Professional MBA
Automotive Industry

Global Production Relocation Mapping

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by

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Vienna, 02.09.2015

Affidavit

I, **Ing.Mag.(FH) Markus Johannes Ganahl**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Global Production Relocation Mapping", 111 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Table of Contents

Title page ... 1
Table of Contents ... 3
List of abbreviations ... 5
Abstract ... 7
1 Introduction ... 8
1.1 Evolution of Globalization ... 8
1.2 Global Production in the Automotive Industry ... 10
1.3 Global Production of Automotive Suppliers ... 11
1.4 Research focus and problem ... 12
1.5 Research questions and aim ... 13
1.6 Hypothesis statement ... 13
1.7 Methodical approach and structure ... 13
2 Theoretical foundations ... 16
2.1 Definition of the term Production Network ... 16
2.2 Production Network Stereotypes ... 16
2.3 Traditional Production Network Theory ... 19
2.3.1 From Operations Management to Network Management ... 20
2.3.2 Production Network Optimization ... 21
2.3.2.1 Production Network Strategy ... 22
2.3.2.2 Production Network Design ... 23
2.3.2.2.1 Production Network Location Criteria ... 24
2.3.2.2.2 Production Network Location Decision ... 28
2.3.2.3 Production Network Migration ... 28
2.3.2.3.1 Detailed Location Decision ... 29
2.3.2.3.2 Organization Changes ... 29
2.3.2.3.3 Recruiting and Training ... 30
2.3.2.3.4 Ramp-up ... 30
2.4 Global Production Relocation in Practice ... 30
2.4.1 Relocation motivation ... 30
2.4.2 Relocation problems ... 31
2.5 Lean Production Network Theory ... 33
2.5.1 From the Toyota Production System to Lean Production ... 33
2.5.2 The seven categories of waste ... 35
2.5.3 Lean Production Principles ... 36
2.5.4 Lean Production Networks ... 37

2.5.4.1 Lean Production Network Location Scenarios 37
2.5.4.2 Lean Production Network Location Decision..............................39
2.5.5 Value Stream Mapping 41
2.5.5.1 Levels of Value Streams...41
2.5.5.2 Value Stream Mapping Procedure..42
2.5.5.2.1 Selecting a Product Family..43
2.5.5.2.2 Mapping the current state..43
2.5.5.2.3 Designing the future value stream 43
2.5.5.2.4 Implementing the future state design......................................45
2.6 Lean Production Networks in the automotive industry...................................46
3 Lean Orientation of Global Production Networks 48
3.1 Lean Orientation of Global Production Network Stereotypes 48
3.2 Lean Orientation Assessment of the Global Production Network of an automotive supplier...49
3.2.1 The automotive supplier 49
3.2.2 Production Network Strategy 50
3.2.3 Production Network Design 50
3.2.3.1 Regional Production Network EMEA 54
3.2.3.2 Regional Production Networks Asia and NAFTA 56
3.2.3.3 Global Region for Region Production Network...........................57
4 Global Production Relocation Mapping 58
4.1 The Global Production Relocation Mapping method 59
4.2 Defining the Product Line to relocate 63
4.3 Mapping the current state 65
4.4 Mapping the relocated state...70
4.5 Visualizing and simulating inventory and transportation costs........................73
4.6 Mapping the optimized relocated state 76
5 Summary and conclusion..85
6 Bibliography...88
7 List of Figures 94
8 List of Appendixes 96

List of abbreviations

a	anno
ASEAN	Association of Southeast Asian Nations
BRIC	Brasil Russia China India
CPT	Carriage Payed To
CKD	Completely knocked down
d	day
DAP	Delivered at Place
DDP	Delivery Duty Payed
EMEA	Europe Middle East Africa
EPEI	Every Part every Interval
ERP	Enterprise Resource Planning
etc.	et cetera
EXW	Ex Works
FCA	Free Carrier
FIFO	First In First Out
ISI	Institut für System- und Innovationsforschung
JIT	Just in Time
JIS	Just in Sequence
KE	Kenitra
Km	Kilometer
MAX	Maximum
MIN	Minimum
KPI	Key Performance Indicator
m	month
NAFTA	North American Free Trade Agreement
NUMMI	New United Motor Manufacturing

OEM	Original Equipment Manufacturer
PESTLE	Political, Economic, Sociological, Technological, Legal, Environmental
RW	Rankweil
SKD	Semi-completely knocked down
TM	Tirgu Mures
TPS	Toyota Production System
USA	United States of America
VMI	Vendor Managed Inventory
VS	Vsetin
w	week

Abstract

To exploit global growth and cost saving opportunities companies have built up global production networks. Originally the primary motivation of companies to globalize production was to take advantage of low-cost labor and the need to meet local-content requirements. Nowadays globalization of production is more and more driven by a dramatic shift in global demands to the emerging markets. In response to the ever increasing cost pressure, strengthened localization requirements and increasing global growth opportunities, also automotive suppliers relocate production from saturated to emerging markets. As a result global networks are created with value creation fragmented in global multi-organizational networks. The impact of relocated global production networks on flexibility, quality and logistics cost is often underestimated. This master thesis researches the problem how automotive suppliers can optimize their global production networks to grow their business, reduce cost and fulfil customer responsiveness requirements.

