shortened. Additionally, the possibility of comparison among the plants is enhanced.[115]

Overall the standardization regarding production equipment has to be seen differentiated. While basic equipment used for standard components should be equal among the network, too much standardization in areas of individual projects makes less sense. The standardization of basic equipment ensures a better exchangeability of workers and focuses the expertise regarding the equipment among the network.[116] However, it is not reasonable to standardize everything. The individual sites should remain independent in their thinking and still strive for innovation. Colotla et al. (2015) state that the right balance between standardization and independence varies strongly by industry and organisation.[117]

The topic of standardization is not only affecting the production layout. Another crucial aspect of standardization in operations can be found way earlier in the production process. Concerning product design emphasis is put on the usage of standardized components during the design process. A thereof resulting late product differentiation as well as the possibility to work with product platforms is facilitating agility in a production system. Furthermore, overdesign of any kind should be impeded as costs are raising and complexity gets increased.[118]

As already discussed a certain degree of standardization among the production equipment is necessary to collaborate within a network. The usage of standard components in designing new devices has major impact on the following production steps as it reduces costs and increases agility. A well-known strategy in production is the usage of “product platforms”. The following definition of Meyer et al. (1997) should clarify the term.[119]

> *“A product platform is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced.”* [120]

[115] cf: Frost et al. (2011), p.5

[116] cf: ibidem

[117] cf: Colotla et al. (2015), p.8

[118] cf: Meyer et al. (1997), p.39

[119] cf: ibidem

[120] ibidem

After the detailed analysis of the operational agility levers which have been used by Liebherr in the past in order to manage production fluctuation in section 4.3, the agility level of Liebherr in each operational sub-category is analysed in section 4.4.1.

3.3.2 Strategic agility

Strategic agility is about the ability of continuous adaption of the strategy in order to optimize the economic situation of the company at any time. This implies for example the re-definition of business models, business setups or changes in the product portfolio.[121]

Companies, which have been operating in markets where customized solutions are demanded by the customers, had to ensure a certain degree of flexibility ever since. Nowadays rising market volatilities are increasing these needs and the manoeuvrability of big producing companies is getting more and more important.[122]

Decentral steered productions systems and the increasing human-machine interaction, however, offer huge potentials. They can be used to facilitate a more efficient, more adaptable production system. Additionally, digitalisation is on the rise and the increased amount of collected data and, therefore, transparency along the whole value chain facilitates quicker and better decisions of the production management.[123]

Another important characteristic of applied strategic agility is the conduction of experiments and strategy projects in order to gain new ideas and reveal untouched market potentials. Agile companies are constantly conducting these projects and if success is expected, they are able to quickly scale their scope.[124]

3.3.3 Organisational agility

Organisational agility includes on the one hand the overall culture of the company and on the other hand the organisational structure. An agile culture is the key to the implementation of agility in the company in the long-term view. Closely connected to the culture is a proactive and adaptive workforce

[121] cf: Rabitsch et al. (2015), p.45

[122] cf: ibidem

[123] cf: ibidem

[124] cf: ibidem

which is also indispensable for a successful agile company. The ability of these workers to manage change and to actively participate in measures to increase agility is of highest importance. Their experience in managing changes and their ability to see and capture opportunities is a prerequisite for an agile culture in the company. One way to drive the employees towards these characteristics is the allocation of more responsibility to the individuals. One example from production could be a flexible shift handover procedure, where the workers can, in coordination with their colleagues and within a certain frame, decide on their own about the start of their shift. Other examples are learning factories or further training of the workers in order to support their initiative.[125]

Besides the company's employees and the culture of a company, structural organisation also plays an important role and needs to be taken into consideration. Flat hierarchies and flexible processes support fast decisions. This fast reaction ability is a key factor in an agile company. Furthermore, transparency and a good functioning information system are indispensable in order to immediately communicate risks and chances among all hierarchies. Due to the speed and diversity of changes in today's manufacturing environments the top management level is no longer capable of dealing with all the problems and, therefore, decision-making power has to be decentralised to at least a certain extent.[126]

3.3.4 Financial and commercial agility

For the sake of completeness the financial and commercial agility dimensions are mentioned too. Financial agility is describing the financial aspects, for example ensuring liquidity in challenging times and so on. The commercial agility dimension is about reaching the customers with the right message in the right place at the right time. A detailed description of the two dimensions would exceed the scope of this thesis and is, therefore, not intended.[127]

[125] cf: Rabitsch et al. (2015), p.46

[126] cf: ibidem

[127] based on papers and research of the IBL Institute at Graz University of Technology

3.3.5 Governance and monitoring system

Likewise, the governance and monitoring systems are not the focus of this research, although a brief explanation of the two dimensions is necessary to sketch the whole image of corporate agility.

In order to manage and control all agility related measures a governance system has to be installed. Its purpose is tracking of the specified agility strategy and its connected goals. Furthermore, the monitoring of uncertainties as well as the decision-making power concerning the activation of agility levers are key tasks of the governance body. Subsequently also the constant measurement of the effectiveness of these levers is necessary.[128]

The monitoring dimension is about the understanding of the volatilities of the market the company is operating in. A good overview of the possible changes and the overall development of the business environment are indispensable to be able to act agile. The monitoring dimension, furthermore, is about the implementation of forecasting systems in order to identify changes on the market as early as possible. Additionally, it should be mentioned that it is not only about identifying upcoming risks, it is also about seeing opportunities in the future. In order to establish a plan of how to deal with the upcoming volatilities, scenario based planning is one opportunity which can help. With the help of scenarios a company can proactive prepare to these situations. Thereby also options of action in case of a deviating future should be considered.[129]

3.4 Key characteristics of agility

After introducing the different agility dimensions in this section the key characteristics of agility are once more emphasized. Rabitsch et al. (2015) outline that the key characteristics presented in Figure 15 are the ones to be addressed in order to become an agile manufacturing organisation.[130]

[128] cf: Rabitsch et al. (2015), p.4

[129] cf: Rabitsch et al. (2015), p.46-47

[130] cf: Rabitsch et al. (2015), p.3

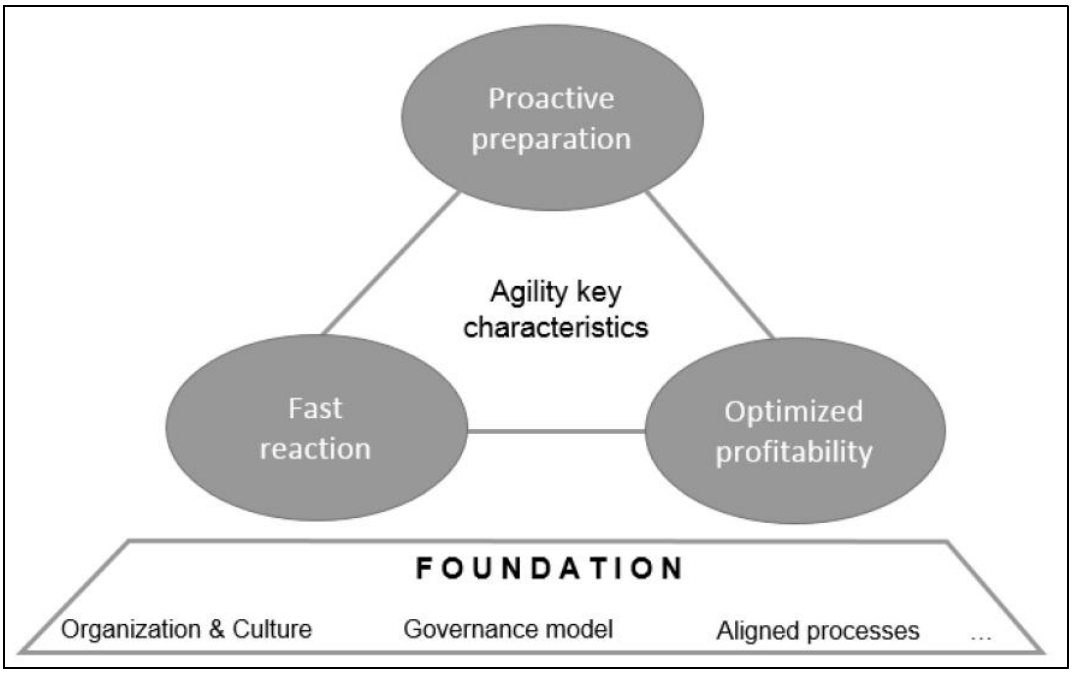

Figure 15: Key characteristics of agility [131]

Proactive preparation is one of the key characteristics. The preparation of measures beforehand is necessary in order to be able to react fast enough to the rapidly changing conditions. Hereby two concepts are suitable: on the one hand an early warning system can help to identify upcoming changes and facilitate a time advantage. Whereas on the other hand forecast systems or scenario based planning can help companies to identify future risks and proactively prepare to these future challenges. The second characteristic is closely connected to the first one as one of the goals of preparation measures is to facilitate a fast reaction. The ability to react fast is, furthermore, depending on the structures and the processes of an organisation. The optimization of profitability is the third key characteristic of agility. It describes the different economic goals a company is aiming for, depending on its current situation. For example agility levers can foster the increase of market share or simply ensure liquidity.[132]

To sum up the picture and foundation of agility, the culture itself as well as the organisational structure have a strong impact on a company's agility. Additionally, a governance model is needed to ensure steering in the right direction. The third component of the foundation is about the alignment

[131] Rabitsch et al. (2015), p.3

[132] cf: Rabitsch et al. (2015), p.3-4

of the processes of an organisation with the overall target of increasing agility.[133]

3.5 Production networks

After the detailed discussion of the agility concept, in this sub-chapter cooperation between companies in the form of production networks is dealt with. Due to increasing product variety, shorter delivery times and a demand for high delivery reliability, companies are forced to enhance the cooperation with each other. In order to ensure the ability of a fast reaction to the continuous and unexpected changes of today's volatile markets, the formation of production networks is facilitated.[134] Figure 16 outlines today's trends leading towards increased cooperation among companies and the formation of production networks. The trends are thereby categorized in market, product and environment related issues.

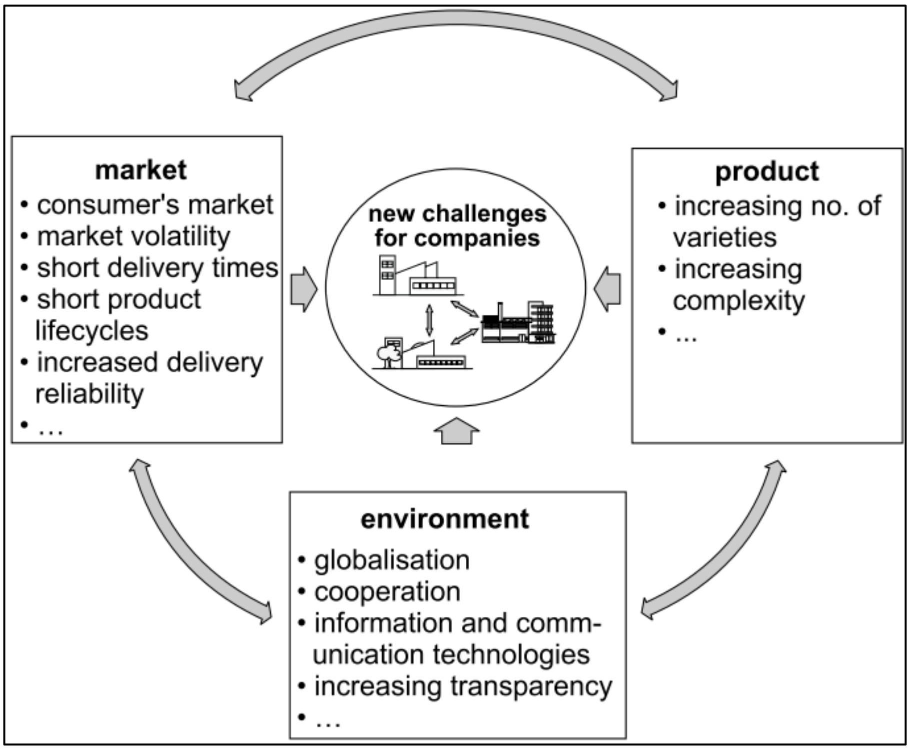

Figure 16: Trends leading towards increased cooperation of companies [135]

[133] cf: Rabitsch et al. (2015), p.4

[134] cf: Wiendahl et al. (2002), p.573

[135] ibidem

This trend towards increased cooperation is not only affecting large international enterprises. Also small and medium sized organisations are more and more forced to increase their cooperation in order to compete in today's globalised markets.[136]

Despite this trend it has to be said that there has always been cooperation among companies. Different concepts of cooperation like the formation of virtual enterprises, supply-chain management or production networks (see Figure 17) are described by Wiendahl et al. (2002). Furthermore, it is stated that while in the past competition between individual companies was predominant, today rather whole supply chains and networks are competing with each other.[137]

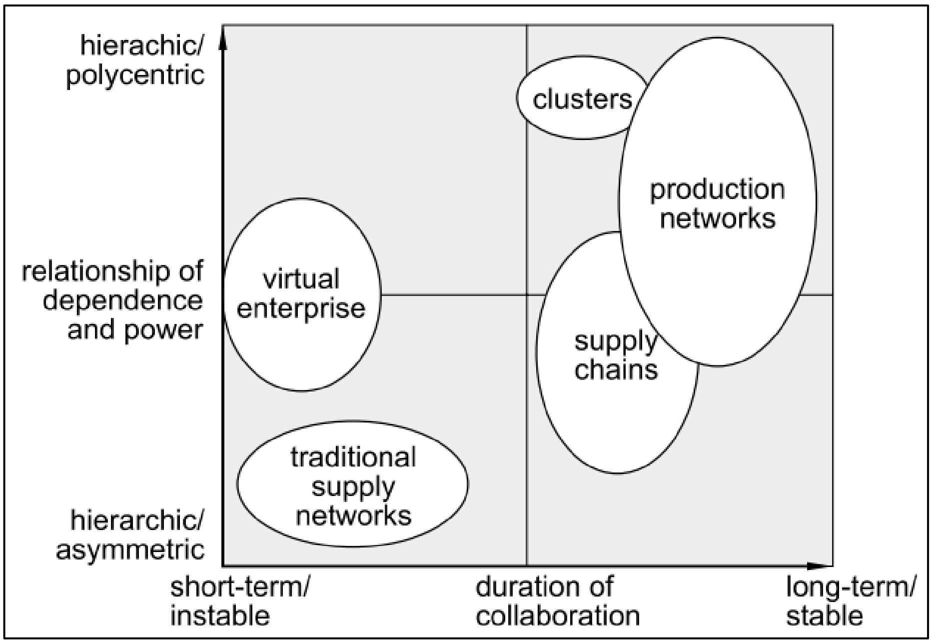

Figure 17: Cooperation concepts [138]

Supply chain management, which came up in the 1990s, is about the concentration on one's core competencies and the outsourcing of parts of production. It represented a fundamental change in manufacturing strategy. Make or buy decisions are a core function of supply chain management. The shift from purchasing single parts towards the procurement of modules and

[136] cf: Lanza et al. (2012), p.257

[137] cf: Wiendahl et al. (2002), p.573

[138] Wiendahl et al. (2002), p.575

components constitutes another important characteristic of SCM. In summary Wiendahl et al. (2002) describes SCM as the management of the flow of material and information along the whole value chain.[139]

Virtual enterprises are quickly set-up, short-term partnerships between manufacturing companies. A strong focus on the customers as well as the mutual use of information systems, are core characteristics of the concept. Furthermore, the formation of virtual enterprises is often based on single projects. Usually the cooperation between the single companies is thereby invisible to the customers as the virtual corporation appears as one organisation.[140]

Production networks are described as partnerships with high versatility. Furthermore, in contrast to virtual enterprises, long-term relationships are necessary to benefit from the advantages such networks provide. A high degree of transparency among the network is also important in order to coordinate the material and information flows. A good information management can, therefore, be seen as crucial to a network's success.[141]

In the work of Wiendahl et al. (2002) subcontracting is described as a strong mean to increase flexibility in those production networks. There are several types of subcontracting known. Technology driven subcontracting for example is about subcontracting single production steps which require certain technologies that are not available at one's own company. This type of subcontracting is often planned in the long-term. Another type of subcontracting is capacity-driven subcontracting. A common trigger for this type is a lack of capacity. Decisions on subcontracting due to capacity reasons are often short-term and require a high degree of flexibility. Furthermore, subcontracting is often done for strategic reasons like for example the maintenance of a supplier relationship.[142]

In order to link the theory of production networks to agility, in the research of Wiendahl et al. (2002) a direct correlation between the networkability and changeability of an organisation and its agility is described. In other words it is stated by Wiendahl et al. (2002) that a very high changeability and networkability can be seen as a crucial requirement to

[139] cf: Wiendahl et al. (2002), p.574

[140] cf: ibidem

[141] cf: Wiendahl et al. (2002), p.575-576

[142] cf: Wiendahl et al. (2002), p.578-579

the existence of agile organisations. In Figure 18 different forms of organisations, from autonomous ones which show low changeability and networkability to agile organisations with a very high ability to integrate and to change, are presented.[143]

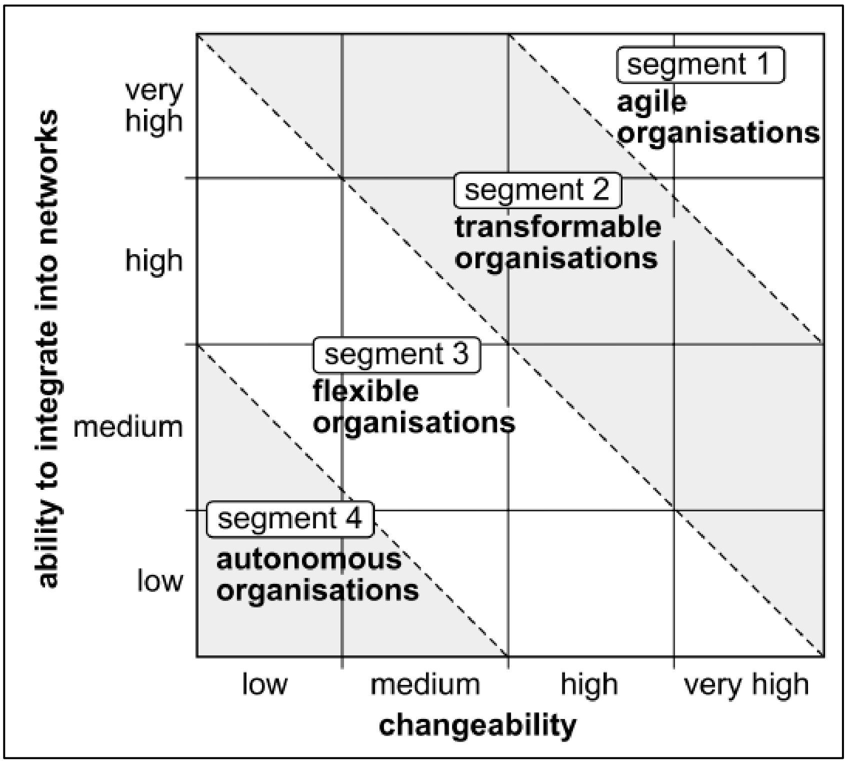

Figure 18: Characterisation of manufacturing enterprises [144]

In line with that Monauni (2014) states that the establishment of production networks offers strong potential to facilitate agility. Furthermore, Monauni (2014) distinguishes between two types of production network configurations. On the one hand volatilities of the market demand for redundant capacity within a production network in order to facilitate the shift of production and thereby balance the overall level of production. On the other hand the need for complementary capacities within the network in order to manage technology driven volatilities is emphasized. Thereby the members of a production network can, via allying their resources, compensate individual weaknesses.[145]

[143] cf: Wiendahl et al. (2002), p.583

[144] Wiendahl et al. (2002), p.583

[145] cf: Monauni (2014), p.658,661

3.6 Summary of literature

In the beginning of the literature review the origin of the term agility was dealt with. Nagel et al. (1991) characterise the term agile manufacturing in the early 1990s. Their work can be seen as a starting point of the agile manufacturing era. Their definition of agile manufacturing has been used as a basis for further research by many authors.[146] After the presentation of various agility definitions, which derived over the years, the one from the Institute of Industrial Management and Innovation Research in Graz was provided:

> *“Agility of a company is the capability to prepare proactively for uncertainties and to react quickly on changes to optimize the economic situation (e.g., EBIT, market share, ROI) of a company by leveraging the value chain.”* [147]

Furthermore the difference between flexibility and agility as well as the interdependencies between the lean and agile production concepts were outlined. Although lean fits best to forecast driven, make-to-stock operations and agility is recommended for order-driven, make-to-order operations, certain intersections between the two concepts were identified.[148] For example continuous improvement or waste reduction can be seen as practices which facilitate both paradigms.[149] Several researchers conclude that a combination of both paradigms is the right way to go. The commonality of these approaches, besides their different names like for example “leagility” or “hybrid strategies”, is the application of lean in the forecast-driven production steps before the decoupling point and agility in later steps of production which are frequently challenged by changing customer requests.[150, 151]

Besides the definition of terms and the description of lean and agility, many agility enablers derived throughout the conduction of the literature review. For example the importance of high qualified employees, the ability of

[146] cf: Nagel et al. (1991), p.1-2

[147] Schurig et al. (2014), p.957

[148] cf: Christopher (2000), p.39

[149] cf: Aitken et al. (2002), p.61

[150] cf: Christopher (2000), p.38, 40

[151] cf: Naylor et al. (1999), p.114, 117

rapid reconfiguration of production, the elimination of non-value adding waste or latest software in production were identified as key enablers of agility.[152,153,154,155]

Furthermore, the dimensions of corporate agility, defined by the IBL-Institute in Graz were presented and explained in detail. Embedded in an overall necessary agility monitoring and governance system the main parts of the corporate agility are the strategic, commercial, operational, financial and organisational dimensions.[156]

In the last section of the literature review theory about production networks and other types of cooperation between companies was provided and linked to agility in production.

[152] cf: Naylor et al. (1999), p.108-109

[153] cf: Nagel et al. (1991), p.1-2

[154] cf: Yusuf et al. (1999), p.37-40

[155] cf: Cho (1996), p.323-324

[156] based on papers and research of the IBL Institute at Graz University of Technology

4 Practical approach

The empirical part of this thesis can be subdivided into three main parts. While the first one is about the analysis of the individual production sites of the MCCtec network concerning their equipment, current developments and production capabilities, the second one deals with production fluctuations at the individual sites and the ability of them to handle those. In the last part, the overall agility of the production network is assessed. Thereby the current agility level of the network among selected agility categories is discussed. In the end of the chapter the conducted quantitative agility evaluation is explained. To avoid unnecessary repetition and complexity, unless stated other, the abbreviations for the different individual sites are used. For details see the list of abbreviations at the end of the thesis.

4.1 Production at the individual sites

In this chapter the individual production sites are analysed in terms of their manufacturing know-how, their current developments in production technologies as well as their ability to produce the whole MCCtec product spectrum. This preliminary study should serve as a basis for the further agility evaluation as it especially shows the capabilities of each individual site and, therefore, outlines the frame for collaboration. The transparency of the production setting of each site is further needed in order to successfully coordinate the cooperation.

4.1.1 Manufacturing know-how and developments

First data about the manufacturing know-how and the available production equipment at each site is gathered. In the following only the major differences of the equipment are mentioned.

Technologies, available in the cutting departments, are quite consistent among the network. Machine levelling represents an exception as it is only available in Nenzing (LWN). However, in Sunderland (LSW) the implementation of it is planned too. Concerning actual developments of new technologies in the cutting department, slightly more differences are visible. [redacted] As a result of this investigation a summary of the current developments in all departments is provided in 5.2. [redacted] Without going into detail it can be stated that while MCR is well equipped for handling big parts, the other sites can process small parts better. One argument supporting this statement is the absence of a small parts manufacturing department at MCR. As the focus there is on machining big parts, the treatment of small parts is normally subcontracted. At LWN the small parts machine shop in addition offers the possibility of automatic feed and enables unmanned shifts. One difference in the assembly department is for example the absence of a tube manufacturing possibility at LCC whereas this is available in all other sites. In the department of painting, the size of the shot blasting and painting cabins and, therefore, also the limited size of the processed parts, mark the biggest difference. A test stand for the finished cranes is available in every production site except at LCC. However, it has to be stated that there are major differences in size. For example the test stand at LSW is, concerning its size, not comparable with the one at MCR. At LWN and LCC separate departments are responsible for the manufacturing of equipment. [redacted] All in all it can be stated that standardization is a very important prerequisite for an agile production network. Not only the production processes but also the available equipment should be more or less standardized to ensure that every production site can help out in case of need. The standardization regarding the basic equipment available at the sites is on a good level, although there is still room for improvement.

In conclusion it can be said that every production site has its own strengths and leading positions in developing different kinds of equipment and techniques. It is crucial to track successful developments early enough and to subsequently manage the dissemination throughout the network to ensure that each site can benefit from the advantages these new technologies offer. On the counterpart repeated testing of equipment which already turned out to be inconvenient, should be avoided. At the end of this thesis the implementation of a central know-how management system is discussed in detail in 5.6.

4.1.2 Production capabilities of the individual sites

This chapter reviews the ability of the sites to produce the products of the MCCtec division. The possibility to shift the production of different products between the member sites can be seen as a big strength. In the company portrait of the site in Nenzing this fact is stated as one of the major four goals of the company. In theory all production sites of the MCCtec division should be able to produce the whole product portfolio of the group. The usage of these synergy potentials is one of the strategic goals of the MCCtec group.[157]

Now, in order to analyse this ability of the individual sites in a first step all products produced at the different sites since 2005 are gathered. Afterwards the production capability of each site, in relation to the products of the MCCtec division, is evaluated. Therefore, the following criteria are used:

- Availability and limitations of the needed assets
- Know-how of the local workers concerning the product
- Transport limitations due to the size of the product

Each of these categories is evaluated separately and in the end an overview of all products and their production capabilities at each of the sites is provided. It has to be stated that the created list can be seen as a rough overview and that extensions in several directions are conceivable. For example the further development of the list towards a detailed analysis of each product's transportation would make sense. The further development of the production possibility analysis towards a fragmentation of each product into its components and their separate analysis in terms of their production possibility would as well increase the value of it. Therefore, this can also be seen as a recommendation for further investigations in this area. The necessary continuous adjustment of the list, to keep it up to date, is another point that should be mentioned. In the following paragraphs the production possibilities of selected product groups are discussed briefly. For a detailed overview of all products, see the appendix of this thesis.

[157] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.5

An excellent example of the close collaboration between the sites of the MCCtec network is the new Reachstacker LRS 545 (see Table 25). While development and design are executed in Nenzing (LWN), product management, service as well as sales and distribution are located in Rostock (MCR). The production itself, however, is taking place in Sunderland (LSW). As one can see from this example it is also possible that three sites are sharing the responsibilities of one product. Concerning the production capabilities it can be said that production would be possible in every site. Although in Killarney (LCC), where no Reachstacker has been built so far, the workforce would need some training in order to be able to build it. Of course, if such a shift of product groups is conducted, at a new site support is needed in order to ramp up the production of the new products. It is common that a delegation of employees from the former producing site visits the new site and shares the knowledge. Therefore, the employees spend time at the partner site in order to support their colleagues. This continuous and frequent exchange is, furthermore, simplified through the Liebherr fleet which consists of seven aircrafts and enables fast and uncomplicated visits. The exchange of knowledge is not only important on the factory level as also the executive directors of the MCCtec sites meet several times a year to discuss current issues. Therefore, the location of these meetings is alternating between the sites of the network.

In order to continue with the discussion of the feasibility of production at the individual sites, the mobile harbour cranes are analysed next. This product group can be divided into two major subgroups. While smaller types up to the LHM 550 can be built at every production site, production of the LHM 600 and LHM 800 type is, due to their size, only possible at MCR. Additionally is has to be said that LCC is not used to the production of mobile harbour cranes and would, therefore, require more effort in order to ramp-up production. The main reasons why it is not possible to produce the two biggest types of mobile harbour cranes there, is their size and subsequently the connected transportation difficulties. Representative for the whole investigation an extract of the complete list shows the production possibilities of LHM cranes throughout the network (see Figure 19).

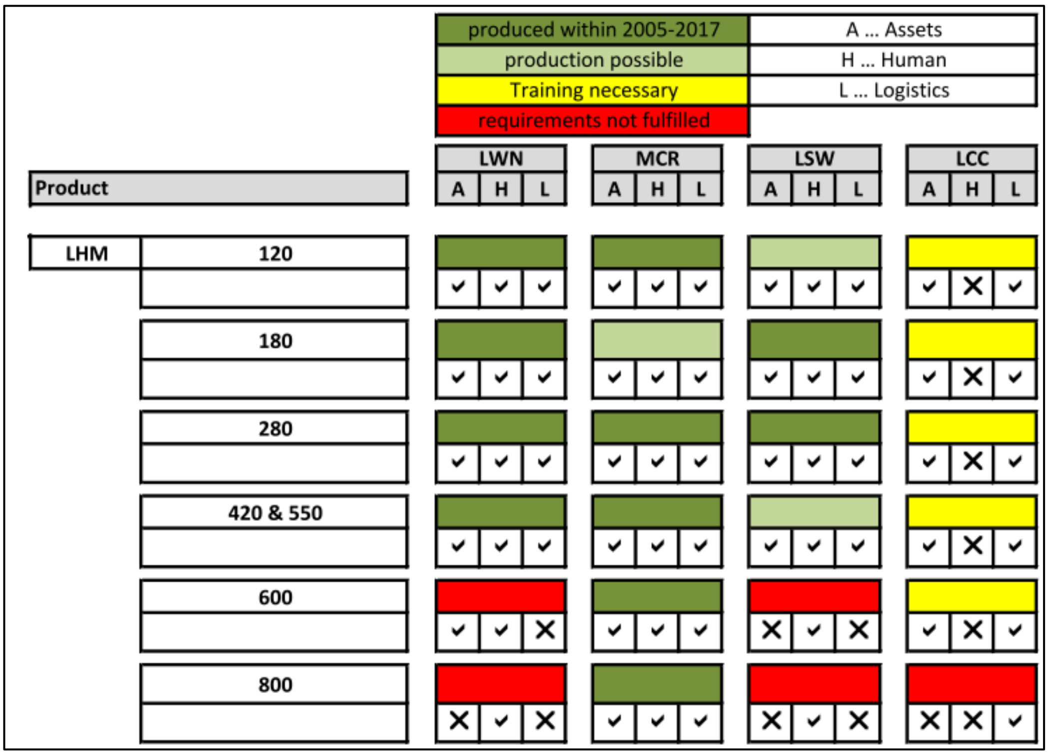

Figure 19: Production possibilities of LHM cranes throughout the network

The product groups of ship and offshore cranes can also be divided. While small cranes can be built by every production site, the bigger ones are solely produced at MCR. Continental machines as the duty cycle crawler crane or foundation equipment are typically produced at LWN. However, if there is need, the other sites are also able to produce the whole portfolio. Although the necessary training of the employees, due to the lack of experience in building these crane types, has to be taken into consideration too.

Ship-to-shore cranes are typically built at LCC. Due to their extraordinary size the only alternative production location is MCR. The smaller devices built at LCC can be produced at all the other sites. However, again training of the employees would be indispensable.

As one can see out of this investigation several crane types can be produced at different production sites of the network. A further splitting of the crane types into their individual parts would presumably show even more potential backup capacities. However, a further detailing of the inspection would exceed the scope of this thesis and is, therefore, not intended.

4.2 Production fluctuations

Before analysing the handling of production volatilities, with the help of agility levers, production fluctuations of chosen product groups, the individual sites and the overall production network in recent years, are presented. By doing so, the highest variation to be handled is identified.

4.2.1 Production fluctuations of individual product groups

In the beginning of the study two representative product groups of the MCCtec division are chosen and their associated production figures of the last years are analysed in detail. The chosen product groups are the HS group and the group of LHM cranes (examples see Table 25). To get more significant results and show the dimensions, the quantity of produced products is transferred into the corresponding average production hours via averaging the hours of selected projects (see Figure 20 and Figure 21). The different product types show a noticeable difference in average production time due to their variation in size.

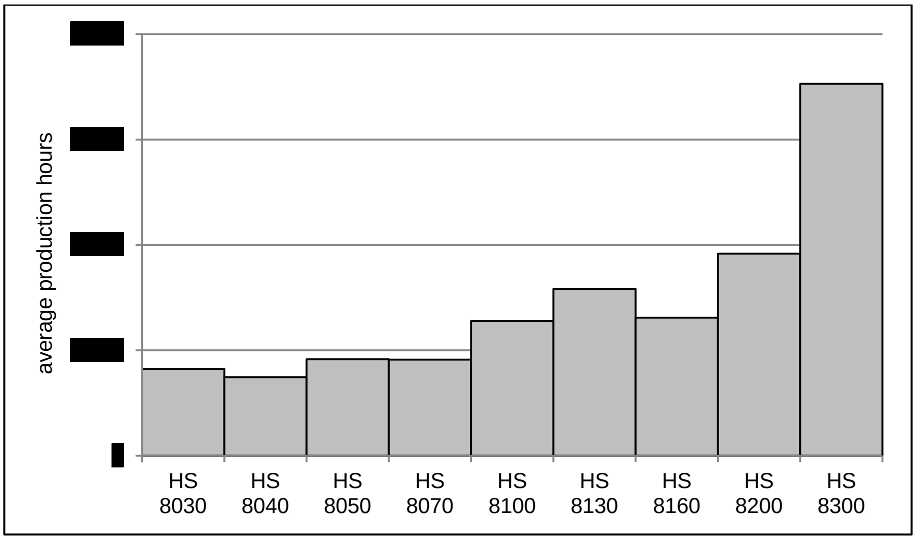

Figure 20: Average production hours HS products [158]

The duty cycle crawler cranes are chosen as representative products because of their high importance to the production site in Nenzing. In the future, the further development of these products will be crucial for the

[158] cf: company-internal source: Production figures, Liebherr Nenzing intranet [31-08-2015]

success of the production site. Regarding production fluctuation, focus is put on the recent years 2013 to 2015, where it was especially high.

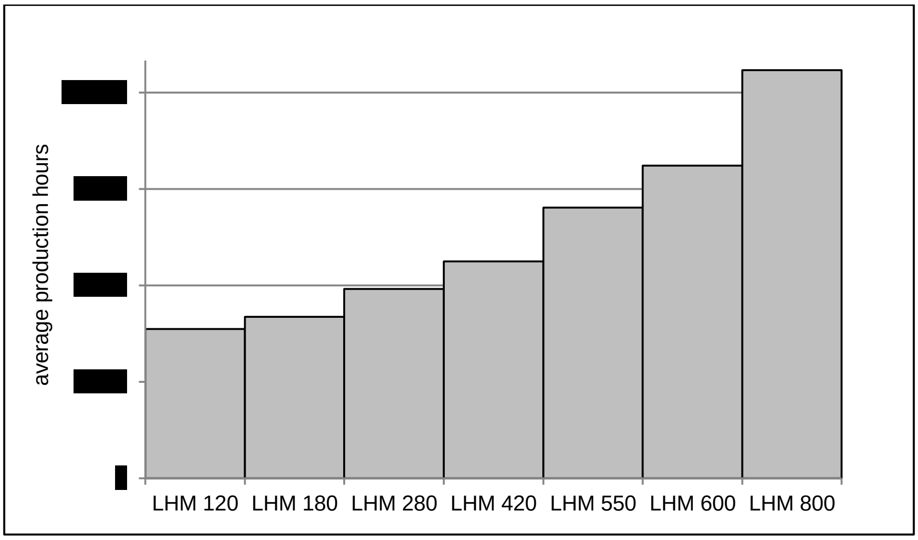

Figure 21: Average production hours LHM products [159]

The product group of mobile harbour cranes is especially important to the production site in Rostock and to the whole MCCtec division because of its high share of the total production volume. Furthermore, Liebherr is the world market leader in the segment of mobile harbour cranes.[160] As a small simplification only the main type LHM, within the group of mobile harbour cranes, is considered. Regarding the LHM production in Rostock the fluctuations between the years of 2009 and 2011 stand out particularly.

Table 5, on the next page, provides an overview of the most important figures of the chosen product groups and summarizes the reasons why they are considered that important to the MCCtec division.

[159] cf: company-internal source: Production figures, Liebherr Nenzing intranet [31-08-2015]

[160] cf: Liebherr annual report (2014), p.23

	HS - Duty cycle crawler cranes	LHM - Mobile harbour cranes
Producing sites	LWN, LHK	MCR, LSW, LWN
Actual product types	9	7
Reasons for analysing	Important product for LWN	World market leader – big share of overall production
External environmental influences	Construction economy	Container handling in harbours
Share of total production hours	[redacted]	[redacted]
⌀ Production hours per crane (planned times)	[redacted]	[redacted]
⌀ Total production hours per year	[redacted]	[redacted]

Table 5: Detailed information about the chosen product groups [161,162]

The 9 different products in the group of duty cycle crawler cranes are mainly produced at LWN. For the sake of completeness the negligible amount of HS cranes produced at a Liebherr site in Hong Kong (LHK) are mentioned too. With an average production time of around [redacted] hours per crane and an average total production time of [redacted] hours per year the HS product group represents around [redacted] of the production in Nenzing. Regarding the whole MCCtec division its share of average production hours is around [redacted]. The demand of duty cycle crawler cranes depends strongly on the construction economy. However, a detailed analysis of this fact would exceed the scope of this study and is not considered further.[163]

The LHM mobile harbour cranes are currently produced at three sites of the MCCtec network. However, the site in Rostock can be seen as the main producer of the cranes. In the past Nenzing was producing LHM cranes but due to several strategic reasons the production is at the moment being shifted to the site in Rostock. Currently the production site in Sunderland is also producing a small amount of LHM cranes. Anyway in the further study solely the numbers produced at MCR are considered because the share of production hours of the other sites is comparatively small. There are currently 7 different LHM products produced. The production time for an average LHM

[161] cf: company-internal source: Production figures, Liebherr Nenzing intranet [31-08-2015]

[162] company-internal source: Pröckl (2015), EK-Stundenentwicklung

[163] cf: ibidem

crane at MCR is almost [redacted] hours. The reason that the production time of an average LHM crane in all sites is a little bit lower than at MCR is their focus on the bigger cranes of the group. In an average year the total production time of LHM cranes adds up to around [redacted] hours. This corresponds to [redacted] of the overall production time of the MCCtec division. This fact once more emphasizes the importance of this product group to the whole company. Furthermore the numbers show the impact one single crane can have on the production as it needs [redacted] of production hours to be built. Another reason for analysing the LHM product group in detail is the participation of three sites at the overall production. Regarding agility this ability of shifting whole products between the sites of the network represents a strong instrument in order to handle market volatilities.[164]

Now as the representative products are introduced and their choice argued, the production fluctuations of recent years are presented. Through presenting the fluctuations in the duty cycle crawler cranes product group and the LHM mobile harbour cranes group, the transition to the variation in production of the whole production sites is carried out. Within the analysis of the HS production figures another interesting event in relation to agility gets evident. In 2015 a big order of 51 cranes was received. Details on that are provided in 4.2.3.[165]

4.2.2 Production fluctuation of the HS product group

During the analysis of the HS production figures of the last years, besides the obvious decrease in 2009, the downturn and following upturn between the years 2013 and 2015 are the most evident fluctuations (see Figure 22). In numbers the production in 2013 of almost [redacted] hours was reduced by around 40% to [redacted] hours in 2014. This drastic decrease was followed by an even stronger increase of around 90% in 2015 where almost [redacted] production hours for HS cranes were needed. Furthermore, according to the current state, the forecast of 2016 shows a stable trend of HS production.[166]