In the first part of the research, global production network stereotypes and methods to optimize global production networks are described. The traditional production network theory proposes a periodic strategic process to optimize global production networks. The lean production network theory proposes to follow lean production network principles and to use extended value stream mapping to optimize value-streams from the suppliers to the customer.

In the second part of the research the lean production network orientation of global production network stereotypes and of the global production network of an automotive supplier are assessed. The “Region for Region” model is identified as a network type with the target to enable global growth and to fulfil the lean production network principles: value stream concentration, customer proximity and optimization of total cost of ownership.

The last part of the research introduces Global Production Relocation Mapping as lean method to visualize, analyze, simulate and optimize the impact of global production relocations on lead-times, inventories, transportation requirements and logistics costs. The method defines a direct production cost saving target that must be met to compensate increased logistics costs. Summarizing the method supports companies to take the right relocation decision and to optimize the global production network to ensure that the relocation will deliver sustainable financial benefits.

1 Introduction

1.1 Evolution of Globalization

Globalization of the world's economy is not new at all, international trade of products has been done already centuries ago between Asia and Europe along the Silk road. Worldwide trade has evolved further ever since. Globalization entered a new era with the Industrial revolution in the 19th century and since then has further developed from cross-border trading to today's globalization (cf. Jacob & Strube 2008: 3ff).

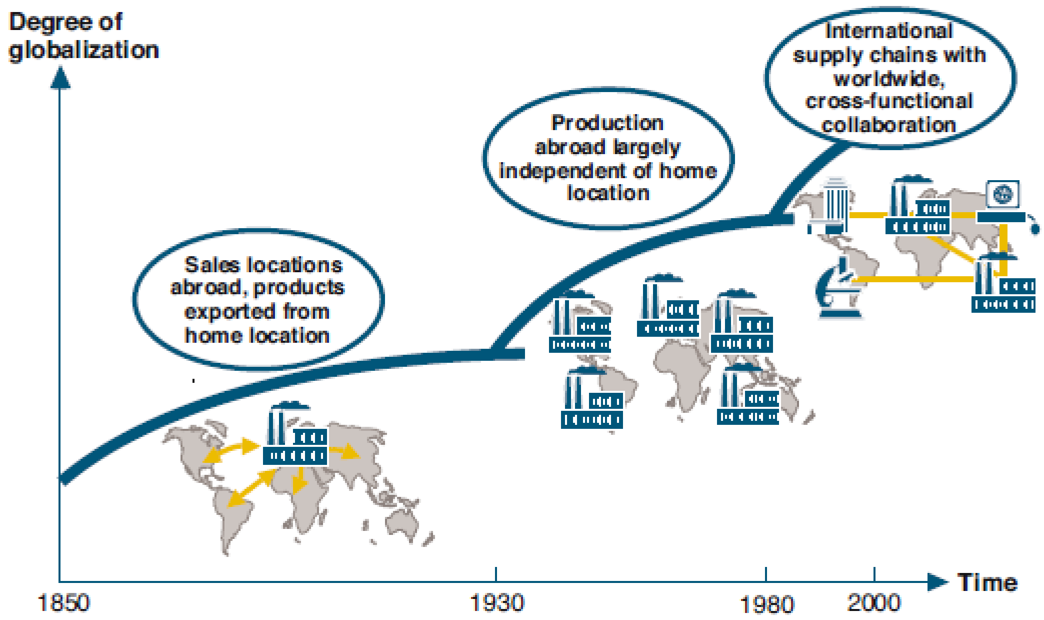

Figure 1: Development of globalization in three phases (Jacob & Strube 2008: 4)

The period from the middle of the 19th century until 1930 was characterized by large scale production sites in the home markets. Products were exported from the home markets and sold through sales offices abroad. Break-through innovations such as the invention of railroads made the international exchange of goods much easier. At the same time the implementation of mass-production enabled the production of much larger production volumes (cf. Jacob & Strube 2008: 3). The biggest manufacturing factory in the world was built by Ford in the beginning of the 20th century. Ford's famous Highland Park Plant was more than 50 hectares in size and consisted of almost two dozen buildings including a power plant and a foundry. The introduction of the first automobile production assembly line in the world in 1913 reduced the assembly time of the famous Model T from 728 to 93 minutes. By 1920 the plant produced a car every minute, and every second car in the world was a Model T (cf. The Library of Congress 2011).

After World War I and the end of the following recession period companies established independent production abroad. The availability of increasingly low-cost, effective communication methods enabled the companies to grow and manage their businesses internationally. Global brands and companies such as Coca-Cola, IBM or Mercedes emerged by entering new markets and building up production abroad. These foreign production sites operated mostly independently and concentrated on winning local markets through local production (cf. Jacob & Strube 2008: 5).