[164] cf: company-internal source: Pröckl (2015), EK-Stundenentwicklung

[165] cf: www.liebherr.com [30-09-2015]

[166] cf: company-internal source: Production figures, Liebherr Nenzing intranet [01-09-2015]

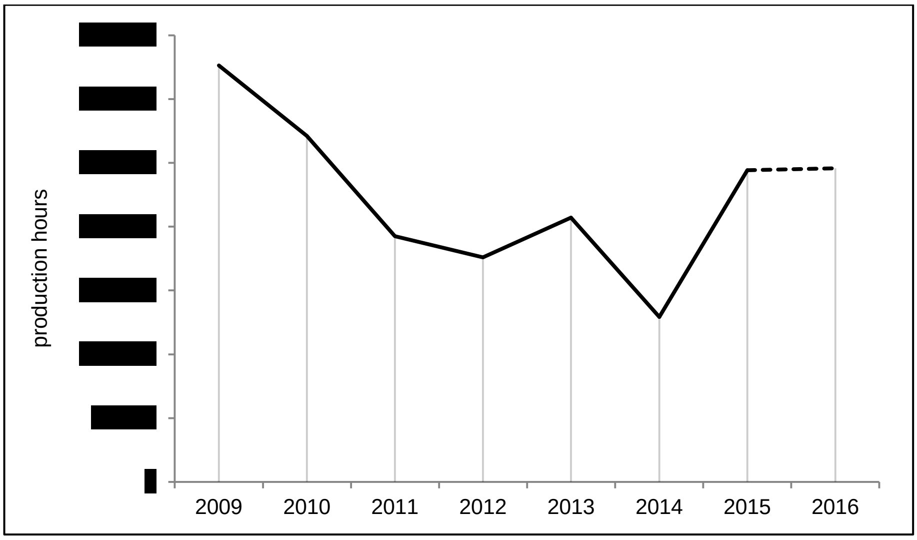

Figure 22: Production hours of HS-cranes at LWN between 2009 and 2016 [167]

4.2.3 Special case: Big order

When looking at the production figures of the individual products of the duty cycle crawler cranes group in the last years, another event catches the reader's attention. In 2015 a big order of 51 cranes of the type HS 825 HD was received from the Turkish General Directorate of State Hydraulic Works (DSI).[168] This big order represents an exception as the demand of this crane type was usually low and so far only single cranes had been sold. In Figure 23 the production hours of the different HS products in the last years are presented. As the HS 825 HD product is rather small and its average production hours lower than most of the other HS products, its impact is limited. The production of 51 HS 825 HD cranes approximately corresponds to the production of 25 average HS cranes. However, such a big order still represents a challenge for the production site and can be seen as a special type of demand volatility.[169]

[167] cf: company-internal source: Production figures, Liebherr Nenzing intranet [01-09-2015]

[168] cf: www.liebherr.com [30-09-2015]

[169] cf: company-internal source: Production figures, Liebherr Nenzing intranet [02-09-2015]

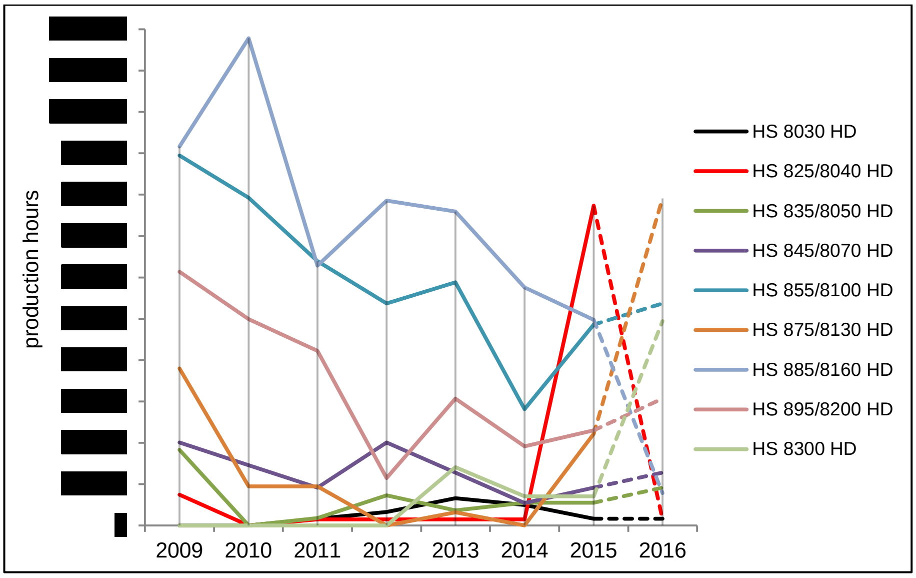

Figure 23: Production hours of HS products from 2009 - 2016 [170]

Concerning the handling of such events the following levers (see Table 6) are gathered through interviews with responsible Liebherr employees at LWN.

Selected levers for the handling of big orders
Deployment of a responsible production engineer for each big order
Installation of a responsible project team
Early prototype testing by the customer to agree on product details
Enhancement of capacity on the concerned production line with own and temporary workers
Negotiations with all suppliers regarding feasibility, time schedule and discounts
Intensive study of profitableness and feasibility

Table 6: Selected levers for the handling of big orders [171]

So far big orders had been rather the exception than the norm, but with the new orientation of the production site in Nenzing towards the solely production of construction machinery and its associated higher quantities it is assumed that their amount will increase in the future. A detailed discussion of each lever would go beyond the scope of this research. However, the further

[170] cf: company-internal source: Production figures, Liebherr Nenzing intranet [02-09-2015]

[171] based on expert interview with T. Pröckl, works organisation LWN [28-07-2015]

improvement and concentration on big order handling can be seen as a potential future research field.

4.2.4 Production fluctuation of the LHM product group

During the analysis of the LHM production figures of the last years at the site in Rostock the fluctuation between the years 2009 and 2011 turned out to be the most critical one. In Figure 24 the production figures of the last years are presented. From the year 2009 to 2010 the production hours were reduced at a rate of more than 40%. In 2011, however, the production was rising again by 75% of the previous year.[172]

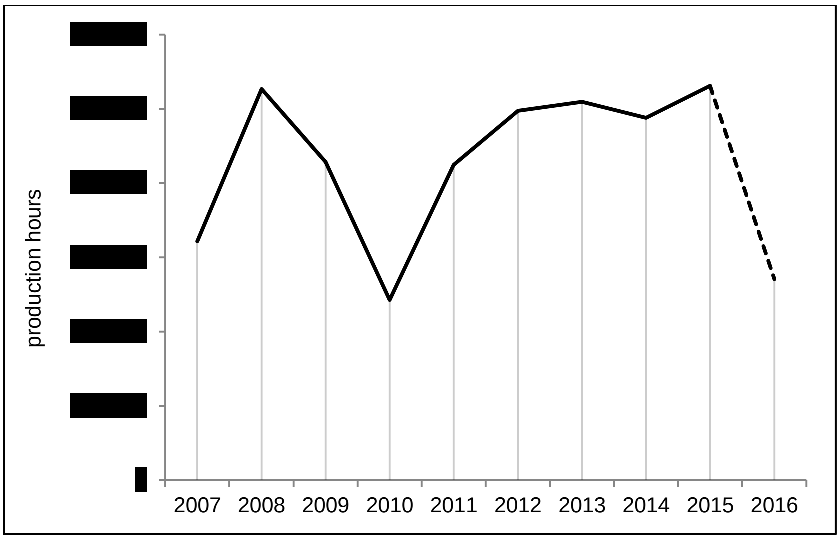

Figure 24: Production hours of LHM-cranes at MCR from 2007 to 2016 [173]

The inspection of the downturn in 2010 is especially interesting when the forecast of the year 2016 is considered. Today's forecasts show that in 2016 the production of the LHM cranes at MCR will presumably decrease at an even higher rate than in 2010. The high share of LHM cranes of the total production at MCR can be seen as an indication that the overall production hours will decline also in 2016. This fact will be one of the key points taken into consideration in the next section.

[172] cf: company-internal source: Production figures, Liebherr Nenzing intranet [01-09-2015]

[173] cf: ibidem

4.2.5 Production figures of the individual production sites

Now that production fluctuation has been shown on the lower level of individual product groups, the investigation of the overall fluctuations in the individual production sites is conducted next. In Figure 25 the development of the overall production fluctuation in Nenzing from 2005 to 2015, including 2016's forecast, is shown.

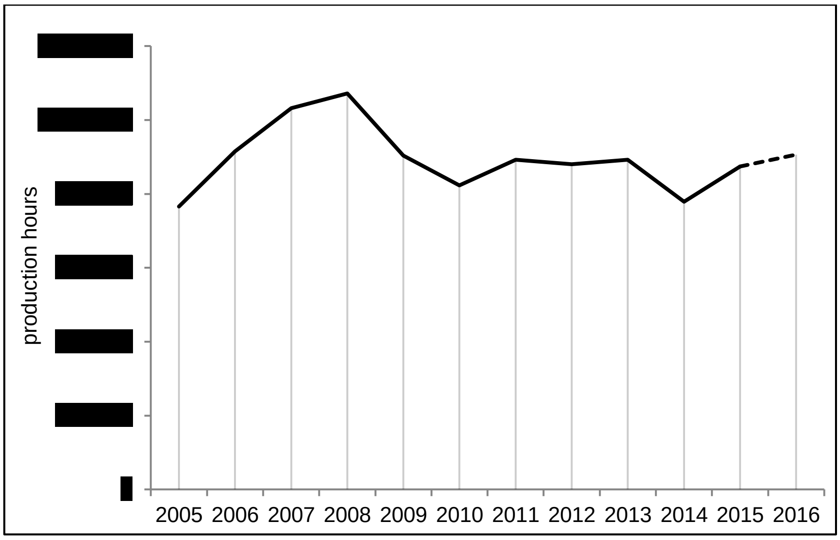

Figure 25: Development of overall production hours at LWN since 2005 [174]

The overall production hour statistics of the site in Nenzing show a stable development. In the years before 2009 a higher amount of production hours is evident. Besides the bend between 2008 and 2010 in recent years the biggest fluctuation occurred between 2013 and 2014. In 2014 the production hours of the whole site in Nenzing decreased by around 13%. In absolute numbers this corresponds to approximately [redacted] hours less than in the year before. In the following year the production increased again by around [redacted] hours, which corresponds to an increase by 12%. Additionally a forecast of 2016 is presented. The trend is indicating a stable development with 4% growth.[175] In Figure 26 the fluctuations of production at the site in Rostock since its foundation, including 2016's forecast, are presented.

[174] company-internal source: Pröckl (2015), EK-Stundenentwicklung

[175] cf: ibidem

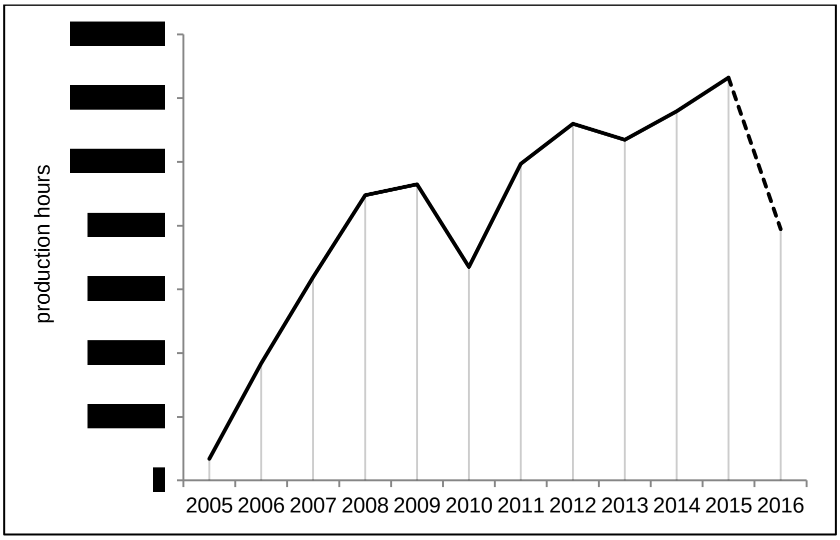

Figure 26: Development of overall production hours at MCR since its foundation [176]

One can see from the figure above that the performance of the whole production site in Rostock was especially varying between 2009 and 2011. This incident posed a big challenge to the MCCtec division and to the production site in Rostock and required certain measures in order to handle the situation. In numbers the production shrank by approximately [redacted] hours from 2009 to 2010, which corresponds to a decrease of almost 30% compared to the previous year. In the year 2011 the production volume increased again by [redacted] hours and a percentage of around 50%. The forecast for 2016 shows a massive decrease of overall production hours at a rate of 38%. [redacted] Next, in Figure 27 the production fluctuations at the two other sites LCC and LSW are shown.[177] One can see that the amount of production hours at LCC is growing at a small but constant rate. One exception is 2010 where production hours declined as in all other sites too. At LSW the production is on a stable, slightly decreasing level since 2006. Forecasts of 2016 show a rather declining trend at LSW.[178]

[176] company-internal source: Pröckl (2015), EK-Stundenentwicklung

[177] cf: ibidem

[178] cf: ibidem

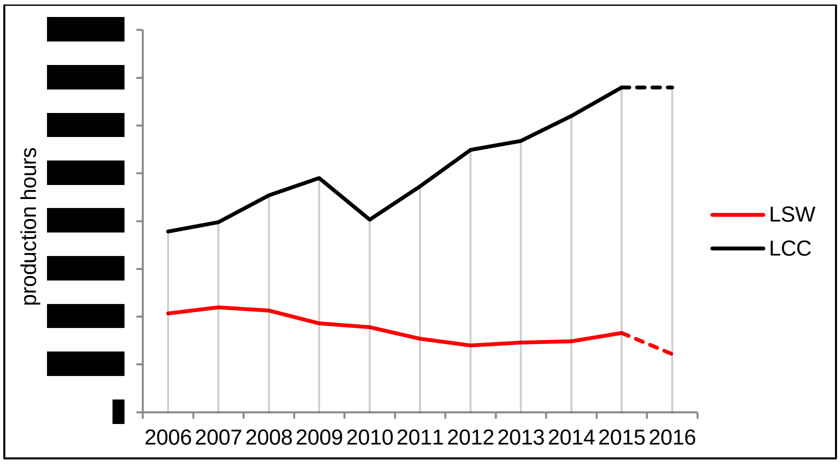

Figure 27: Development of production hours at LSW and LCC since 2006 [179]

4.2.6 Production figures of the MCCtec division

To conclude this section, the fluctuations in production hours of the overall MCCtec division in recent years, is shown in Figure 28. A forecast of 2016 is provided as well.

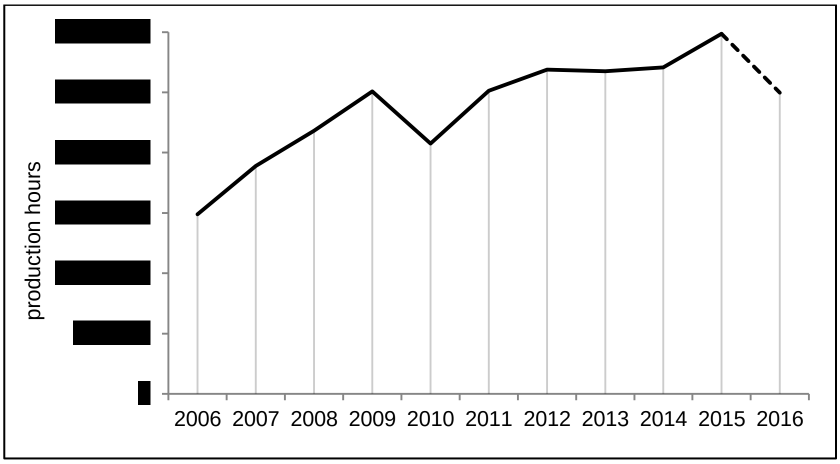

Figure 28: Production hours of the MCCtec division from 2006 to 2016 [180]

The fact that the MCCtec division consists of four production sites can be seen as an advantage as fluctuations of individual sites can be cushioned to a certain extent. However, especially in the years 2009 to 2011 a strong

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[179] company-internal source: Pröckl (2015), EK-Stundenentwicklung

[180] ibidem

fluctuation is evident. Over the years a small increase is noticeable, but similar to the years 2009 and 2010 the forecast for 2016 indicates a decline in production hours. The reason for this is mainly the decrease of production, which is expected in Rostock, next year.[181]

4.3 Operational agility levers to handle production fluctuations

In order to assess the ability of the production network to handle high variations in production, the highest fluctuations of the past and the set measures, are investigated. A special focus is put on the years 2009 to 2011 at MCR and 2013 to 2015 at LWN. Additionally, the forecasts of production hours for 2016 are considered. These focuses call on the one hand for the search of the best agility levers to manage a decline in the amount of production hours by almost 40% within one year. On the other hand levers to handle production increases by up to 50% in the same time period are demanded. In a first step of the analysis of the production site’s and the network’s ability to handle such high fluctuations the levers, which were applied in the past, are gathered via expert interviews.

Lever	Type of agility	Lever category
Adjustment of temporary workforce in production	Labor	Number of employees
Exchange of workers within the sites and the division	Labor	Employee transfer
Adjustment of shifts	Labor	Work time flexibility
Flexible working hours - time accounts in production	Labor	Work time flexibility
Short time work	Labor	Work time flexibility
Subcontracting within the division and with external partners	Assets	Adjust capacity and availability
Shifting production of whole products to the network partners	Assets	Adjust capacity and availability

Table 7: Agility levers in operations [182,183]

[181] cf: company-internal source: Pröckl (2015), EK-Stundenentwicklung

[182] based on expert interview with T. Pröckl, works organisation LWN [28-07-2015]

[183] based on research of Alexander Pointner / IBL Institute at Graz University of Technology

Together with the consideration of further suitable levers from theory, Table 7 shows the outcome of this inquiry. In addition the categorization of the levers and the type of agility which is concerned, are presented.

4.3.1 Adjustment of temporary workforce in production

Without doubt one of the most effective levers in levelling production capacity at the individual sites is adjustment of the temporary workforce amount. The big advantage of hiring temporary workforce for a company is the connected flexibility of capacity adjustments. The short notice period and the resulting limited risk of investment are the crucial points. The regular notice period of a temporary worker at LWN is two weeks. In special cases this time can differ. A too frequent substitution of workers should be avoided because of the lack of training of new staff. While a fork lift operator can probably work independently within one day, an assembly operator has to be trained for weeks in order to perform well.

Another decisive factor is the planning procedure of the amount of temporary workforce. At LWN a rough plan of the upcoming year is carried out annually. However, almost every day an adaption of the amount is requested by the responsible persons of the production lines.

Regarding the profitability of employing temporary workers it can be said that a long-term employment of workers with temporary contracts is rather expensive and should, therefore, be avoided. Because the immediate availability comes at a price, the duration of approximately 6 months marks a turning point in the profitability of temporary workers. However, at LWN individual cases with temporary workers who have been employed for around 15 years are known as well.[184]

Type of temporary workforce	Amount
Blue collar workers	284
White collar workers from MCR	114
Others (white collar workers, staff of external engineering offices,…)	63
Total amount	461

Table 8: Composition of temporary workforce at LWN in October 2015 [185]

[184] based on expert interview with A. Nigsch, human resources LWN [07-10-2015]

[185] based on e-mail communication with A. Nigsch, human resources LWN [07-10-2015]

In order to get a feeling of the amount of the temporary workers at the sites, Table 8 shows the current composition of temporary workforce in October 2015 at LWN. The conspicuous high amount of white collar exchange workers from MCR can be seen as a special occasion and is caused by a shift of the maritime products from Nenzing to Rostock and the associated know-how transfer between the sites. Another result of this reduction of product groups and the associated change in many departments at LWN is the general high amount of white collar workers with temporary contracts. Additionally it should be mentioned that workers from the warehouse and transportation departments which have no direct influence on the planning of production hours are included in Table 8 too. After clarifying the most important characteristics and the pros and cons of temporary workforce as well as its current composition at LWN in the following the applicability of the lever to handle demand fluctuation will be analysed.