After 1980 the globalization of production entered into a third phase, enabled by technological progress, reduced trade barriers and declining transaction cost. Many companies used these opportunities and established global production networks, allowing them to benefit from economies of scale by manufacturing components centrally and shipping them to foreign assembly plants to tailor or assemble the final products to local customer needs. Such global production-networks sometimes even grew even faster than the markets were deregulated. CKD (completely knocked down) or SKD (semi-completely knocked down) assembly plants were widely used to avoid high import duties on finally assembled cars (cf. Jacob & Strube 2008: 6).

During the past few years globalization of production has been further boosted by enormous developments in transportation, logistics and information and communication technologies and various trade agreements enabling easy exchange of goods and services worldwide (cf. Kampker et al.: 45; Reichl et al. 2014: 7).

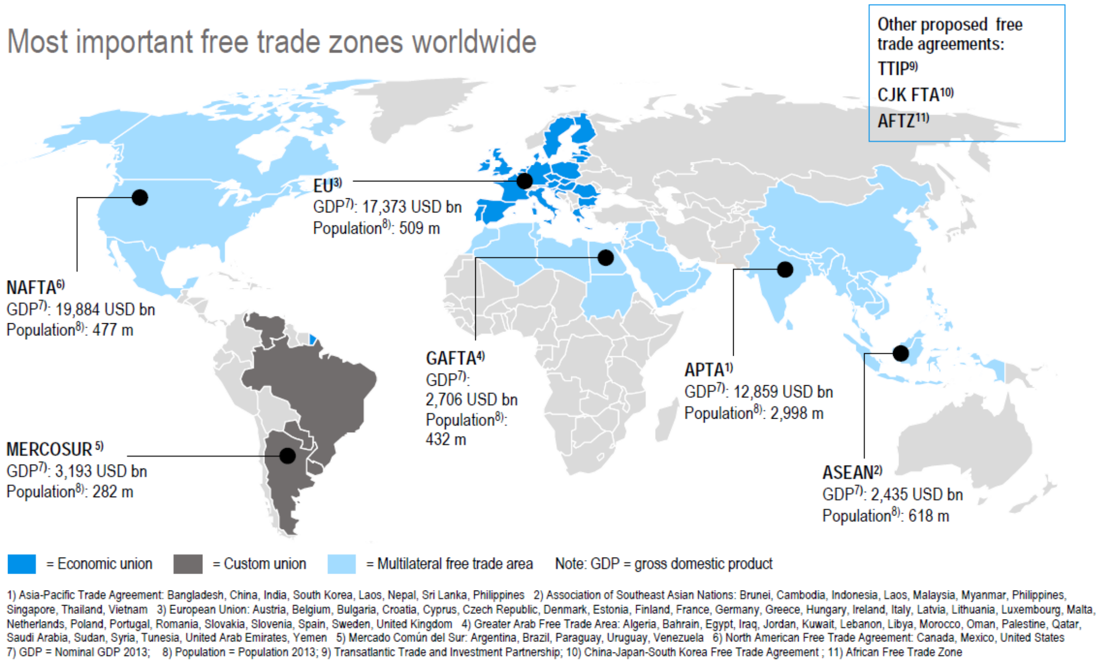

Figure 2: Most important free trade zones worldwide (Reichl et al. 2014: 7)

To exploit global growth and cost saving opportunities companies have built up global production networks (cf. Jacob & Strube 2008: 3; Christodoulou et al. 2007: 7; Palm 2014a: 137; Abele & Reinhart 2011: 11; Kinkel & Maloca 2009: 4; Zanker et al. 2013: 4 ; Bürstner 2011: 397). Globalization is expected to further continue and accelerate since emerging and developing economies still have huge growth potentials with its expanding middle classes (cf. Jacob & Strube 2008: 7; Reichl et al. 2014: 9). The tremendous dynamics of the globalization trend is also demonstrated in a study of the Frauenhofer ISI institute. The number of German companies operating production sites abroad nearly doubled between 2009 and 2012. Forty percent of mid-sized companies and more than eighty percent of large companies operate production sites outside of Germany (cf. Kinkel & Maloca 2009: 4; Zanker et al. 2013: 9).

1.2 Global Production in the Automotive Industry

The automotive industry has become a global industry. Originally the primary motivation of automotive companies to globalize production was to take advantage of low-cost labor in developing countries and the need to meet local-content requirements. Nowadays globalization of production is more and more driven by a dramatic shift in global demands to the emerging markets (Spindelndreier et al. 2015: 6). With demands for vehicles declining in most mature markets the automotive industry is turning its attention even more strongly towards the expanding middle classes in the growing markets (Meyer 2013: 4). The share of the BRIC countries is estimated to surge up to 50 percent of the total new car sales before the end of this decade (Meyer 2013: 34). China has emerged as the world's biggest market and is estimated to account for 29 percent of worldwide cars and light vehicles sales by 2019, far surpassing Europe with 16 percent and US and Canada with 18 percent combined. With the shift of demand also the shift of production to emerging markets accelerates. By 2019 China is projected to account for 29 percent of the world's automotive production, nearly as much as Europe, US and Canada together (Spindelndreier et al. 2015: 6). Considering these impressive numbers it is not surprising that market growth in emerging nations was rated the most important Key Automotive Trend until 2025 in KPMG's Global Auto Executive Survey 2014 (Meyer 2014: 5).