At the site in Nenzing the share of production hours performed by temporary workers on the shop floor level decreased from an average value of around 30% until 2008 to around 20-25% of the overall production hours in recent years. Because of the good order situation in 2015 the share was temporarily higher again than 30%. At the site in Rostock a similar trend is noticeable. However, there is one exception. In 2010 almost all temporary workers were dismissed due to the massive decrease of production. In this context it should be mentioned that both sites in general try to keep a small amount of temporary workers in order to secure the workplaces of their long-term workers. This means in case of decreasing production the temporary workforce is reduced and workplaces of long-time workers are not affected in first place. But as already discussed earlier the decline in 2010 was so huge that unusual measures were indispensable and plans had to be changed. The following two figures show the correlation of total production hours with production hours of temporary workers at the sites (see Figure 29 and Figure 30).[186]

[186] cf: company-internal source: intranet production hours controlling [09-08-2015]

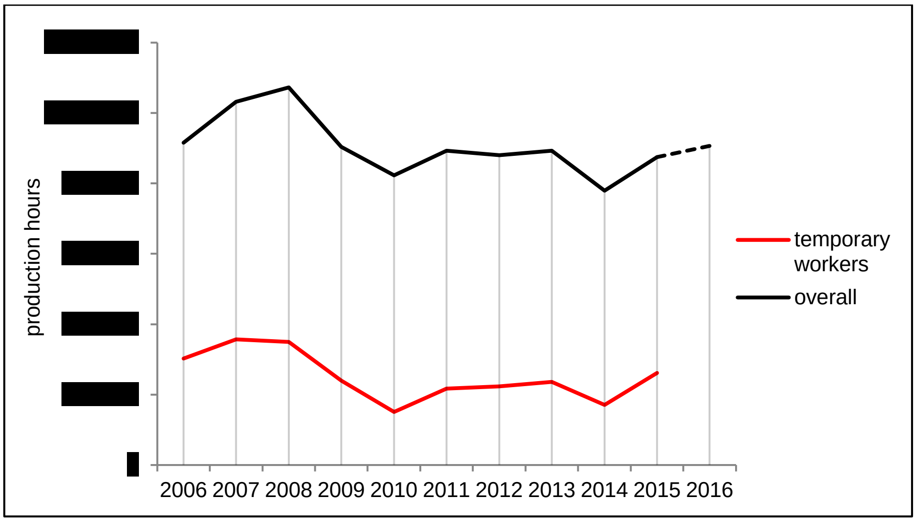

Figure 29: Production hours of temporary workers and overall at LWN [187]

At LWN in the year 2015 around [redacted] production hours have been performed by temporary workers. This implies that a certain cushion is available in case of a massive downturn of production. Although it has to be considered that a reduction to zero is not likely due to already mentioned reasons.[188]

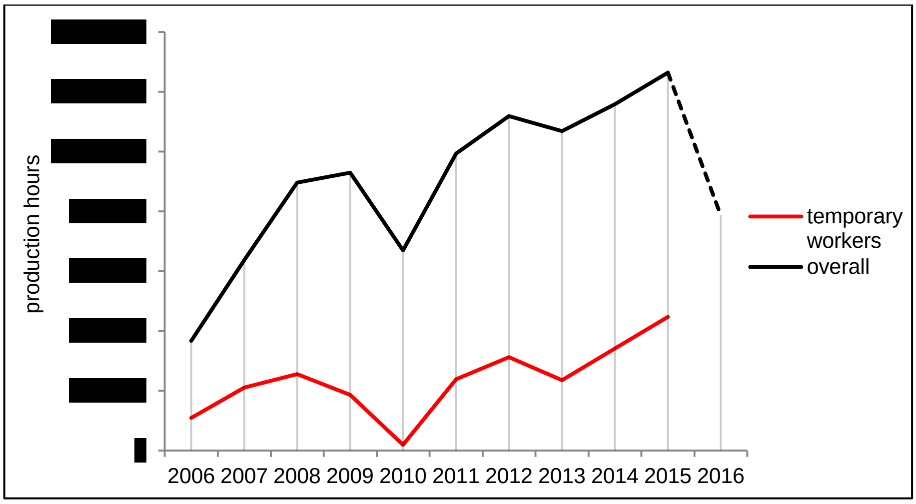

Figure 30: Production hours of temporary workers and overall at MCR [189]

[187] company-internal source: intranet production hours controlling [09-08-2015]

[188] cf: ibidem

[189] ibidem

In Figure 30, which shows the development over the years at MCR, it is conceivable that in 2016 the trend of temporary workers will be declining again. Due to the fact that an even higher decrease in production hours as in 2010 is expected, special actions will be required to manage the situation. As a result of this investigation the reduction of production hours of temporary workers in 2010 as a lever to manage the decline of production is presented in 5.3. And as the forecast for 2016 is similar to the situation in 2010 a comparison should outline the commonalities but also show the essential differences.

4.3.2 Exchange of workers within the sites and the division

As the levelling of temporary workers can be applied in every single site, the possibility to exchange workers is a big advantage that comes with working together in a network which consists of several production sites. An exchange of workers can have several causes. For example if a certain expert is missing at one site, the possibility of exchanging staff inside the network can be very useful. As an example non-destructive testing engineers usually employed at MCR are currently working at the site in Nenzing. Another trigger for exchanging workers can be for example training. As one focus of this thesis is the management of demand volatilities within a production network, special attention is paid to the exchange of workers in order to level out capacities. In 5.3 the reasons for exchanging workers within the network are listed and once more outlined.

Referring to the difficult situation in 2009 and the forecast of 2016 at MCR the exchange of blue collar workers to the network partners is another important remedy to manage these fluctuations. Of course one prerequisite for this lever is the ability of the sites to employ these workers for their part. Currently the lever is, among others, considered in order to manage the upcoming production decline at MCR in 2016.[190] An estimation of the potential amount of exchange workers is difficult to determine because it depends on the one hand on the individual skills of the workers and on the other on the particular capability of the partner sites to host them. Due to these reasons this lever will not be analysed any further but it is stated that the option of exchanging workforce can be seen as a huge strength of the MCCtec production network. For the sake of completeness the possibility to

[190] based on expert interview with T. Pröckl, works organisation LWN [08-10-2015]

exchange workers within one site is also mentioned. One characteristic example is the exchange of locksmiths between the equipment manufacturing and the steelwork department at LWN.

4.3.3 Flexible working hours – time accounts in production

Another strong lever to cushion production declines and related staff reduction is the usage of time accounts in production. The idea is that the workers are working more hours in times with higher demand and note their overtime on an account. If overcapacity is coming up, the workers can work fewer hours and the filled up time accounts get reduced again. This lever cannot be seen as a long-term solution but it’s an effective way to bridge a certain time gap of more or less demand. If the schedule planning of the next year shows that staff reductions in certain departments are inevitable, the option of using the remaining time on the accounts is checked first. This is especially important to avoid staff reduction of high skilled workers.

4.3.4 Adjustment of shifts

The adjustment of shifts can be seen as an option to react immediately on changing demand in individual departments within one production site. At LWN the standard is a two-shift operation. The shifts plans are implemented via a combination of normal working hours with additional night shifts or by an alternation of early and late shifts. However, if there are enough orders and production is running on peak levels an extension to a three-shift operation for a certain time period is conceivable. In general it can be said that night shifts or three-shift operations are preferably avoided because of the higher stress of the workers who have to work at night and the higher costs of labour for the company. In addition it can be said that productivity figures are worse during night shifts.[191]

The number of shifts is determined in the annual overall capacity planning and is continuously adapted during the whole year depending on the current degree of capacity utilization. Thereby the possible range of adjustment lies between the normal duration of a working week of 38,5 hours up to 116 hours when a three-shift operation is in place. This broad range offers great opportunity to react on demand peaks in the different departments. Concerning the case examples of decreasing and increasing

[191] based on expert interview with T. Pröckl, works organisation LWN [08-10-2015]

overall demand in one production site the effectiveness of adapting the shifts is limited because, as already mentioned, it is more a tool for balancing production or reacting on shortages in individual departments. If shifts are increased in one department, others can probably no longer keep the pace. Of course it always depends strongly on the individual circumstances.

4.3.5 Short time work

Caused by the drastic decrease of demand in 2009 short time work was induced at the site in Rostock. Due to the fact that MCR was growing at a rapid pace it was decided that the main burden will be carried by the site. Hence MCR was the only site of the MCCtec network which switched to short time work during this period.

Generally the lever of short time work is trying to be avoided because it is quite expensive for the company. Therefore, it can be seen as kind of a last resort to a strong decline in production. From the worker’s perspective the measure is seen very critical too because reduced wages are the consequence.

Around the years 2009 and 2010 also other sites of the Liebherr group, as for example the one in Bischofshofen, faced short time work. For around 50 workers from Bischofshofen, who were strongly dependent on a stable income, the Liebherr Group offered the possibility to them to work at LWN for the affected time period. This incident shows impressively the care of the family-run company towards its workers and the importance of the possibility of exchanging workers in critical situations.

4.3.6 Subcontracting within division and with external partners

Definitely as well one of the most important levers to manage production fluctuation is subcontracting. The possibility to steer the amount of work which is outsourced to subcontractors is a very powerful tool to level out production. Concerning the MCCtec division the most suitable components for subcontracting are steelwork parts as the complexity is manageable and strategic important know-how can remain inside the own company. Therefore, the majority of subcontracting parts are steelwork components. However, lately a trial with subcontracting of assembly has been conducted at LWN.[192]

[192] based on expert interview with M. Bösch, subcontracting LWN [12-10-2015]

At LWN usually every three months a strategy meeting is held and the order situation as well as the available capacity is discussed. Thereby the subcontracting department has to decide individually along three criteria if assigning production hours to subcontractors make sense or not. These criteria are feasibility, capacity and costs.

In a first step the feasibility of the concerned component is considered. In most of the cases this is not the crux as the design department is urged to consider feasibility already earlier in the process. A rather important criterion is the available capacity as it can vary strongly from time to time. In the end also costs have to be considered. However, sometimes strategic aspects overrule cost arguments. For example diversification among the suppliers is indispensable and, therefore, the work load to be subcontracted is usually split up.

The maintenance of supplier relationships is a very important point as the establishment of new ones is a time consuming matter which lasts up to 12 months and also causes cost disadvantages. If orders to a supplier are stopped completely for a certain time period the fast resumption of work is unlikely. Therefore, at LWN a big advantage is seen in the diversity of the suppliers. In general there is no differentiation between production network partners and external suppliers. The sites of the MCCtec network as well as all Liebherr sites of the group are considered as suppliers to each other. Of course if there are big troubles with low production or capacity shortages in other sites of the network, they are prioritized in a way. However, first and foremost the own risk is evaluated and as a precaution not too many production hours are shifted to a single subcontractor. One example of subcontracting within the division is the steelwork production of the new HS 8300 crane. Although it is a product of the site in Nenzing, the main part of its steelwork is currently being produced at MCR.

As especially steelwork is suitable for subcontracting, the numbers of production hours in the steelwork department at LWN are provided in Table 9. While actual extrapolations of 2015 show around [redacted] production hours, the forecast of next year is a reduction down to [redacted] hours. The amount of currently planned subcontracting production hours at LWN adds up to about [redacted]. These numbers together imply certain latitude. It can be said that [redacted] to [redacted] hours out of these [redacted] can be retracted if overcapacity is coming up. The other way round the maximum amount of production hours which can be given to subcontractors is not the decisive factor as multiple suppliers are available. Of course also the individual circumstances have to be considered if production hours are planned to be retracted from subcontractors.[193]

	Production hours [h]
Steelwork department 2015	[redacted]
Steelwork department 2016	[redacted]
Current subcontracting	[redacted]
Possible increase of subcontracting	[redacted]
Possible decrease of subcontracting	[redacted]

Table 9: Subcontracting potential at LWN [194]

At LWN the extended workbench can be seen as a special feature. It is about the subcontracting of single work steps of ongoing projects mainly caused by capacity shortages. One exception is the electro galvanizing which is solely produced externally because it is not feasible at LWN.

In conclusion it can be said that subcontracting is well suitable for peak-shaving and it can also be seen as an opportunity to retract subcontracted production hours in case of overcapacities. Thereby the cost advantages gained through subcontracting have to be compared carefully with the costs of empty halls and underemployed workers.

4.3.7 Shifting production of whole products to the network partners

Another option besides adjusting the number of workers at the individual sites or subcontracting of single components is the shifting of products between the network partners. In this case the responsible person is the head of the MCCtec division management. A shift of production of whole products is rather the exception but in some cases it makes sense. With this instrument huge amounts of production hours can be shifted and production fluctuation can be managed effectively. The drawback can be seen in the slowness of this measure and the reduced productivity if the products are produced for the first time at the new site. In this case a huge effort is necessary to ramp up the production at the new location. From experience it

[193] based on expert interview with M. Bösch, subcontracting LWN [12-10-2015]

[194] ibidem

can be said that usually higher costs due to extra work have to be expected in such a case.

One example of a recent huge strategic shift of product groups is the earlier already mentioned transfer of all maritime cranes from Nenzing to Rostock. Occasionally smaller maritime cranes are still produced at LWN but in the future the bulk of them will be produced at MCR. The site in Sunderland is as well producing maritime cranes, although to a way smaller extent.

4.3.8 Evaluation and classification of the levers

Now that all of the levers have been described in detail, this section is about the evaluation and classification of these applied agility levers in order to determine the most suitable ones. On the one hand the application possibilities of the levers are discussed as well as if they can be seen as more production site or network related levers. Table 10 provides a first classification of the levers.

Lever	Scope
Adjustment of temporary workforce in production	Production site
Exchange of workers within the sites and the division	Production network
Adjustment of shifts	Production site
Flexible working hours - time accounts in production	Production site
Short time work	Production site
Subcontracting within the division and with external partners	Production network
Shifting production of whole products to the network partners	Production network

Table 10: Scope of the operational agility levers [195,196]

Production site related levers:

The lever of time accounts in production can be seen as a local measure to handle production fluctuations. There is no need for a network and every

[195] based on expert interview with T. Pröckl, works organisation LWN [28-07-2015]

[196] based on research of Alexander Pointner / IBL Institute at Graz University of Technology

individual site can apply this lever on its own. The existence of a flexible working hour regulation can be seen as a crucial requirement to the flexibility of a production. It has to be distinguished between flexitime of office employees and the working time accounts in production. In production the workers are not authorized to dispose their overtime independently. This, in fact, is a tool to manage the capacity of a whole production department. The lever can be seen as useful if small fluctuations in individual departments of a production site are concerned. If the fluctuations are on a higher scale the lever is often not sufficient to cushion the volatility and further levers have to be applied in order to prevent a reduction of staff.

The lever of adjusting shifts can as well be seen as an individual production site related measure. The problem of adjusting the shifts is as well its limited time horizon. On the one hand the strain for the workers is increased if they, for example, have to work at night, and on the other hand the monetary aspects have to be considered. As already mentioned in the description of the lever, it can be seen as an opportunity to temporarily ensure more output of single departments but in the end its long-term effect is limited.

A third lever which can be seen as local measure is the introduction of short time work. It represents an exception in this lever collection as its scope is limited to declining production. However, the reduction range of production hours through the introduction of short time work is bigger than the one of the adjustment of shifts or the usage of working time accounts. It is stated that short time work comes with plenty of burdens. These disadvantages are affecting the company, but also its employees. Company related issues are for example the high costs and the threatening image loss through such a severe measure. The workers are mainly affected through the temporarily reduction of their wages. To sum up the lever of short time work can be seen as a last resort to a heavy decrease of production but is not suitable to react on increasing demand.

The possibility of adjusting the temporary workforce of the individual production sites is the last production site related lever. At LWN and MCR the temporary workforce adaption is one of the major levers to react on increases or decreases in production. At LCC and LSW the possibility of capacity adjustments through temporary workers is lower because the amount of them is usually lower. The major difference to the three previously mentioned levers is the time horizon. Although the adjustment can be done within a short time the new capacity level can remain on higher or lower level for a longer time. This combination of fast adaption and long-term impact is the major advantage of this lever. The scope of the adaption is depending on the previous amount of temporary workers and can, therefore, differ strongly. The temporary workforce is additionally seen as a cushion to prevent a company from laying off long-term staff.

Production network related levers:

In the following paragraphs some of the strengths of the MCCtec production network are highlighted. The existence of a production network enables further levers in order to react on volatilities.

The exchange of workers within the division is one example of the opportunities such cooperation offers. Sharing a big expert pool provides the possibility to further train ones workers but also enables a simple exchange caused by different capacity utilizations. The ability of the sites to host exchange workers from other sites is one of the key factors concerning the feasibility of this lever.

Subcontracting within and out of the network is another strong tool to manage production fluctuation. The cooperation within the MCCtec network offers the opportunity to subcontract a part of the orders, but the production still remains in the same division. Subcontracting within the division is especially useful if the capacities of the network partners differ strongly. Concerning the increase of subcontracting, a big scope is given. However, the reduction of subcontracting is limited due to above mentioned reasons of maintaining the cooperation with the suppliers at least on a minor level.

The shifting of the production of whole products inside the MCCtec network is a major strength. However, this lever has to be considered as an exception to the others as an adjustment in this field is rather a question of strategy and is decided on executive level.

During this section a lot of possibilities to manage fluctuating production hours had been presented. In conclusion it can be said that the company’s performance of managing these up and downturns is already on a good level, however, there is still room for improvement. In 5.3, as a result of this analysis, the best suitable operational agility levers are presented.

4.4 Qualitative analysis of the agility level

This part of the study is about the qualitative analysis of the agility level of the overall network along selected categories. As already discussed in the theoretical part of this thesis, agility in production can be divided into seven different categories. Since a detailed assessment of all categories would exceed the scope of this thesis, the following agility categories and their sub-categories are looked at more closely:

- Agility in operations
    - Labor
    - Assets and production process
    - Network
    - Logistics
    - Purchasing
    - Product design
- Strategic agility
- Organisational agility
    - Culture and people
    - Organisation and processes

Financial and commercial agility related issues as well as the agility governance and monitoring system are not treated further. The information of the following analysis is gathered through expert interviews, the study of company internal material as well as own observations.

4.4.1 Agility in operations

In this section agility aspects concerning the agile operations category are discussed. The category is divided into sub-categories which are discussed one by one.

Labor:

As the main part of the agility levers discussed in the previous chapter are associated to this sub-category and in order to avoid repetition, only brief outlines are given.

Employee transfer:

The possibility of the MCCtec division to have a large amount of versatile skilled employees available can be seen as a big strength. Transferring employees between departments within one site or across the production network can help in many ways to overcome troubles. In 5.3 the reasons and benefits of exchanging employees like the levelling of capacity or the exchange of experts, will be presented. The most important requirement for a successful transfer of employees is their versatile applicability. Recommendations on how to increase the skills of workers by introducing job rotation or job enlargement are for example given in 5.6. In conclusion it can be said that for the MCCtec division employee exchange within the production sites and across the network is already on a good level and can be seen as a big strength. However, there is some improvement potential left in the organisation of systematic versatile training of the workers.

Number of employees:

This section deals with the possibility of the individual production sites to adapt their number of employees if necessary. The main agility lever within this category is the adaption of the temporary workforce. The possibility to react quickly to capacity fluctuations with the adjustment of the number of temporary staff is important as it offers a big scope of adaption. In order to prohibit a fire and hire philosophy, the site in Nenzing tries to stabilize the number of long-term employees by the continuous adaption of the amount of temporary staff. Details about the temporary workforce policy at LWN are discussed in 4.3.1. In conclusion it can be said that the planning procedure and the permanent review and adaption of the number of temporary workers is already on a good level. The planning of the works organisation department at the beginning of every business year and the permanent communication of the human resource department with the responsible foremen from the production lines can be seen as sufficient. Therefore, no further suggestions are provided in this respect.

Working time flexibility:

Several levers in order to steer the working time have already been introduced in the previous chapter. To summarize it can be said that with the experienced application of levers like flexibility in holiday periods, working time accounts in production, the adaption of shifts or the experience with the implementation of short time work, the MCCtec network is well positioned in this respect and no further recommendations for adjustments are necessary at this point.

Assets and production process:
Next, issues regarding the assets and production processes of the production sites are discussed in detail. Thereby several areas like for example the adjustment of capacity and availability via subcontracting or the standardization of production equipment in order to ensure exchangeability, are considered.

Adjustment of capacity:
An effective possibility to manage the capacity utilization and, therefore, the agility is the steering of the degree of subcontracting. External subcontractors as well as also subcontractors out of the own network are commissioned to produce mainly steelwork parts in order to level out one's own production. In case of high long-term fluctuations even the production of whole products can be shifted between the network partners. This possibility of shifting the production of parts and even whole products within the intra-firm network can be seen as a major strength of the MCCtec network. Together with the option of subcontracting external partners, this capability of shifting orders is a robust mechanism and can to a certain extent help to balance out the production of the sites. In order to ensure a good exchangeability of orders between the sites of the network a standardized machine park is advantageous. This aspect will be discussed later on in more detail.

At LWN a separate department is responsible for any subcontracting and the extended workbench (Explanation see 4.3.6). The fact that external suppliers are treated in the same way as members of the MCCtec network is a potential point for improvement. Hereby a closer collaboration would more effectively hamper overcapacities and underemployment in the individual sites.

Another way to adjust the capacity of production in respect to the available assets is the opportunity to lease or rent production equipment. Within the MCCtec this approach is not common. There is a clear process in place to handle investment decisions. First several different investment options are evaluated and rated among certain criteria. After clarifying the circumstances and comparing the investment alternatives, a decision towards one of the options is made. Once the investment is approved, in most cases the new equipment is directly purchased.

Standardized production equipment:

Another important point regarding the assets of production is the standardization of production equipment within the network. In order to further develop the idea of enabling versatile skilled workers to work site independently and to improve the exchangeability of orders, a certain degree of standardization concerning the equipment within the network seems to be essential.

The analysis conducted in 4.1 shows that standardization regarding production equipment among the network is already on a good level. Although, there is still some room for improvement left. The tracking of the current developments which is also a part of the inquiry in 4.1 can especially be seen as crucial to the cooperation within the network. The analysis of the current state is essential because at the moment there is no summarized overview of all the production know-how at the individual sites available. Furthermore, relevant enhancements in production technologies are currently not systematically communicated. Because sharing of new insights and improvements in production technologies can be seen as crucial to the overall optimisation of the network, closer attention should be paid to it. It should also be considered that a successive adaption of these improvements at all the sites can multiply the positive effects.

This lack of transparency concerning production technologies and current developments and, therefore, of the possibility to increase the benefit from the network, is finally taken as a reason to suggest a new centralized production know-how management entity. Details are provided in 5.6.

Collection of real time production data:

Another important issue is the collection of real time production data. Currently the implementation of a division-wide Manufacturing Execution System (MES), in order to steer the production in real-time, is considered. With the help of these real time data the capacity shortages and other upcoming problems in production can be identified earlier and an appropriate action can be taken within short time The capability to instantly react on any changes in production can be seen as a key instrument in order to increase agility. However, a detailed discussion about it would go beyond the scope of this study and is, therefore, omitted.

Agile production technology:
Tracking the latest trends in production technology is indispensable to a modern, successful organisation. Thereby additive manufacturing technology like for example 3D-printing should be mentioned as the most important. The applicability of 3D-printing technology or other additive manufacturing technology to the production of Liebherr is currently tested by a group of employees. As the current progress of the research in this respect was not determined, it is not further discussed. In conclusion, the importance of tracking these latest production trends is once again underlined.

Production process layout:
As already treated earlier, there are several manufacturing paradigms known in literature. Lean manufacturing and agile manufacturing have already been described in detail in previous sections of this research. In 3.2, similarities and differences between the two paradigms are outlined. At LWN a lean initiative has been started lately. Thereby lean practices are tested and implemented along the production. Due to the changing strategic orientation of LWN from the project oriented offshore and maritime market towards a more series manufacturing oriented continental market, developments in this area are especially important for the company. While lean methods are more suitable to a balanced production, agile manufacturing is more suitable to volatile demands. Similar to the presented concept of leagility or hybrid strategies a bisection of the production process seems to be favourable. Applying lean principles before the decoupling point, the point where the product differentiation takes place, and agile principles at the processes which are more driven by customer requests. Details to the concepts are presented in 3.2.

Scalability of the production sites:
The option of expansion at the individual sites can be seen as an essential and important point for agility in the long-term view. Hereby significant differences between the sites are noted. While at the site in Rostock expansion towards more land was recently conducted, it is still in planning in

Sunderland. In Nenzing, however, a further expansion is not very likely due to geographical limitations.

Recently new landmass was banked up towards the sea in Rostock. In Figure 3 one can see the expansion. This enlargement of the production site area is important as the products, which are produced at the site, demand a lot of storage space. Additionally, an extension of the office building at MCR is currently going on. This fact reinforces the future strategy of the production site to be solely responsible for the maritime products of the MCCtec and further grow as an independent part of the network. Another issue regarding the scalability of the MCR production site is its branch site in Lubmin. It is about 120 km away from Rostock and also located directly at the Baltic Sea which offers great opportunities in direct off-site shipping of the produced products. In Lubmin Liebherr rented a 500m production hall in order to extent the capacity. Today even a 1000m long hall is available at Lubmin. The huge dimension of the production hall can be seen as insurance to capacity shortages in the future. Furthermore, the production hall is big enough to handle the big parts of the ship-to-shore cranes from the site in Killarney. Therefore, lately also steelwork parts of the STS cranes are produced in Lubmin.

Regarding possible expansion of the other production sites of the network, the situation in Sunderland is outlined briefly. As space is limited at LSW the management is currently thinking to expand the site area through acquiring the neighbour ground. In addition there is already a budget reserved for the renovation of the buildings at the site. However, the projects are stopped at the moment because of the desolate condition of the area to be bought and the unsettled question of the responsibility for its cleaning. Figure 31 outlines the current problem and the reason for the hold of the project.

Figure 31: Reason for hold of expansion plans at LSW

In conclusion it can be stated that an expansion of the production area would solve issues related to the restricted space and is, therefore, highly recommended. The prompt clarifying of the neighbourhood issue can be seen as crucial to the further development of the site.

Further expansion at the site in Nenzing is limited due to geographical reasons. In the past years several extensions of the production facilities have been conducted. For example the office building was extended, a new production hall was established lately and a big parking house for the employees was built. The limited available space and range of expansion potential of the location in Nenzing can be seen as critical.

Network:

The decentralized network of the Liebherr Group consists of eleven business groups which operate autonomously. Thereby the Liebherr-International AG, situated in Switzerland, is the holding company and is currently directing, coordinating and monitoring all issues and projects in regard to all central company matters. The board of shareholders solely consists of Liebherr family members and has the final say in all fundamental matters like the company policy, development and product policy as well as the financial and investment policy.[197]

The decentralised divisions on the other hand act autonomously which facilitates a quick reaction to market changes. Through this organisation, operations are carried out in a tailored and target-orientated manner. Decentralised operations are research and development, production, marketing or sales and distribution. Besides the four production sites, an international service network ensures qualified customer service and the supply of spare parts.[198,199]

One example for the close connection and cooperation within the network is the recent shift of the maritime products from LWN to MCR, as already mentioned in 2.2.3. In the past Liebherr already applied this splitting approach successfully several times. One of the main arguments is that in the future it is important for locations to have the opportunity to grow.[200] As in

[197] cf: www.liebherr.com [30-10-2015]b

[198] cf: www.liebherr.com [28-07-2015]b

[199] cf: www.liebherr.com [30-10-2015]a

[200] cf: Liebherr annual report (2014), p.25

Nenzing the capacity limit has almost been reached and the demand for maritime cranes had constantly been rising, this shift of production was a reasonable decision. The transportation issues at LWN are no longer relevant when the big maritime cranes are directly produced and shipped off the site in Rostock. This is another important benefit of this shift. On the contrary, this change implies some additional challenges to the network. On the one hand there is the new responsibility at MCR and the lack of know-how in the beginning. On the other hand the site in Nenzing is challenged to develop the construction machinery sector and increase sales in order to maintain its capacity utilization. Although the currently performed know-how transfer between the sites is costly and challenging, it can be said that the advantages outweigh any disadvantages. But what cannot be neglected is the threat of losing the manufacturing know-how of maritime cranes at the site in Nenzing. In order to maintain the possibility that LWN can help out with the production of maritime cranes in case of capacity shortages, it should be ensured that not the whole manufacturing know-how gets lost.

In conclusion it can be stated that the possibility of shifting production between the sites is a strong instrument and ensures a robust production network. The option of shifting can on the one hand be seen as a lever to enable a levelled production within the sites. On the other hand it serves as insurance if there is any breakdown in one of the sites. This strong backing and close collaboration increases the overall agility of the network.

Logistics:

This section emphasises on the problems concerning the handling of the big components of the MCCtec products. As a lot of parts are bulky, the transportation between the departments within the sites is slow and inconvenient. Another crucial issue is that the required space at the individual sites for storing the finished and semi-finished products is limited. This issue is especially crucial at the smaller sites. In the past finished products sometimes even had to be stored at an external location due to a lack of free space at LWN.[201]

Furthermore, the transportation of the bulky finished products to the customers is also essential as it implies huge effort (see Figure 32). Time and financial wise, transportation is especially an issue when big cranes are

[201] based on expert interview with T. Pröckl, works organisation LWN [28-07-2015]

concerned. Road transport is limited and, therefore, shipping directly off the site is a big advantage. Unfortunately a direct sea access is only provided at MCR. At LSW direct shipment was also possible in the past but due to the increasing sanding up of the river which connects the site with the sea, the transportation on the water is nowadays limited. Hence, at LSW most of the times a short road transport is indispensable. Killarney and Nenzing are facing similar problems as road transportation is unavoidable due to a missing sea access. While the distance to the next suitable harbour at LCC is rather short with around 40km, the transport through whole Germany is a cost intensive endeavour for finished products, produced by the site in Nenzing. Figure 32 shows a road transport at LCC and thereby the dimensions, of the parts to be transported, are outlined.

Figure 32: Road transport of a STS Crane component at LCC

As already mentioned before, in the past most of the maritime products were produced in Nenzing. Therefore, after finishing production, most of the time a transport towards the Baltic Sea was necessary in order to ship the crane to the customers. Nowadays the big cranes are solely produced in Rostock. However, some maritime cranes are still produced at LWN and, therefore, special transports are still carried out. Along the way to the sea, especially the road tunnels are setting limits. It is not possible to exceed the size of 4,5m in height and 6m in width. The following pictures should emphasize the difference of water and road transportation of big cranes. It is obvious that shipping a crane fully assembled is way easier and cheaper than a number of expensive road transports. The necessary disassembly and reassembly of the cranes is additionally hindering.

Figure 33: Water transport of a fully assembled LHM 600 [202]

Figure 33 shows a water transport of a fully assembled LHM 600 crane with a weight of 590 tons and a maximum height of 38 meters. The difference in effort and also in costs gets clearly visible when comparing it to Figure 34. It shows the complex transport of an undercarriage of an LHM 400 crane. The weight of the component is 94 tons. The maximum width of the transport is approximately 5,5 meters.[203]

Figure 34: Transportation of an LHM 400 undercarriage [204]

In conclusion it can be said that the advantage of the site in Rostock and its branch site in Lubmin regarding transportation is striking. The trend towards

[202] www.schiffsjournal.de [20-10-2015]

[203] cf: www.ditzj.de [20-10-2015]

[204] www.ditzj.de [20-10-2015]

bigger cranes is reinforcing this advantage additionally. However, especially at the sites in Nenzing and Killarney the transportation via the road seems unavoidable and has to be accepted as a fact. These limits and the fact that the handling of the bulky components at the sites is difficult are lowering the agility extent of the whole network respective the logistics sub-category.

Purchasing:

The analysis of the purchasing category is mainly dealing with the sourcing strategy and the cooperation with current suppliers. Investigations concerning purchasing were conducted at the site in Nenzing.

Sourcing strategy:

It can be said that multi-sourcing is one important pillar of the purchasing philosophy at LWN. Especially in the field of subcontracting multi-sourcing is frequently used. Multi-sourcing clearly reduces dependencies on individual business partners. On the one hand the risk of a supplier loss is reduced and on the other hand the negotiation position towards the suppliers is enhanced. In addition, becoming a Liebherr supplier is limited as potential future partners must own a certificate which identifies them as a reliable business partner. This check also includes the sub-suppliers as their reliability is crucial too.

Cooperation with current suppliers:

In order to maintain a good business relationship with the suppliers, it is necessary to regularly place orders and keep the cooperation up. In case of an interruption of a business relationship the rebuilding of the needed structures can take up to 12 month, of course always depending on the parts to be purchased. Furthermore, the price is probably not as good as it was before the break. This issue is especially crucial among important components whose supply is indispensable to the continuity of one’s own production. Concerning this critical parts additional safety stocks are installed in order to ensure a continuous supply. Purchasing standard parts is centralised across the whole Liebherr Group. This offers synergy effects and price advantages. This centralised purchasing also facilitates the supply within the Liebherr group. For example almost all diesel engines are bought directly from another Liebherr company. However, in single cases engines are also bought externally. This fact should be analysed as the Liebherr internal purchasing offers benefits to both involved parties and can, therefore, be seen as a benefit to the whole group. A detailed investigation of these individual cases would, however, exceed the scope of this thesis and is omitted.

In conclusion it can be said that the MCCtec network is well positioned concerning an agile purchasing strategy. Multi-sourcing and well established relationships to reliable suppliers provide a good basis. The existence of safety stocks for critical parts as well as the detailed analysis of the supplier's and sub-supplier's ability to deliver on time is reducing risks and increasing the overall agility.

Product design:

The agility in the product design of the MCCtec division is described by emphasizing the choice of materials, the usage of standard parts and the design process in general.

Choice of materials:

In the field of product design the early on made decisions are affecting the agility along the whole subsequent production process. Already at the choice of the raw material, availability and the procurement possibilities should be considered. Another crucial aspect is the design for raw material flexibility. This flexibility is only available to a certain extent because sometimes products require certain materials in order to guarantee the exact quality targets. All of the products of the MCCtec division require a high level of quality and, therefore, the material choice is limited. However, an early on consideration of these issues certainly increases the agility of the whole production cycle.

Standard parts:

Another issue which is important is the usage of standard components and standard parts. Standard parts offer advantages like the reduction of complexity, the reduction of necessary sourcing partners or their versatile applicability. Concerning the MCCtec product design departments it is clearly communicated that this issue is crucial to the development process. Throughout the network designers are well trained to pay special attention to the usage of standard parts within their designs. Furthermore, the usage of standard parts also facilitates the exchangeability of the production within the network. Connected to this issue is the design for multiple plants. If the exchangeability of the production is considered early on in the design process, huge advantages regarding the shifting of production between the sites are ensured.

Modular design and product platforms:
Concerning modular design it can be said that the importance of the concept is rising. However, the applicability of modular design at the MCCtec products has to be seen differentiated as it is more suitable to the construction machinery sector than for example to the highly project-oriented offshore products. The usage of product platforms as they are known in the automotive business is so far hardly applied in the production of Liebherr. In fact, there are some crane types which consist of the same platform but in general this concept is rather not common at Liebherr. The possibility of the implementation of product platforms or the increase of modular design should be considered individually for each product group. A detailed investigation of this aspect is, however, not part of this thesis as it would exceed the scope.

Design process:
Late product differentiation can be seen as crucial to the agility of a production system because last minute customer change requests can more easily be considered and generate less costs. At LWN it is common to produce a certain amount of cranes on stock. These are standard models and the individual equipment is added as soon as a crane is ordered by a customer.

4.4.2 Strategic agility

After discussing the agility aspects concerning the operations category, the next part of the research is about strategical considerations influencing the overall agility of the MCCtec division.

Re-shaping of the product portfolio:
The continuous review of the current product portfolio is an important component of strategic agility considerations. Similar to the previous point, it is sometimes reasonable to close down existing product areas and invest into new ones. Often close business segments are especially interesting in this case. Already existing know-how inside the company can be helpful to

ensure a head start. This procedure has often been successfully applied by the company Liebherr in the past.

Concerning the current situation of the MCCtec division a closer look at the offshore and ship cranes segment is indispensable because production figures are steadily declining in recent years. For the field of offshore cranes, the current low oil price is particularly restraining the business. In Figure 35 the development of the offshore and ship cranes production figures of the last years is shown. Additionally it has to be mentioned that especially in the offshore crane segment the significance of the produced quantity of cranes is limited because of varying crane sizes. In this single-unit project based production the production hours per crane are varying strongly. However, in general it can be seen that demands are declining in recent years. A similar trend is obvious at the ship cranes segment. While in 2008 over the whole MCCtec network almost 200 ship cranes were produced per year, nowadays the amount is way smaller.[205]

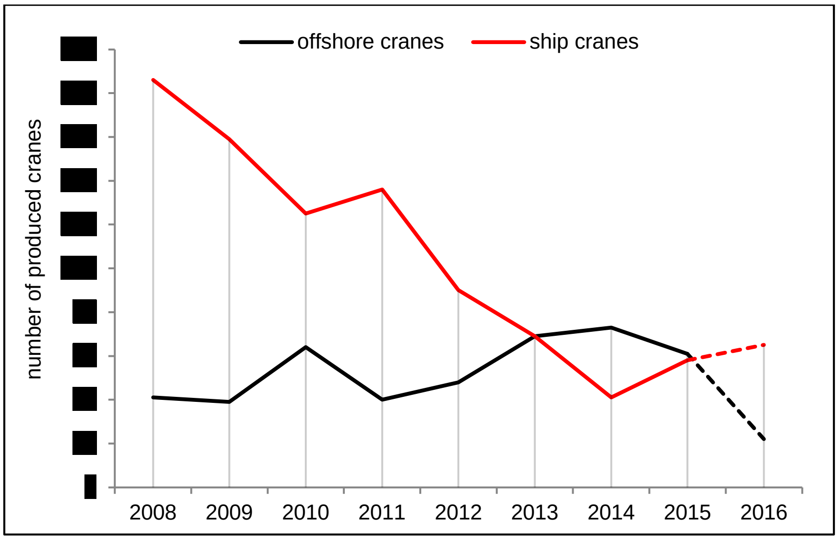

Figure 35: Development of offshore and ship crane production of MCCtec [206]

The MCCtec is constantly researching for new products. [redacted]

[205] cf: company-internal source: Production figures, Liebherr Nenzing intranet [28-10-2015]

[206] ibidem

[redacted]

Re-defining the business model:
A similar approach is the continuous review of the current business models. As the product life period of cranes is quite long, alternative business models to the production and selling of new devices are important to ensure steady revenues. Thus, after-sales revenues are getting more and more interesting. Concerning after-sales, service, maintenance, repairs, spare part supply and the preservation of customer loyalty are the most important elements.