1.3 Global Production of Automotive Suppliers

Automotive Suppliers also seek cost reduction and growth opportunities by accessing new markets. There are two major opportunities for suppliers to grow in new markets. One opportunity is to supply and grow with their existing (global) OEM (Original Equipment Manufacturer) customers in the new markets. The second opportunity is to win new businesses with local OEM customers in the emerging markets (cf. Achterholt 2009: 10). A survey of the Boston Consulting Group with 42 global automotive suppliers demonstrates how automotive suppliers are adopting their global production networks. In response to the shift of the centre of gravity more and more capacity is relocated from the USA and Europe to Mexico, Eastern Europe and China.

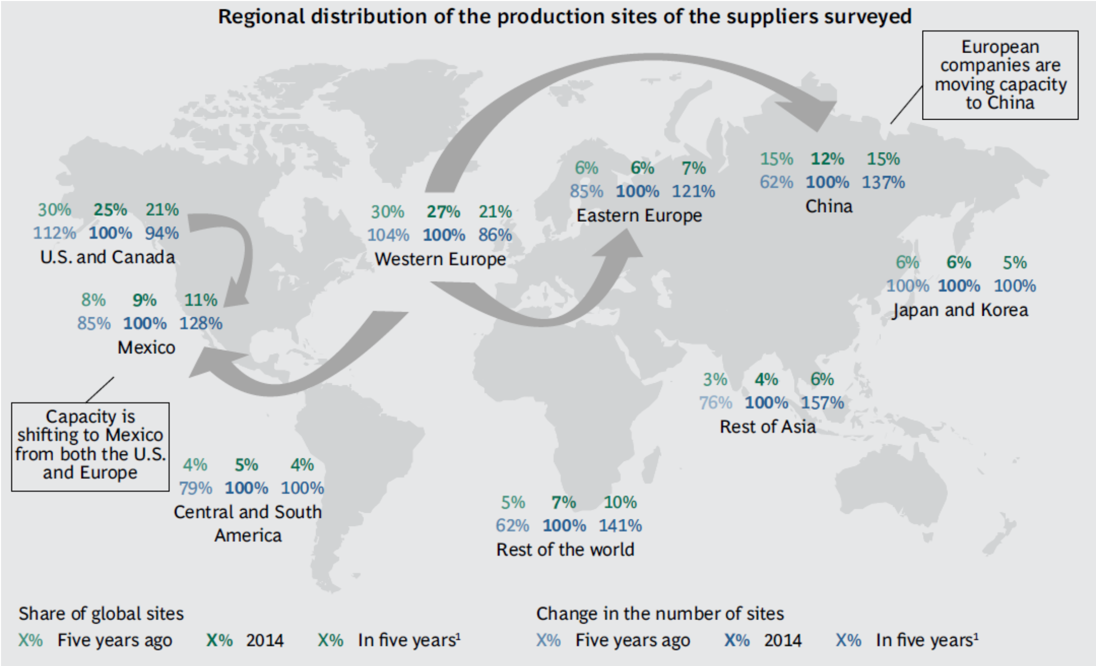

Figure 3: Suppliers are shifting plants from the USA and Europe to Emerging Markets (Spindelndreier et al. 2015: 7)

Suppliers very often are challenged to localize their production close to their customer's sites abroad. Especially Automotive Tier 1 suppliers[1] delivering their products "Just in Time" or "Just in Sequence" are requested to set up their operations in close proximity to the OEMs. Spindelndreier et al. (2015: 3) call the conflicting requirements for suppliers to locate facilities close to customers and to optimize cost the "proximity paradox"*.* Locating new facilities close to the customers' sites usually increases complexity and cost for the suppliers. Not following the customers' request means to give up significant growth potential and is a risk to lose key customers and market share. Mastering this dilemma is "…one of the most serious management challenges that the global automotive industry will face over the next few years" (Spindelndreier at al. 2015: 3).

1.4 Research focus and problem

This master thesis researches the problem how automotive suppliers can optimize their global production networks to grow their business, reduce cost and fulfil customer responsiveness requirements.

[1] Tier 1 suppliers are direct suppliers to OEMs

1.5 Research questions and aim

Based on the research problem and focus, the following central research questions shall be answered:

- What are strategies and methods to optimize global production networks?
- What are the motives of companies to relocate production?
- What is the impact of global production relocations on the value stream?
- How can the impact of global production relocations on the value stream be visualized, quantified, simulated and optimized efficiently?

The aim of this master thesis is to develop a method enabling automotive suppliers to visualize, analyze, simulate and optimize the impact of global production relocations on lead-time, inventory, transportation requirements and logistics costs.

1.6 Hypothesis statement

Based on the current knowledge derived from literature review and the professional experience of the author the following hypothesis is stated:

The (potentially negative) impact of global production relocations on the value stream is often underestimated. Through visualization and simulation the impact can be identified, quantified, evaluated and optimized.

1.7 Methodical approach and structure

The master thesis uses literature research and a quantitative simulation approach to elaborate the research aim of this master thesis and to answer the research questions. The thesis is structured in five chapters:

The first chapter introduces the topic global production of automotive suppliers and defines the research focus and problem of this thesis. The research questions and research aim as well as the hypothesis statement are formulated and the methodical approach and structure of the master thesis are described.

In the second chapter the theoretical foundations of the global production network theory are studied. The definition of the term “Production Network” and the presentation of global production network stereotypes further lead into the topic. Based on literature study the traditional production network theory and a method to optimize global production networks are described. Afterwards the major motives of companies to relocate production and the major problems that arise in relocated production networks are identified. The following part presents the lean production network theory and the lean tool value stream mapping as a method to reduce lead-time, improve responsiveness and optimize logistics costs in global production networks. The second chapter concludes with historical and todays examples of lean production networks in the automotive industry.

Chapter three first assesses the lean orientation of the global production network stereotypes. Than the global production network of an automotive supplier is assessed regarding its lean orientation. The “Region for Region” model is identified as a network type that targets to fulfills the lean production network principles: value stream concentration, customer proximity and optimization of total cost of ownership.

The fourth chapter enhances the extended value stream mapping tool and introduces “Global Production Relocation Mapping” as a lean method to visualize, analyze, simulate and optimize the impact of global production relocations on lead-time, inventory, transportation requirements and logistics costs.

Chapter five will answer the research questions and summarize the results of the master thesis.

Figure 4: Structure of the master thesis

2 Theoretical foundations

2.1 Definition of the term Production Network

A wide range of different terms such as “Production Network”, “Manufacturing network”, “Manufacturing Footprint”, “Industrial Footprint”, “Production Footprint”, “Value-added network” are used by different authors discussing global production networks (cf. Thomas 2013; Friedli et al. 2013; Schönsleben 2011; Shi & Gregory 1998; Colotla et al. 2003; Shorten et al. 2006; Christodoulou et al. 2007).

Besides using different vocabulary, the authors also use different definitions. Some authors limit global production networks to the management of the self-controlled production network of a company, so-called Intra-company networks (cf. Shi & Gregory 1998; Shi 2005). Others use a much wider scope and also consider suppliers and customers or competitors as part of the network (cf. Sydow 1992). For this thesis the following definition for global production networks will be used:

A production network is the value adding network of different production plants of a company in different global locations and the relationship of these plants between each other and with its global external suppliers and customers.

2.2 Production Network Stereotypes

Production network stereotypes can be used to illustrate the main principles of global production network configurations. With the help of these stereotypes the advantages and disadvantages of certain production network setups can be characterized (cf. Meyer & Jacob 2008:164ff). Production networks are typically structured according to geographic alternatives and each alternative is defined by a different trade-off between production cost and know-how (i.e. economies of scale and scope) and the logistics cost and delivery time (i.e. importance of local adaptation and transaction cost). Meyer & Jacob (2008:164ff) define five Global production network stereotypes: World factory, local for Local, Hub & Spoke, Sequential or Convergent, Web structure.

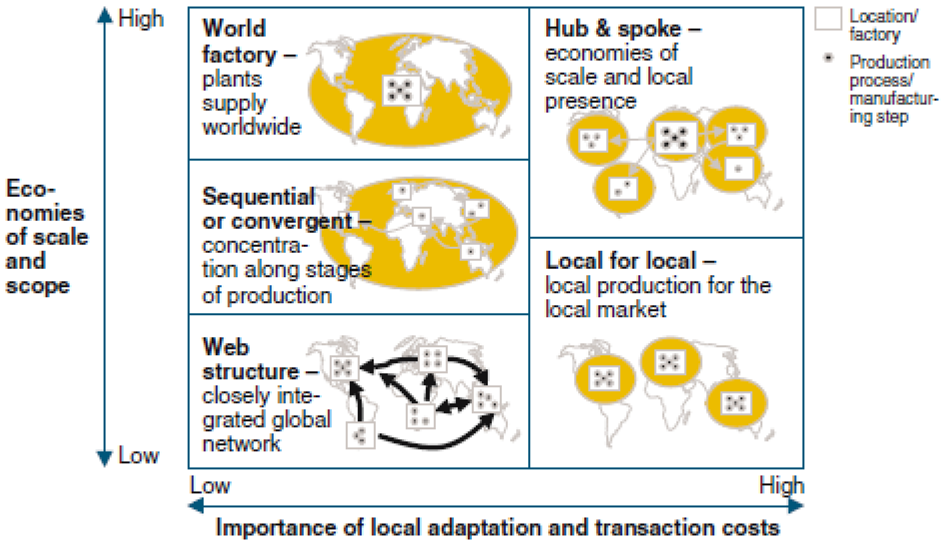

Figure 5: Global production – network stereotypes (Meyer & Jacob 2008: 164)