Progressive digitalisation is facilitating this approach because more and more sensors are built in the devices in order to track its current status. In the Liebherr products a system called LiDAT is implemented. It can be seen as a comprehensive data collection and tracking system and it offers a wide variety of applications like for example an intelligent maintenance scheduling for maximum machine availability. Furthermore, it helps to plan and prepare necessary spare parts, early on.[208]

To sum up it can be said that Liebherr eagers to provide its customer with devices that offer the latest technology. Systems like LiDAT are a benefit to the customers on the one hand, but also to the company on the other hand as diagnosis of problems, planning of service and maintenance as well as spare part supply is simplified through such intelligent systems. The further improvement of these technologies is indispensable and the importance to stay up-to-date and to track the latest developments is crucial to obtain the important after-sales revenues.

Re-designing the business setup:
Besides the question of new products and new business models, the vertical integration is an important, agility related, strategic issue. The extent of vertical integration has to be regularly reviewed. At LWN the make or buy decision of steelwork in the future is a more and more upcoming issue. A good example comes from another site of the Liebherr Group. The production site in Ehingen, Germany, which produces similar but slightly bigger construction machinery than Nenzing, has already been outsourcing

[207] based on expert interview with T. Pröckl, works organisation LWN [28-10-2015]

[208] www.liebherr.com [29-10-2015]

steelwork for some time. As LWN in the future will as well focus its production solely on construction machinery, similar considerations are advisable. The issue is aggravated by the fact that in Nenzing space for expansion is limited and if the amount of cranes is further increased, the assembly department has to be enlarged in the long-term. Therefore, ideas like the outsourcing of steelwork at LWN, in order to free space for the assembly, are reasonable.[209]

In conclusion it can be said that it is important to any agile enterprise to continuously track the opportunities a re-design of the business setup provides. Respective the MCCtec especially the issue of vertical integration of steelwork is crucial.

4.4.3 Organisational agility

The following category is about considerations among the culture and employees as well as the organisation and processes of the MCCtec division.

Culture and people:

As already discussed in 3.3.3 the organisational agility of an organisation depends strongly on its people and their attitude towards change and continuous adaption. In the internal company portrait of LWN it is emphasized that there is a demand for autonomously working employees. Furthermore, the need for flexibility in thinking and the willingness to continuously adapt to customer requests is mentioned.[210]

Due to frequent changes in customer requests and the need for the company to adapt to the resulting capacity utilization, flexible working hours are a basic pillar of the organisation of Liebherr. Different time models like flexitime for the office employees or working time accounts in production are provided in order to adapt to current demands. These flexible working times are on the one hand helping the company to smooth fluctuating capacity utilization and on the other hand request a high level of individual responsibility by the workers. The benefit of the workers can be seen in the increase of independence regarding their individual working time planning.[211]

A second pillar of an agile culture is the further education of the workers in order to support their initiative. Hereby the training center at LWN

[209] based on expert interview with T. Pröckl, works organisation LWN [28-10-2015]

[210] cf: Rabitsch et al. (2015), p.46

[211] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.6

and the Liebherr Academy in Rostock play an important role. Furthermore, the dual education system at the MCCtec sites should be mentioned. This system can be seen as an important part of the education system. The apprenticeships are learning on the job at the company and once a week they visit a vocational school. This well-functioning system is especially important because of the lack of skilled workers in production. Having such a system in place where junior staff is early on integrated in the company, can be seen as a big strength.[212]

A third point which has to be mentioned in this respect is the effort of the Liebherr Group to ensure a continued existence of all its locations. So far not a single Liebherr site had to be shut down. This location security on the one hand provides positive effects on the company culture, although on the other hand it also impedes the simple relocation of production sites and, therefore, the agility of the whole group.[213]

Furthermore, the company offers a lot of additional benefits to its employees in order to increase their motivation. The sponsored lunch, the organised transport to the company and the recently built parking house at LWN are just some of the additional incentives provided by the company.

To sum up the philosophy of Liebherr, to see its employees as the most important element of the company and to encourage their development, is matching with the criteria an agile organisational culture has to fulfil.

Organisation and Processes:

In 3.3.3 the main characteristics of an agile organisational setup were presented. Flat hierarchies, flexible processes, transparency as well as a good functioning information system are seen as prerequisites.[214]

The individual production sites LWN, MCR and LCC are led by four managing directors. Due to its smaller scale at LSW only two managing directors are in charge of the lead. The responsibilities are split into the four categories sales, production, design and controlling.[215]

Superordinated four of them are managing the whole MCCtec division. All of them hold a double role as they are responsible for the whole division

[212] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.7-8

[213] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.5

[214] cf: Rabitsch et al. (2015), p.46

[215] cf: company-internal source: Organigram MCCtec (2015)

and their individual production site.[216] In the portrait of the production site in Nenzing the organisation of the MCCtec division is described as flat, market oriented, efficient and non-bureaucratically. Furthermore, the importance of the use of synergies between the sites within the network is emphasized once more.[217]

In order to benefit from these synergies a certain degree of standardization is necessary. The standardization along production assets has already been discussed in detail in a previous part of this research. At the organisational level standardization is important too. Hereby, the deviant department denotations at the individual sites have to be mentioned in particular. In order to enable a better comparability of production on department level within the network, assimilation is suggested in 5.6. Another crucial point of organisational standardization is the integrability of the software used in the individual locations. Without going into detail the necessity of similar software is emphasized as otherwise cooperation between the employees of different sites would be extremely difficult.

Due to the production shift of the maritime cranes from Nenzing to Rostock, a reorientation on production level at LWN was intended lately. A division of the steelwork department into individual fractals according to main assembly groups should increase the independence, self-organisation and vitality of these groups. In order to benefit from this new organisational structure a close collaboration with the construction department is necessary as the main assembly groups of the different products should be similar in structure and geometry. Benefits to be expected are cost reductions, a reduction of lead time and a reduction of inventory while at the same time quality stays on a high level and satisfaction of the workers is increased.

In conclusion it can be said that especially at LWN some changes in the processes and the organisation of production are necessary to adapt to the new orientation and related challenges of the production site. Concerning the overall organisation of the group it can be said that the decentralised divisions are increasing the agility. Although decentral organisation is increasing agility, a certain degree of standardization is also necessary to facilitate the collaboration within the network. Therefore, for example issues like the assimilation of department denotations have to be looked at closely.

[216] cf: company-internal source: Organigram LWN (2015)

[217] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.5

4.5 Quantitative agility evaluation

In order to draw the right conclusions and to illustrate the current situation of the MCCtec division, a quantitative evaluation of the current agility level along selected agility categories, is conducted in the end of this research. Basis of this evaluation is on the one hand the derived knowledge from previous chapters and on the other hand a list of agility levers, provided by the IBL Institute of Graz University of Technology.

Through the rating of the selected 69 agility levers the current agility level of the division derived. In order to receive significant results additionally experts from each production site of the network are involved and delivering their opinions. In the end all the gathered results are smoothened. The derived values and its interpretations as well as a comparison to a similar study conducted in the automotive supplier industry are provided in 5.4 respective 5.5.

5 Results

In this chapter the results of the thesis are presented in a compact form. In the beginning the found agility enablers from literature are listed and some of them are described in detail. Concerning the practical study, first the main differences in production equipment and the current developments respective production technologies at the individual sites are presented. As a result of this pre-study the individual production capabilities are described. The outcome of the agility lever study, the three best operational agility levers to handle fluctuating production, are presented afterwards. In the end the current agility level of the network is evaluated and as a result recommendations, in order to increase the overall agility, are provided.

5.1 Agility enablers

Through the conducted literature research several agility enablers have been found. In Table 11 they are summarized.

Agility enablers
Knowledge-driven enterprises – high qualified employees
Ability of rapid reconfiguration of the production
Production of customized, high quality products
Increased cooperation with other enterprises
The elimination of non-value adding processes
Latest software in production
Quicker and cheaper product development
Shortening of lead time
Core competence management
Modular product facilities
Development of production facilities

Table 11: Agility enablers from literature [218,219,220,221]

[218] cf: Naylor et al. (1999), p.108-109

[219] cf: Nagel et al. (1991), p.1-2

[220] cf: Yusuf et al. (1999), p.37-40

[221] cf: Cho (1996), p.323-324

In the following paragraphs selected agility enablers out of Table 11, which are considered most suitable to a company like Liebherr, are once more highlighted and linked to the current situation at the MCCtec network.

Knowledge-driven enterprises - high qualified employees:
One of the biggest strengths of the company Liebherr is its high qualified staff. As price pressure is constantly high and market conditions are rough, Liebherr is differentiating its products from the rest through innovative technologies which are implemented in their machines. The prerequisite for this approach is the existence of high skilled staff.

Therefore, it is emphasized that a knowledge-driven enterprise like Liebherr should ensure to implement the knowledge and experience of its people into its strategies and solutions.[222] In line with that Yusuf et al. (1999) states that an organisation can only be successful if it's able to incorporate knowledge and skills of its employees into its solutions.[223]

Ability of rapid reconfiguration of production:
The ability of the rapid reconfiguration of production is another crucial prerequisite in acting agile. As production fluctuation is a recurrent issue, the best possible preparation to it is indispensable. Rapid reconfiguration is facilitated by several preparatory agility measures, which are presented in 5.6. In order to reconfigure production actively in case of production fluctuation, several agility levers can be used. The best levers are presented in 5.3.

Production of customized, high quality products:
Another notable strength of the company Liebherr is its customized, high quality products. A requirement for producing high quality products is the existence of high qualified staff, whose importance was already mentioned above. Furthermore, quality has to be checked intensively in order to guarantee certain standards. As labor costs and other expenses are high in the countries of the MCCtec production, it is important to the company to differentiate its products through high quality. This enables Liebherr to sell its

[222] cf: Yusuf et al. (1999), p.37-40

[223] cf: Yusuf et al. (1999), p.39-40

products at a higher price than most of the competitors and thereby ensure the compensation of the higher production costs.

Increased cooperation with other enterprises:

Respective the MCCtec division this enabler is about the increased cooperation within the network. The importance of the strength of having four powerful production sites within the own network cannot be stressed enough. Therefore, it is all the more important to foster this cooperation. The possibility to shift production hours and to profit from each other's knowledge has to be captured in order to increase the benefits.

The elimination of non-value adding processes:

Although one may think the principle of eliminating non-value adding processes is solely belonging to the lean manufacturing paradigm, its importance to agility should not be disregarded. In literature the elimination of as many non-value adding activities as possible is also attributed to agile manufacturing. However, in order to keep up a robust production system, which is still able to react quickly on changes, a careful consideration of reducing stocks or non-value adding activities in general is necessary. When thinking about waste reduction, a differentiation of non-value adding and non-value adding but necessary processes, is highly recommended.[224]

Latest software in production:

Initiatives like the recent development of the MES are important to the future of the MCCtec's production network. With the help of real time data from the shop floor, volatilities can be tracked earlier and thereby a fast and appropriate reaction to any changes is facilitated. Furthermore, a certain degree of standardization among the network concerning the used software is indispensable. There is no sense in using inconsistent software because complexity is senselessly increased and the cooperation and exchange of information is impeded.

The necessary upgrade of the Enterprise Resource Planning system (ERP) should be mentioned as well. Currently the system Baan 4 is used as ERP-system among the sites of the network. However, this software is outdated and should be replaced with an up to date solution in order to

[224] cf: Naylor et al. (1999), p.111

benefit from the advanced functions, new software provides. Of course, in order to manage such a reorganisation, a close collaboration between the sites of the network is once more indispensable.[225]

5.2 Production capabilities of the individual sites

In order to provide an overview of the production capabilities of each production site of the network, first the existing manufacturing equipment and the current developments in production technologies are tracked. On this basis the capability of the production sites to build the products, of the MCCtec division, is evaluated. It can be stated that every production site has its own strengths and leading positions in production technology. It is crucial to track promising developments early enough and to subsequently manage the dissemination among the whole network in order to ensure that each site can immediately benefit from the advantages. The management of the developments in production technology is among others discussed in 4.1.1. The current developments at the individual production sites are summarized in Table 12.

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 12: Current developments in production technologies

[redacted]

[225] cf: Gausemeier et al. (2014), p.373-374

[redacted] Concerning standardization of already existing equipment, it can be said that the division is already doing well. However, some inconsistencies are found and the most conspicuous ones are outlined in Table 13.

	LWN	MCR	LSW	LCC
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 13: Main differences in existing manufacturing equipment

A high degree of standardization concerning the equipment is an essential requirement for the exchange of workers and production between the sites. This possible exchange is one of the major strengths of the division and should be supported. It is emphasized that in theory all production sites of the MCCtec division should be able to produce the whole product portfolio of the group. The usage of these synergy potential is one of the major strategic goals of the MCCtec group.[226] Out of the created overview of the production capabilities at the individual sites, the following conclusions are drawn:

Mobile harbour cranes:

The production of smaller mobile harbour cranes up to the LHM 550 is possible at every site. Although at the site in Killarney additional training of the staff would be necessary, as no experience in producing these types of cranes exists. Big mobile harbour cranes, however, can solely be produced at the site in Rostock. In Killarney it is possible to produce these cranes with

[226] cf: company-internal source: Portrait Liebherr Nenzing (2015), p.5

high effort too, but the production facilities in Nenzing and Sunderland are definitely too small to handle the big dimensions.

Ship and offshore cranes:

Concerning ship and offshore cranes a similar bisection is evident. The smaller cranes can be produced at every site and the bigger ones solely in Rostock. Killarney holds again a special position, as staff would need training in order to build the cranes for the first time.

Construction machinery:

The fact that construction machinery is solely produced in Nenzing is critical, because at any other site the staff would need extra training in order to build the machines. However, concerning the agility of the network, an alternative production location would be favourable and increase the failure safety and manoeuvrability and finally the overall agility of the network.

STS, RTG, RMG, Straddle carrier:

A similar consideration is reasonable regarding the ship-to-shore container cranes and the other container handling cranes, which are built in Killarney. All the other sites would need training of their staff in order to produce the complete products for the first time. Furthermore, STS cranes can only be produced in Killarney and Rostock, as the other sites are too small to handle the big components, the cranes comprise. The production of gantry cranes is, furthermore, not possible in Sunderland due to similar reasons.

To summarize, several crane types can be produced at different production sites of the network. This exchangeability of the production of whole products can be seen as a big advantage, such a production network offers. Of course in reality rather the production of single components is shifted between the sites. However, sometimes it is necessary to displace the production of whole products due to strategic reasons or breakdowns at one site. A further splitting of the crane types into their individual components would enable a more detailed investigation on the production possibilities at the sites. But as it would exceed the scope of this thesis, it is not part of this research.

Another issue, which came up during the investigation of the production capabilities, is the inconsistent department names at the individual sites. Especially at the site in Killarney, they differ from the rest of the division. In 5.6 a recommendation of the assimilation of the department names is formulated. In advance in Table 14 an overview of the inconsistencies is provided.

Department	LWN	MCR	LSW	LCC
Cutting	ZAA	ZAA	ZAA	ZAC
Steelwork	ZAB	ZAB/ZBB/ZDB	ZAB	ZAS/ZAF/ZAG
Welding	ZAD	ZAD/ZBD/ZDD	ZAD	ZAY/ZAW/ZAX
Small parts manufacturing	ZAE	ZAE	ZAE	ZAS/ZAY
Small parts machine shop	ZAF	ZAF	ZAF	ZAM/ZAS
Big machine shop	ZAG	ZAG	ZAG	ZAM
Assembly cranes	ZAH	ZAK	ZAK	ZAA
Assembly electric	ZAL	ZAL	ZAL	ZAE
Paint shop	ZAP	ZAP	ZAP	ZAP
Test stand cranes	ZAM	ZAN	ZAN	n/a
Equipment manufacturing	ZAU	n/a	n/a	ZAF

Table 14: Department names at the individual production sites

5.3 Best operational agility levers to handle production fluctuations

After establishing an increased transparency among the network, the results of the agility lever study out of 4.3 are provided in this section. Thereby the most effective levers in order to manage production fluctuation are presented and their potentials are described in detail. In Table 15 the levers are listed.

Lever	Lever category	Scope
Exchange of workers within the sites and the division	Employee transfer	Production network
Subcontracting within the division and with external partners	Adjust capacity and availability	Production network
Adjustment of temporary workforce in production	Number of employees	Production site

Table 15: Best suitable operational agility levers in order to manage volatilities [227]

[227] based on research of Alexander Pointner / IBL Institute at Graz University of Technology

The exchange of workers and the exchange of production hours which is described by the first two agility levers can be seen as the major advantage a production network like the MCCtec network offers. The adjustment of temporary workforce in production is in turn limited to single production sites and enables managing fluctuations between single departments. In the following paragraphs the reasons for choosing exactly these agility levers are presented. Furthermore, the major benefits of the chosen levers are also outlined.

Exchange of workers within the sites and the division:

While the exchange of workers inside the individual sites can be seen as a local measure, the exchange among the network offers a higher scope of adjustment and represents one of the main advantages of such a union. This is one of the reasons why this lever was chosen to be one of the best to handle fluctuations. Furthermore, the exchange of workers is not limited to the MCCtec network as also the participation of other Liebherr companies is conceivable. In Table 16 different reasons for exchanging workers are shown.

Reasons for exchanging workers	Example
Missing expert	Non-destructive testing engineers from MCR working at LWN (2015)
Know-how exchange	Know-how exchange between MCR and LWN in the course of the shift of product groups (2015)
Capacity levelling	The Liebherr site in Bischofshofen sent around 50 workers to Nenzing during short-time work (2009)
Training / further education	Regular exchange of apprentices within the network in order to gain experience

Table 16: Reasons for exchanging workers within the network

The maximum possible amount of exchanged workers is hard to estimate and depends on the individual circumstances. During the shift of product groups between LWN and MCR, a high amount of MCR employees have been working at LWN in order to get trained for their new jobs. In the beginning of October 2015, 114 white collar workers from MCR were located in Nenzing.[228] Another prevailing question, caused by the latest forecast of

[228] based on e-mail communication with A. Nigsch, human resources LWN [07-10-2015]

expected production hours in 2016 at MCR, is the temporary displacement of blue collar workers from MCR to other sites of the network in the next year.

As one can see the lever of exchanging workforce between the departments of the individual sites or among the whole network, offers great opportunities to level production. In addition, other issues like missing experts or know-how exchange are solvable through the application of this lever. This wide range together with the involvement of the whole network is the main reason for the selection.

Subcontracting within the division and with external partners:
The second chosen lever is also affecting the whole network as it is about the shift of production within the network. Furthermore, also subcontracting with external partner firms is concerned. This lever was chosen as one of the best to handle production fluctuation because of the high potential it offers. When talking about subcontracting at the MCCtec division, mainly steelwork is affected. An interview with the responsible employee at LWN, revealed the subcontracting figures of the site in Nenzing. They are presented in Table 17.

Current subcontracting	[redacted]
Possible increase of subcontracting	[redacted]
Possible decrease of subcontracting	[redacted]

Table 17: Subcontracting potential at LWN [229]

As one can see subcontracting is well suitable for managing capacity bottlenecks and it offers a huge amount of production hours which can be retracted in case of overcapacities and underemployed workers. This applicability in both directions of the fluctuations combined with the simple and quick application, are the main reasons for selecting subcontracting as one of the best operational agility levers.

[229] based on expert interview with M. Bösch, subcontracting LWN [12-10-2015]

Adjustment of temporary workforce in production:

The third lever, which was chosen, is the adjustment of temporary workforce in production. The big difference, compared to the other two levers, is its scope. The adjustment of the amount of temporary workers can be seen as a production site internal measure and only has limited influence on the production network. Furthermore, the hiring of temporary staff comes with several advantages and disadvantages. As a first result of the investigation of this lever, they are summarized in Table 18.

Advantages	Disadvantages
Quick adaption of capacity in production	Often particular training is necessary
Short notice period	Quality issues due to less experience
Less contractual obligations for the company	Expensive solution in the long-term
Protection of workplaces of long-term employees	Difficult to find qualified workers for specific jobs

Table 18: Major advantages and disadvantages of temporary workforce

Besides the description of the pros and cons, the planning procedure and the profitability of this lever, the study in 4.3.1 shows its importance in short-term levelling of capacities. The extent of this ability is shown by the example of 2010 at MCR. Back then, almost the whole temporary staff had been dismissed due to a massive decrease of production hours. In Table 19 the situation in 2009 and 2010 is shown. Information about the total production hours and the hours conducted by temporary staff is provided.