The **"World factory"** model supplies its customers globally from one single pant. This model makes sense in industries with major economies of scale, economies of scope, high product value density, and reasonably long delivery lead times. Although world factories have lost their importance in many industries, this model is still very important in the high-tech industry such as semiconductor or chip production to realize maximum economies of scale in production and economies of scope in know-how and availability of critical personnel (Meyer & Jacob 2008: 165). Production at only one location for the entire world market also was a dominating model in the past in the automotive industry. The probably best known example of a World factory in history is Ford's River Rouge factory in Detroit (USA) with an almost fully vertically integrated production network from raw materials to the finished car in one single huge production location. Today almost all OEMs have globalized their production networks, the value chain has been outsourced to a large extend and final assembly is performed in much more flexible and smaller plants closer to the markets.

The second classic production network type is the **"Local for local"** model. Companies implemented this model to meet the flexibility and short delivery time requirements of customers. In this model economies of scale is of lower importance and the local plants typically have relatively little interaction. Local for local models are suitable for market-specific products with low value density, large numbers of variants or if delivery requirements are very strict. This model also is used in the automotive industry, especially for large volume systems with a high number of variants such as seats or cockpit modules, where the suppliers build up production sites next to the sites of their OEM customer to deliver them Just in Sequence to their assembly lines (Meyer & Jacob 2008: 166). This version of a local for local model is also called “Feeder Plant” (Shorten et al. 2006: 9). However, apart from such specific industry requirements the “Local for Local” model is losing its importance more and more due to its cost disadvantages (Meyer & Jacob 2008: 166).

The **“Hub & Spoke”** model tries to achieve both, economies of scale and market proximity. Knowledge-intensive, economies of scale-sensitive and capital-intensive production of parts and components is concentrated in one global or in only a few regional locations, while market requirements such as many variants and short delivery times are achieved through a larger number of close-to-the-market locations for final product customization or assembly. The hub and spoke model also can help to reduce logistics cost. Firstly, local assembly of variants can help to reduce inventory in the total supply chain. Secondly, custom duties often can be reduced since components and parts often are subject to lower customs duties than imported finished products (Meyer & Jacob 2008: 166). This benefit was the main driver for Automotive manufacturers to install CKD or SKD assembly plants in markets with local-content requirements. Especially BRIC and ASEAN markets installed high import duties on finally assembled cars but much lower duties on imported components and parts to increase local content. In the CKD or SKD hub & spoke model components or entire construction kits are manufactured in central production locations and shipped to the local plants, where they are assembled to the final car (cf. Meyer & Jacob 2008: 166; Palm 2014a: 145ff).

The **“Sequential or Convergent”** model maximizes economies of scale and scope in each manufacturing step with every manufacturing step concentrated at a different location. This structure requires a lot of international transportation to move the parts from production location to production location along the value chain. Therefore this model mainly makes sense for products with very high value density such as electronic components, where the share of transport costs is almost negligible. Besides electronics manufacturing the “Sequential or Convergent” model also can be found in production of food additives and chemicals (Meyer & Jacob 2008: 167).

The **“Web structure”** model aims to smooth capacity utilization despite volatile demand in individual markets. This network type is relevant for companies with a high vertical integration and the need to balance production capacity across production locations. The model can also be used for internal competition, since basically all production facilities are able to manufacture all products. For this model to be beneficial the products need to have a relatively high value density and a sophisticated logistics structure to ensure effective transportation and distribution. The model also can be found in the automotive industry to achieve high utilization of capital-intensive production via flexible global order allocation to production locations worldwide (Meyer & Jacob 2008: 167).

The described idealized production network stereotypes can be used as a helpful tool in the discussion and decision-making process to (re-)design and optimize global production networks. However, production networks always have to be tailored to a company’s specific value chain and competitive situation.

2.3 Traditional Production Network Theory

With the globalization of business and new market- and cost reduction opportunities for companies the design and operation of global production networks became an increasingly important issue and has been researched more intensely.[2] The initial focus of the emerging production network theory was the definition of the ideal location of an individual manufacturing site within the production network. This focus then was enlarged with a strategic perspective, defining the role of each manufacturing site in the network. Later the integrated network perspective researched the interaction between the different production network locations within the production network (cf. Shi & Gregory 1998: 197). Latest scientific work (cf. Thomas: 2013; Friedli et al. 2013) focuses on the interaction of production network strategy, production network configuration and production network coordination.

[2] A structured overview of the relevant scientific literature can be found in Thomas (2013: 28).

2.3.1 From Operations Management to Network Management

Historically, research in production or operations management has focused on individual manufacturing sites or plants (Friedli et al. 2013: 15).

Operations Management is defined as "…all activities that relate to the creation of goods and services through the transformation of inputs to outputs" (Sihn 2014a: 8). Operations Management has an operational and a strategic dimension. The operational dimension is about efficiency and doing the right things right, while the strategic dimension is about effectiveness and doing the right things (Walters 2002: 315).