	2009	2010	Decrease 09-10
Overall production hours [h]	[redacted]	[redacted]	[redacted]
Temporary workforce production hours [h]	[redacted]	[redacted]	[redacted]
Residual value [h]			[redacted]

Table 19: Reduction of temporary workforce in2010 at MCR [230]

[230] company-internal source: intranet production hours controlling [09-08-2015]

Table 19 shows that the reduction of almost the whole temporary workforce in 2010 was not enough to cushion the decline in production hours. After the reduction of the temporary workforce there was still an overcapacity of almost [redacted] production hours left.

	2015	2016	Decrease 15-16
Overall production hours [h]	[redacted]	[redacted]	[redacted]
Temporary workforce production hours [h]	[redacted]	[redacted]	[redacted]
Residual value [h]			[redacted]

Table 20: Reduction potential of temporary workforce in 2016 at MCR [231]

Table 20 shows the situation in 2015 and 2016. Due to the fact that in 2015 the temporary workforce is on its highest level ever, the reduction of production hours can more effectively be cushioned by the release of temporary staff. However, even if the whole temporary workforce would be dismissed, there is still a residual value of around [redacted] production hours left. Furthermore, it has to be considered that the skills of every temporary worker need to be checked individually because their skills are more or less indispensable to the company. Besides, also the distribution of the temporary workforce and the capacity utilization of the individual departments are factors, to take into account. Hence, it has to be assumed that the amount of temporary workers can certainly not be reduced to zero as a residual amount of workers is indispensable and the distribution, among the individual departments, limits the reduction. These facts imply that the application of further agility levers will be necessary to cushion such a high decline in production, as it is predicted for 2016.

5.4 Current agility level

In this section the results of the conducted agility evaluation are presented. As a basis for this evaluation, the findings of the qualitative agility discussion in 4.4 are used. With the thereby derived information about the current situation of the MCCtec production network and the agility know-how of the IBL Institute of Graz University of Technology, the following quantitative

[231] company-internal source: intranet production hours controlling [09-08-2015]

results derived. In order to receive significant results experts from every production site of the network are consulted. In the end the ratings of the different locations are averaged. The results are presented in Figure 36.

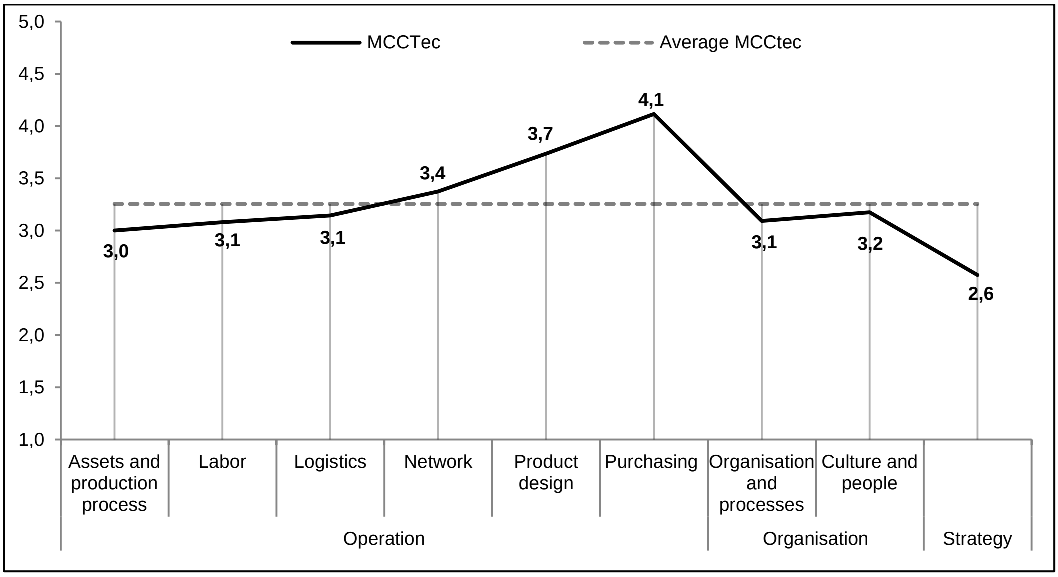

Figure 36: Current agility level of MCCtec

The chart in Figure 36 shows the current agility level of the MCCtec division among selected agility sub-categories. Highest agility is thereby associated with 5 and lowest with 1 point. While the agility level among the sub-categories network, product design and purchasing is rather high, in other categories like assets and production process, labor, logistics, organisation and processes, culture and people and particularly strategy, room for improvement is evident. In the following paragraphs a short statement to each category is provided. Thereby the reasons for the individual ratings are argued and further details are outlined.

5.4.1 Agility in operations

Assets and production process:

The rating of the assets and production process sub-category is below the overall mean value of the evaluation. On the positive side it can be said that external and internal subcontracting within the division is already on a good level. Furthermore, the standardization among the production equipment is well advanced, although there is still some improvement potential left. The possibility to change the takt times and the levels of automation are additionally increasing the agility level of this sub-category. Concerning the leasing or renting of equipment as well as the application of new business models with existing equipment, room for improvement is found. The tracking of additive manufacturing technology is another crucial point which should be considered closely.

Labor:
Concerning the shop floor, the agility rating is, though it's slightly higher, as well below the average value of the overall agility. Although the rating is rather on a lower level the adaptability of the production of the MCCtec division can be seen as advanced. Due to the fact that the MCCtec products are often project oriented and imply changes on the shop floor on a daily basis ever since, there are measures in place which ensure a certain degree of manoeuvrability. A lot of these measures are already dealt with in 4.3. However, improvement potential is evident in the field of job rotation and job enlargement. Thereby a more systematic approach is conceivable. Details on this recommendation are provided in 5.6.

Logistics:
The facts that the products of the MCCtec division are bulky and difficult to handle, result in a rather low rating of the sub-category logistics. Transportation is not only a big issue within the production site as the shipment of the finished products is crucial too. Thereby the shift of production of big cranes to the production site in Rostock, which is directly located at the Baltic Sea, facilitates the dispatch.

Network:
The good cooperation with the suppliers as well as the customers is the main reason for the good rating in this sub-category. The possibility to shift parts of production between the network partners if necessary and the provided backup in emergency situations are two further positive points which influence the rating to an above the average value.

Product design:
Concerning product design the strengths can be seen in the design for multiple plants and the standardization among the network. The fact that the different sites are able to produce most of the products enhances these

points. A close collaboration between the purchasing and product design department is, furthermore, fostering the right choice of materials and usage of standard parts. Room for improvement is seen in the development time and the modular design of the products. Product platforms are not common and could, especially concerning the standard machines, be an option for the future. Especially at LWN where the production is more and more changing to series manufacturing of the construction machinery cranes this option is promising.

Purchasing:
The evaluation of the sourcing strategy and the cooperation with current suppliers implies a high rating of the purchasing sub-category. The multi-source strategy and collaborative relationship with the suppliers can be seen as main factors. Safety stocks for critical parts and agile suppliers are preventing bottlenecks and increasing the overall agility. All in all the purchasing sub-category shows the highest agility rating within this evaluation.

5.4.2 Organisational agility

Organisation and processes:
Although the MCCtec division strives to have a flat hierarchy, the size of the company requires a certain degree of steering. Positive aspects within this sub-category are the knowledge sharing among the employees, the supported risk surfacing and the little fluctuation of managers. Room for improvement is seen in the standardization of processes and the planning of those. All in all a value close to the average was ascertained in this sub-category.

Culture and people:
In order to ensure agility in an organisation, an agile attitude of the workforce is indispensable. The evaluation of this sub-category also led to a value close the average. The regular commissioning of external experts as well as the internal knowledge and experience exchange within the production network are arguments which facilitate agility a lot. The continuous uncertainty and changing environment in the production of customized cranes as well have always been fostering agile mind-sets. Concerning the versatile skilling of the workforce, certain room for improvement gets evident. However, the

versatility of the workforce is hampered by the need of specialists in order to manage the high requirements at some production steps.

5.4.3 Strategic agility

The last sub-category of the agility evaluation is about the strategy. Strategic planning and the responsiveness of an agile strategy are the main decisive factors. The continuous drive towards innovation and new products is a very important characteristic of Liebherr. The sensing of new trends and changes, like it is also described as necessary in agility literature, can be seen as crucial.[232] Emphasize should be put on the observation of macro trends on the market. Additionally important is the manoeuvrability in case of new arising opportunities. Hereby a fast decision making is important in order to reallocate the necessary needs. Due to the decentralised structure of the MCCtec division, the prerequisites for a fast respond to these needs are given. In conclusion it can be said that the agility level in this sub-category is moderate and, therefore, certain room for improvement is given.

5.5 Comparison with automotive supplier industry

In order to increase the significance of the results, values from a similar study, concerning automotive suppliers, are presented in Figure 37.

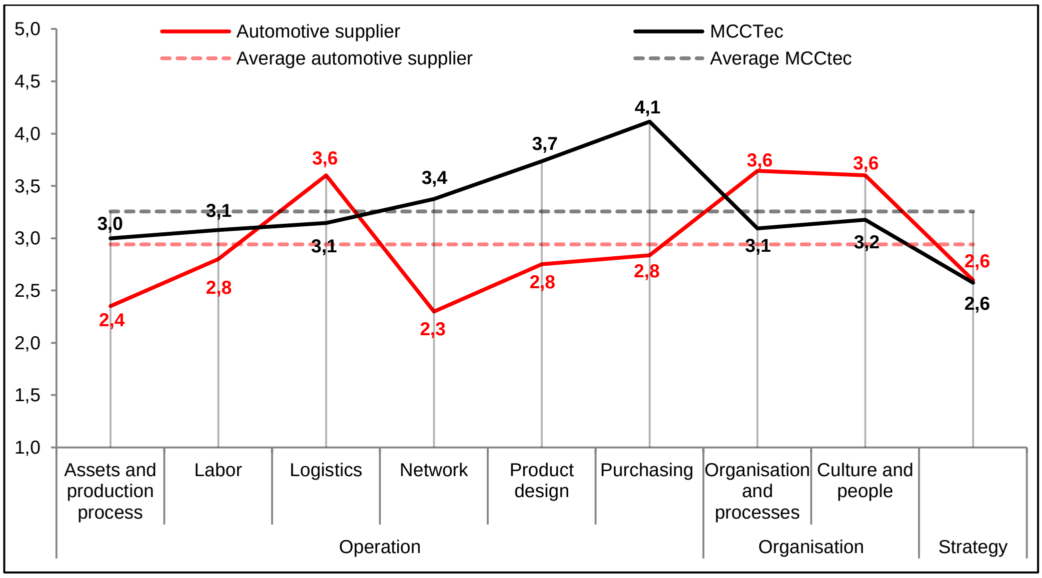

Figure 37: Comparison to the automotive supplier industry

[232] cf: Sharifi et al. (2001), p.792

When looking at the ratings of the assets, production process and the labor sub-categories, higher agility on the shop floor level of the MCCtec production sites than those of the automotive supplier industry become evident. Furthermore, a high difference in the agility concerning the network is obvious. Concerning logistics and the organisational sub-categories, a comparison to the automotive supplier rating imply certain room for improvement. However, within product design and especially purchasing, the results of the study are good, compared to the automotive suppliers. The rating of the sub-category strategy is equal.

In conclusion it can be said that the average value of the agility level of the MCCtec division is above the one of the automotive supplier industry. Reasons for this gap are seen in the difference of the production strategy. While the MCCtec division is inherently used to customization, fluctuating production and small quantities, the production setup of the automotive supplier industry is rather dimensioned towards lean aspects suitable for a stable demand of high quantities.

5.6 Recommendations to increase the agility level

In the following section the derived recommendations to increase the agility level and, therefore, prepare proactively to volatilities, are presented. In Table 21 the recommendations are listed and subsequently the ideas behind them are described one by one.

Investments towards a more agile workforce
Introduction of a centralized production know-how management
Extension of the organisational standards among the network
Maintenance of the exchangeability of production within the network
Closer collaboration in subcontracting within the division
Installation of agility governance and monitoring system
Close consideration of interdependencies of leanness and agility

Table 21: Recommendations in order to increase the agility level

Investments towards a more agile workforce:

As already mentioned earlier, according to Kidd (1994), the knowledge and skills of a company’s employees are one of the most crucial prerequisites to its success.[233] Therefore, the first improvement suggestion is about redesigning and upgrading the jobs in production. The idea is to broaden the knowledge of the workers through systematic job rotation and job enlargement in order to redeploy them more flexible if needed. The expected rise in versatility can be seen as an advantage within the production sites and throughout the whole network. It can be stated that versatile skilled workers are of great value to the company. On the one hand the motivation of the workers rises if their jobs are getting more diversified and on the other hand flexible deployable workers increase the overall agility of the organisation. The two important terms, job rotation and job enlargement, are introduced briefly in the next paragraph.

Job rotation in general is about the systematic exchange of workplaces. The purposes are the extension of know-how and experience of the workers as well as the prevention of work monotony and unbalanced strains.[234, 235] Job enlargement is about the increase of work assignments of the individual workers. The integration of new work processes in the workers duties decrease the overall grade of division of labour and increase the agility level of production. [236]

In reference to its application at LWN it can be said that in-between the production lines some job rotation is already present. As some work steps are rather difficult and require a certain level of experience and expertise its implementation latitude is limited. However, to a certain degree increased job rotation and job enlargement with the result of a more versatile workforce can certainly help to prepare proactively to fluctuations in production and should, therefore, be considered carefully. The derived pool of versatile skilled workers can then be seen as insurance to volatile times. Increased versatility ensures that if production fluctuation demands a rising manning at a certain department, enough skilled workers are available to meet the requirements. This capability of having the right workers in place in case of demand volatilities can be seen as crucial in order to prevent bottlenecks. In order to reach this increase in versatility, besides job rotation and job enlargement, also specific trainings for selected sparsely staffed

[233] cf: Kidd (1994), p.10

[234] cf: Marwa et al. (2014), p.47

[235] cf: Dimitrios et al. (2013), p.86

[236] cf: Marwa et al. (2014), p.47

machines and operations are conceivable. A crucial prerequisite for interchangeability of staff within the network is the standardization of the equipment. With the help of standardization, workers can autonomously operate machines within hours, independent from their prior location.

In conclusion it can be said that an increased investments in the workers, like job rotation or job enlargement at the production lines, offers several advantages. The increase of job rotation and job enlargement can be very costly. However, the benefits outweigh the expenses by far. Although a clear guidance and continuous tracking of the success of the measures is indispensable to prevent failure.

Introduction of centralized production know-how management:

The importance of fostering and subsequently disseminating innovation among the whole network cannot be stressed enough. The ability of an international production network to spread the innovations and best practices, developed at individual locations, across the whole network, is in the long-term crucial to its success.[237]

Therefore, the limited overview about the available production know-how respectively technologies and current developments in production technology at the individual sites of the MCCtec network is finally taken as a reason to suggest a centralized production know-how management. The development of the new technologies should thereby remain at the decentral sites due to the individual requirements. However, an increased central steering of the development process is intended. The desired outcome of the installation of such an organisational element is increased transparency concerning production equipment and currently developed production technologies at the individual sites in order to ensure a better cooperation and increased benefits. The studies in 4.1 can be used as a basis for this idea. If new enhancements in production technology, either developed centrally or at the individual sites, are achieved, they should in the long-term become standard among the network. Furthermore, a certain degree of standardization among the machines is facilitating a better exchange of workers as they are able to operate the machines in every location.

Additionally, the system should enable the sharing of individual employee production know-how. This ensures that besides information about

[237] cf: www.mckinsey.com [19-11-2015]

the existing machines and conducted developments, also important information about the correct usage of machines and experience can be exchanged. The idea is that a system is put in to place where workers from each site can share their knowledge in an easy way. Of course a part of these interactions are already common across the network especially between the foremen of the production lines. However, improvements of these possibilities of exchanging information towards an extension of the accessibility for a broader bunch of employees, fosters a more frequent sharing of knowledge. The main intention behind this recommendation is the usage of the untouched potential which is given through the similarities of the production equipment and the associated processes. Furthermore, a frequent exchange enhances the knowledge of each interacting worker and increases responsibility among the workforce. In conclusion the major advantages of such a system are provided in Table 22.

Enhanced transparency among the network
Faster adaption of successful developments at each site of the network
Productivity increase at each site
Extension of problem solving options
Increased responsibility of each worker
Facilitation of continuous improvement across the whole network

Table 22: Major advantages of a central production know-how management

Extension of organisational standards among the network:

During the analysis of the production equipment of the MCCtec production sites a lack of standardization among an organisational issue became evident. Department denotations among the sites in Nenzing, Rostock and Sunderland are, apart from minor exceptions, consistent. However, at the site in Killarney denotations are partially different. The problem is reinforced by the fact that the denotations are not only different, they are overlapping as well. As for example the name of the small parts manufacturing department at LWN and LSW is ZAF, whereas at LCC the ZAF department is responsible for equipment manufacturing and parts of the steelwork. The reason of this inconsistency can be seen in the history of the division. As in recent years LSW and MCR were subsidiaries of LWN, also their department names are consistent. The departments at LCC, however, have been different ever since.

In order to increase the collaboration of the sites, this state is no longer acceptable. These overlapses and inconsistencies cause confusion and impede a good basis for comparison among the different departments of the network. In order to further integrate the site in Killarney into the network, an adaption of the denotations either at LCC or the other three sites is highly recommended.

Maintenance of the exchangeability of production within the network:

A big strength of the MCCtec production network is the ability of the individual sites to produce the whole spectrum of the product portfolio. This enables the network to split the work among the network if needed and offers big capacity latitude.

As current plans are to relocate the maritime crane production to Rostock and stop the maritime production in Nenzing completely, the risk of losing the manufacturing know-how for maritime cranes in Nenzing from time to time is evident. In order to ensure exchangeability in the future it is crucial to not completely lose this know-how. One approach could be to remain producing a few smaller maritime cranes per year at LWN.

The other way round the fact that solely LWN is producing construction machinery can be seen as critical. Assuming that the production of construction machinery is increasing in a way that LWN is no longer capable of managing such a high amount of orders, there should be an alternative site in the network which has experience in producing construction machinery as well. Otherwise the advantage of the exchange of production hours within the network is reduced significantly. So far the numbers of orders in construction machinery were no problem to the site in Nenzing. But as in the future the focus in Nenzing is solely put on these kinds of machines, their development and increase of production, the preparation to these scenarios is becoming more and more important.

Closer collaboration in subcontracting within the division:

The collaboration between the production sites of the MCCtec division is already on a good level. However, during the analysis room for improvement concerning subcontracting was identified. Thereby a closer collaboration would be reasonable as the whole division would benefit from it. At the moment the impression was prevalent that there is no further distinction between subcontracting partners within the network, in other words the four production sites of the MCCtec, and external steelwork suppliers. The reasons are the partially higher reliability and adherence to delivery dates of the external partners. This fact results in subcontracting agreements with external partners although within the MCCtec division production sites would also be capable of managing the demand. Without going into details, this practice is rather questionable from a MCCtec perspective and should be investigated.

Installation of agility governance and monitoring systems:
Although this is not a main focus of this research, the installation of governance and monitoring systems is indispensable to ensure agility in long-term view. The main purpose of an agility governance system is the management and control of all agility related measures. Continuous tracking of the specified agility strategy and its connected goals can be seen as the main task. Besides monitoring, the decisions when to activate which agility lever, is another important function of this system.

Concerning the monitoring system a deep understanding of the environment and its volatilities is crucial. It includes the implementation of a forecasting system in order to identify changes on the market early on. These systems on the one hand facilitate the cushioning of risks as it enables a quick reaction and on the other hand identifies future opportunities.