The operational dimension preliminary focuses on planning, organizing, staffing, leading and controlling all processes related to the creation of goods and services (cf. Sihn 2014a: 8; Walter & Wolf 2007: 3). The strategic dimension goes beyond designing and managing individual production locations and contributes to the question in which markets to compete and where to enter new markets and how to configure and coordinate self-controlled company-networks (cf. Friedli et al. 2013: 17).

Supply Chain Management widens the perspective of intra-company networks and also includes suppliers and customers into the scope. Supply Chain Management in its core focuses on the material and related information flows and their systematic organization and coordination within and between companies. Christopher (2005:5) argues that the term "Supply" is misleading since the chain in reality is driven by the customer and not by the supplier. Walters (2002: 103) therefore uses the term "Value Chain Management" to express the broader and customer-centric concept of managing of the whole value chain from the supplier to the customer.

As a result of the more and more fragmented and geographically distributed value creation the attention nowadays has further enlarged from separate supply or value chains to **Value Added Networks** (cf. Prinz et al. 2010: 85). Value added networks are "networks of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher 2005: 17).

2.3.2 Production Network Optimization

Very often production networks have grown over time and the potential benefits are not fully realized (cf. Kampker et al: 45; Shorten et al.: 1; Ponton et al.: 488; Spindelndreier et al. 2015: 10). Top consultants such as the Boston Consulting Group and McKinsey report huge potential to optimize such global production-networks with long-term savings of up to 40 percent of total landed costs and many companies have realized the massive opportunity to reconfigure their global production network (cf. Christodoulou et al. 2007: 7; Spindelndreier et al. 2015: 12; Meyer & Jacob 2008:140; Shorten et al. 2006: 1). But taking the right decisions in designing and adjusting the production network is very challenging due to the large numbers of influence factors and their dynamics (cf. Kampker et al: 45; Christodoulou et al. 2007: p. 3; Palm & Sihn 2010: 78).

To resolve this issue different authors have developed models how to optimize global production networks (cf. Christodoulou et al. 2007; Shorten et al. 2006; Neuner & Kwasniok: 2010; Friedli et al. 2013; Thomas 2013; Abele et al. 2008; Garcia Sanz et al. 2007). The models differ depending on the perspective and research focus, describe different criteria of importance and use different procedures.

This chapter structures and summarizes the process to optimize global production networks into three phases:

- define the production network strategy,
- design or redesign the production network and
- migrate to the optimized production network.

This strategic process has to be re-evaluated periodically and the global production network has to be adjusted continuously in case of changes of relevant factor.

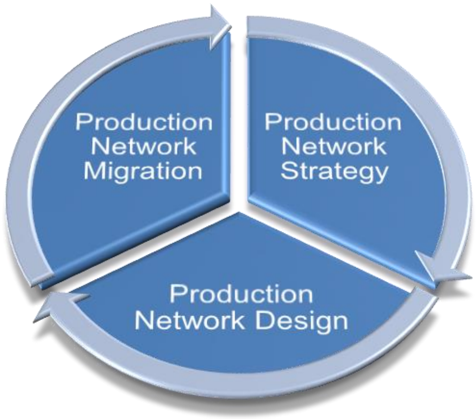

Figure 6: Three phases to optimize Production Networks

2.3.2.1 Production Network Strategy

The Production Network Strategy addresses the fundamental question why a company requires a global production network and why the production network should be changed or optimized. To answer this question it is instrumental to start from the production strategy, which is derived from the business strategy of an enterprise. The **production strategy** defines how a company plans to achieve differentiation versus competition and therefore to achieve sustainable competitive advantage (cf. Pümpin & Amann 2005: 30). The dominating success factors of production historically have been cost and quality, later delivery reliability and flexibility and nowadays also innovation and service are named as decisive factors to succeed in the market (cf. Thomas 2013: 54) These differentiation factors cannot be achieved in parallel, but companies need to assess their relative importance for their sustainable competitiveness and prioritize them.

Companies with global production networks have to further derive a **production network strategy** from the production strategy. The production network strategy defines the strategic network capabilities of a company to successfully compete in the global market. Strategic production network capabilities researched in literature are

- access to markets,
- access to resources,
- cost reduction

- efficiency opportunities,
- mobility and
- learning

(cf. Wildemann 1996a: 229; Wildemann 1996b: 41; Thomas 2013: 60).

Companies also have to perform different trade-offs between the network differentiation factors (Shi & Gregory 1998: 209). A typical example of such a trade-off is the advantage of market-proximity of a Local for Local Model versus the Economies of Scale advantage of a centralized global production site (see 2.2).

2.3.2.2 Production Network Design

The Production Network Design[3] addresses the central question of how many production sites a company needs with which capabilities and where to locate and how to link them. To design global production networks three important decisions need to be taken.

Firstly, it is important to specify the scope or **role of the individual plants** within the network. This includes the definition of the products or components to be manufactured by each plant and the required competences and processes to produce them (cf. Neuner & Kwasniok 210: 12).