Close consideration of interdependencies of leanness and agility:
The last recommendation is about the close consideration of the interdependencies the lean and agile paradigms have. While the lean philosophy fits best to low variety and high volume production combined with predictable demand, agility can be seen as the answer to volatile demand of variable, low volume production. However, this first classification may not take into consideration the many intersections those two paradigms have. On the one hand the elimination of waste in production like overprocessing, waiting times or defects can be associated with both philosophies. Furthermore the continuous improvement process facilitates lean and agile production. On the other hand also a kind of sequential combination is conceivable. The idea is to apply lean principles at earlier processes of production and as soon as customer changes arise, the focus is put on agility

in order to ensure a quick and appropriate reaction. This approach is not new as combinations of the two concepts called “leagility” or “hybrid strategies” have already been introduced earlier.[238,239] Further overlaps like the reduction of setup time, the 5S principle or other quality improvement tools are described by Hallgren et al. (2009).[240]

In conclusion, a close consideration of the relation between the lean and agile philosophy, with all its overlaps and contradictions, is highly recommended. Besides common applicable principles like the reduction of waste or the continuous improvement process, also a sequential combination of the two paradigms is conceivable. Referring to the production of Liebherr cranes especially at the production of standard models with high sale figures, the application of lean production in early processes is reasonable. However, as soon as customization takes place, it is important that the implemented lean principles do not impede the agility of the whole system.

5.7 Summary of the results

In the beginning of the practical study the individual production sites were analysed separately in order to enhance transparency among the network. Thereby the existing manufacturing equipment and the current developments in production technologies were tracked.

On the basis of this analysis the capability of the individual production sites of being able to produce the whole product portfolio of the MCCtec division was evaluated next. The production of the whole product portfolio, and thus the unlimited exchange of production, is solely possible in Rostock. The other sites mainly struggle due to the space and transportation issues of the bigger models. As in reality rather the production of single components is shifted between the sites, a further extension of the developed production capability matrix to the point of single parts is recommended.

Furthermore, to improve the steering of current developments and to ensure a fast dissemination of successful initiatives across the network, an implementation of a central manufacturing knowledge management is recommended. This new entity should be centrally organised and fulfil a supportive function to the divisional management. The development and

[238] cf: Naylor et al. (1999), p.114, 117

[239] cf: Christopher (2000), p.38, 40

[240] cf: Christopher (2000), p.39

testing of the new technologies should thereby remain at the individual sites. However, an increased central steering and monitoring is intended.

Another issue which came up during the investigation of the production capabilities at the individual sites is the inconsistent department names. Especially at the site in Killarney they differ significantly from the names of the rest of the group. Due to reasons of comparability and standardization an adaption of these names is recommended for the future.

After the analysis of production fluctuations in recent years the most suitable operational agility levers in order to handle these volatilities were elaborated. Through conversations with Liebherr employees on the one hand and the search for further suitable levers in agility theory, suitable levers were found. The three levers listed in Table 23 are considered to be the most suitable ones to handle fluctuating production in respect of the company Liebherr.

Lever	Lever category	Scope
Exchange of workers within the sites and the division	Employee transfer	Production network
Subcontracting within the division and with external partners	Adjust capacity and availability	Production network
Adjustment of temporary workforce in production	Number of employees	Production site

Table 23: Best operational agility levers in order to manage volatilities

While the exchange of workers within the site and the adjustment of temporary workforce are seen as the most effective site-internal measures, subcontracting and the exchange of workforce across the network are considered to be most effective beyond the individual site borders.

In the last part of the chapter the current agility level of the MCCtec network was evaluated. Through the discussion of relevant issues and the subsequently conducted quantitative agility study, including the knowledge of experts from all production sites of the network, the current agility level of the MCCtec division was elaborated. The outcome of the evaluation is shown in Figure 38. Highest agility is thereby associated with 5 and lowest with 1. While the agility level among the operative sub-categories network, product design and purchasing is above the overall average value, the sub-categories assets and production process, labor, logistics as well as the organisational and strategical sub-categories show room for improvement. Furthermore, a comparison to the automotive supplier industry is provided.

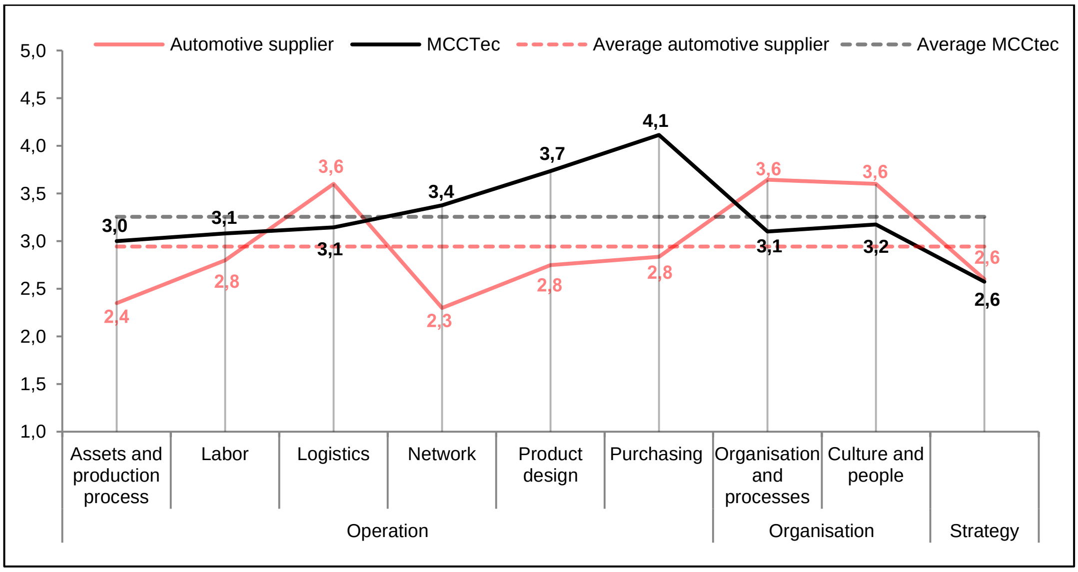

Figure 38: Current agility level of MCCtec

In order to further facilitate a good handling of volatilities on the shop floor level and to successively enhance the agility level, an increased investment in the own workforce is recommended. Concerning the production process a close consideration of the combination of the lean and agile philosophy is suggested. Besides the continuous drive towards innovation and the sensing of new trends, in the future it will be crucial to establish processes of how to deal with risks and uncertainties. Therefore, the importance of the implementation of an agility governance and monitoring system, which is responsible for managing agility related measures, is emphasized. In Table 24 the elaborated recommendations are once more summarized.

Investments towards a more agile workforce
Introduction of a centralized production know-how management
Extension of the organisational standards among the network
Maintenance of the exchangeability of production within the network
Closer collaboration in subcontracting within the division
Installation of agility governance and monitoring system
Close consideration of interdependencies of leanness and agility

Table 24: Recommendations in order to increase the agility level

6 Conclusion and outlook

Through the conducted literature research, at the beginning of this thesis, the current state of science in the field of agility in production was presented. The development of the term over time and finally the agility definition of the IBL-Institute in Graz, were provided as a basis for the whole thesis. Besides, a delimitation of the lean and agile production paradigms as well as theory about production networks and its connection to agility, were elaborated.

In the practical part of this thesis, focus was especially placed on the operational dimension of agility. However, in order to provide a comprehensive overview, organisational and strategic aspects were considered too. Before the in-depth analysis of the agility of the Liebherr MCCtec network was carried out, the production capabilities of the individual sites had been analysed. Afterwards, on the basis of historical production data, the best operational levers to handle production fluctuations were identified. The analysis showed that the adjustment of temporary workforce, the exchange of workers among the network and subcontracting are the most effective levers to handle those uncertainties.

In the concluding part of the research, the current agility level of the network was evaluated. Therefore, a detailed discussion of topics currently challenging the MCCtec division was conducted. Through the derived information and the consultation of experts of the individual production sites, a quantitative evaluation of the agility level was elaborated. While the sub-categories purchasing, product design and network show a rather high agility level, improvement potential is evident concerning strategy and the organisational sub-categories. A comparison of the derived values with those from a similar study of the automotive supplier industry, underlines these statements.

Based on the results of the agility analysis several recommendations to further increase the agility level derived. Besides the introduction of systematic job rotation and job enlargement, the establishment of a centralized production know-how management in order to increase transparency and facilitate a fast dissemination of developments in production technologies across the whole network is seen as a way to increase agility. Furthermore, the extension of organisational standards, like the assimilation of department denotations within the network, is recommended. As the exchangeability of production between the sites is seen as a major strength of such collaboration, the importance of the further advancement of this option is emphasized. Concerning the production process a close consideration of the interdependencies of lean and agile principles, which were outlined during this research, is seen as crucial. As a last recommendation the necessity of an agility governance and monitoring system to steer and control agility related measures is stated.

With the provided information about the current agility level and the identified weak points to overcome, the MCCtec division of Liebherr is now capable of proactively prepare to these challenging circumstances and step by step further improve the agility level of its production network. In conclusion it can be said that the agility of the MCCtec network is already on a good level. However, in order to ensure best possible preparation to increasing volatility and uncertainty and the linked necessity of a fast and appropriate reaction, further engagement within the topic of agility in production is highly recommended.

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CIM	Computer-Integrated Manufacturing
DSI	Turkish General Directorate of State Hydraulic Works
EBIT	Earnings before interest and taxes
ERP	Enterprise Resource Planning
FE	Foundation equipment
HS	Hydroseilbagger
IBL	Institute of Industrial Management and Innovation Research
JIT	Just in time
LCC	Liebherr Container Cranes Ltd.
LHM	Liebherr Hafenmobilkrane
LSW	Liebherr Sunderland Works Ltd.
LWN	Liebherr-Werk Nenzing GmbH
MCR	Liebherr-MCCtec Rostock GmbH
MES	Manufacturing Execution System
MRP	Material Requirements Planning
ROI	Return on Investment
STS	Ship-to-shore
TQM	Total Quality Management

Appendix

In Table 25 examples of the MCCtec product groups are shown: [241]

Product group examples

Rail-mounted ship-to-shore container cranes

Rail-mounted container stacking cranes

Rubber tyred gantry cranes

Straddle Carriers

Ship crane CBB 120(81)-16(24) Litronic

Heavy lift offshore crane MTC 78000

[241] cf: www.liebherr.com [04-08-2015]

Mobile harbour crane LHM 600

Reachstacker LRS 545

Crawler crane – LR 1100

Duty cycle crawler crane – HS 8100 HD

Piling & drilling rig LRB 255

Table 25: Product group examples

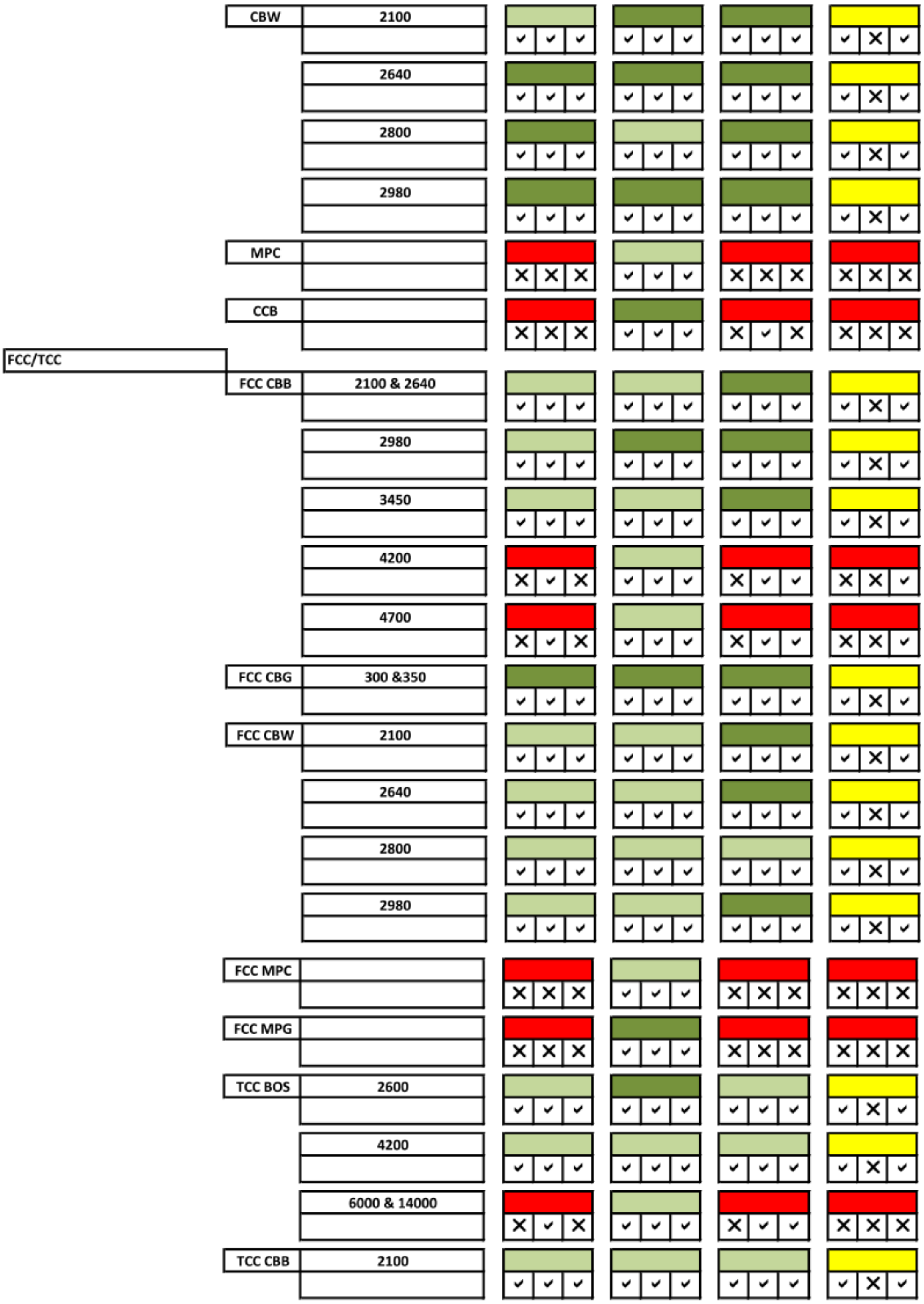
In Table 26 the complete outcome of the production capabilities research of the individual production sites is presented.

Production experience/capabilities of all MCCtec GmbH production sites

Legend:
- produced within 2005-2017
- production possible
- Training necessary
- requirements not fulfilled

A ... Assets
H ... Human
L ... Logistics

Product Group	Product		LWN	A	H	L	MCR	A	H	L	LSW	A	H	L	LCC	A	H	L
Reachstacker	LRS	545	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		645	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
Mobile harbour cranes	LHM	120	produced within 2005-2017	✓	✓	✓	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		180	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		280	produced within 2005-2017	✓	✓	✓	produced within 2005-2017	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		420 & 550	produced within 2005-2017	✓	✓	✓	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		600	requirements not fulfilled	✓	✓	✗	produced within 2005-2017	✓	✓	✓	requirements not fulfilled	✗	✓	✗	Training necessary	✓	✗	✓
		800	requirements not fulfilled	✗	✓	✗	produced within 2005-2017	✓	✓	✓	requirements not fulfilled	✗	✓	✗	requirements not fulfilled	✗	✗	✓
	LPS	120	production possible	✓	✓	✓	production possible	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		180 & 280	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		420 & 550	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		600	requirements not fulfilled	✓	✓	✗	produced within 2005-2017	✓	✓	✓	requirements not fulfilled	✗	✓	✗	Training necessary	✓	✗	✓
	LFS	120	production possible	✓	✓	✓	production possible	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		180	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		280 -550	production possible	✓	✓	✓	production possible	✓	✓	✓	production possible	✓	✓	✓	Training necessary	✓	✗	✓
		600	requirements not fulfilled	✓	✓	✗	produced within 2005-2017	✓	✓	✓	requirements not fulfilled	✗	✓	✗	Training necessary	✓	✗	✓
Ship cranes	CBB	2100	production possible	✓	✓	✓	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		2640	produced within 2005-2017	✓	✓	✓	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		2980 & 3450	production possible	✓	✓	✓	produced within 2005-2017	✓	✓	✓	produced within 2005-2017	✓	✓	✓	Training necessary	✓	✗	✓
		3800 - 4700	requirements not fulfilled	✓	✓	✗	produced within 2005-2017	✓	✓	✓	requirements not fulfilled	✗	✓	✗	requirements not fulfilled	✗	✗	✓


CBW
2100
2640
2800
2980
MPC
CCB
FCC/TCC
FCC CBB
2100 & 2640
2980
3450
4200
4700
FCC CBG
300 &350
FCC CBW
2100
2640
2800
2980
FCC MPC
FCC MPG
TCC BOS
2600
4200
6000 & 14000
TCC CBB
2100

		2640 & 2980	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		3450	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	TCC CBG	300	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		350	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	TCC CBW	2100	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		2640	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		2800	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		2980	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	TCC MPC		✗ ✗ ✗	✓ ✓ ✓	✗ ✗ ✗	✗ ✗ ✗
	TCC MPG		✗ ✗ ✗	✓ ✓ ✓	✗ ✗ ✗	✗ ✗ ✗
Offshore cranes	BOS	1900	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		2600 & 4200	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		6000 - 45000	✗ ✓ ✗	✓ ✓ ✓	✗ ✓ ✗	✗ ✗ ✗
	CAL	45000 & 64000	✗ ✗ ✗	✓ ✓ ✓	✗ ✗ ✗	✗ ✗ ✗

CAL	45000 & 64000	✗ ✗ ✗	✓ ✓ ✓	✗ ✗ ✗	✗ ✗ ✗
CBO	3600	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
MTC	1400	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	1900 & 2600	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	3100	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	6000	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	78000	✗ ✓ ✗	✓ ✓ ✓	✗ ✓ ✗	✗ ✗ ✗
RL	650	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	850	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	1250	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	1500 & 2650	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓

		4200	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	RL-K	2650	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		4200	✓ ✓ ✗	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
		7500	✗ ✓ ✗	✓ ✓ ✓	✗ ✓ ✗	✗ ✗ ✗
	RL-T	2650	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	RL-S	650	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✗ ✓
	TCC	14000	✗ ✗ ✗	✓ ✓ ✓	✗ ✗ ✗	✗ ✗ ✗
Duty cycle crawler cranes	HS	8030 -8300	✓ ✓ ✓	✓ ✗ ✓	✓ ✗ ✓	✓ ✗ ✓
Crawler cranes	LR	1100-1300	✓ ✓ ✓	✓ ✗ ✓	✓ ✗ ✓	✓ ✗ ✓
Foundation equipment	LRB	125-355	✓ ✓ ✓	✓ ✗ ✓	✓ ✗ ✓	✓ ✗ ✓
	LB	16-44	✓ ✓ ✓	✓ ✗ ✓	✓ ✗ ✓	✓ ✗ ✓
	LRH	100	✓ ✓ ✓	✓ ✗ ✓	✓ ✗ ✓	✓ ✗ ✓
Ship to shore container crane	STS	customized	✗ ✗ ✗	✓ ✗ ✓	✗ ✗ ✗	✓ ✓ ✓
Rail mounted gantry crane	RMG	customized	✓ ✗ ✓	✓ ✗ ✓	✗ ✗ ✓	✓ ✓ ✓
Rubber tyre gantry crane	RTG	customized	✓ ✗ ✓	✓ ✗ ✓	✗ ✗ ✓	✓ ✓ ✓
Straddle carrier	SC	3 high	✓ ✗ ✓	✓ ✗ ✓	✓ ✓ ✓	✓ ✓ ✓
		4 high	✓ ✗ ✓	✓ ✗ ✓	✓ ✓ ✓	✓ ✓ ✓

Table 26: Production capabilities at the individual production sites