Secondly, the **coordination principles or linkages** of the global production network need to be specified. The most important coordination issues are

material- and information flow between the participants of the global production network (including capacity planning, market allocation and purchasing),

coordination of product innovation (depending on the strategic decision whether product innovations are centralized and standardized across the globe or if local production sites are entitled to design or adopt products to local market needs) and

coordination of process design (companies need to decide if they want to use identical processes and equipment in each plant to maximise synergies or if they allow the plants to use different processes and equipment and local supplier bases in the different markets) (cf. Christodoulou et al. 2007: 27).

[3] *Production Network Design is also referred to as Footprint Design (cf* Christodoulou et al. 2007; Neuner & Kwasniok 2010; Shorten et al. 2006)

Finally, once the plant roles and coordination principals are defined the central question **where to locate the plants** can be answered.

2.3.2.2.1 Production Network Location Criteria

Determining the ideal location of plants requires a structured methodology, sound quantitative analysis and thorough approach on uncertainty factors (cf Neuner & Kwasniok 210: 14). Meyer & Frank (2008: 172) define five criteria categories that must be evaluated to decide on the target locations:

- manufacturing and material costs,
- market and logistics,
- technology,
- external factors, and
- transition financials.

The first four categories determine the long-term total landed costs. The fifth category covers the cost to implement the target production network.

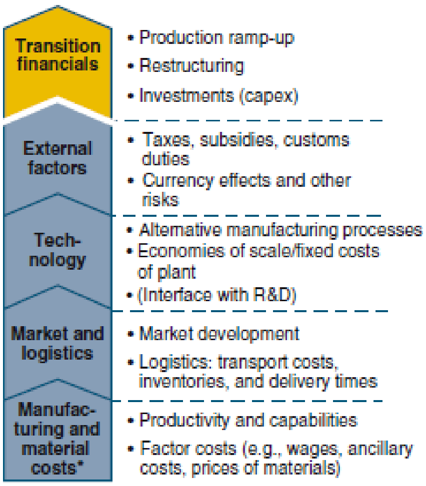

Figure 7: Location Criteria (Meyer & Jacob 2008: 172)

Manufacturing and material costs

Although there are other important factors to be considered which will be discussed later, the major factors influencing the production network locations definition usually are manufacturing and material costs. Relocating production to low labour cost countries can significantly reduce labour costs. However, there are also limiting factors to be considered. For example, automated manufacturing processes have a much lower potential to reduce labour cost compared to manual and labour-intensive processes (cf. Christodoulou et al. 2007: 29).

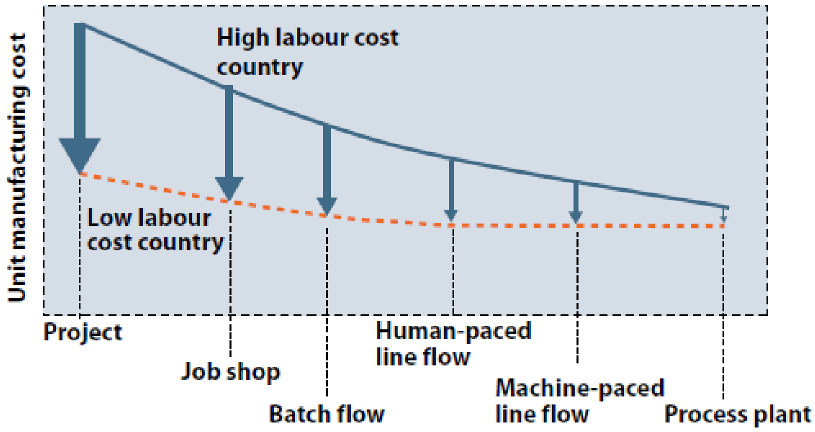

Figure 8: Impact of moving to a low labor cost country (Christodoulou et al. 2007: 29)

Material costs also need to be evaluated carefully, since cost and availability can vary significantly between different locations and geographies (cf. Christodoulou et al. 2007: 29). The same applies for productivity and capability. For countries where no productivity values are available for comparable manufacturing processes, estimates have to be made using available statistics such as level of education etc. Often labour costs have to include bonuses to attract and retain better skilled and motivated personnel so that a higher productivity can be achieved (cf. Meyer & Jacobs 2008: 173).

Market development, Customer requirements and Logistics costs

Market development, Customer requirements and logistics costs have a considerable impact on the design of an optimized production network. Finding a realistic long-term market forecast is an absolutely crucial variable in designing a production network since plant investments usually are huge investments and often are justified over a long period (cf. Christodoulou et al. 2007: 24). Also it is very important to understand and consider the customers flexibility requirements. Often automotive customers require their suppliers to follow them to new markets and to open production sites close to their own production locations (see 1.3). Such customer proximity, delivery times and flexibility requirements have a significant influence on the location decision. If the customers' responsiveness expectations are not that high, it may still be possible to supply customers globally from one or a few central locations to benefit from manufacturing and material economies of scale and scope. However, long shipping-distances not only reduce flexibility but also lead to higher logistics costs. When calculating the logistics costs it is very important to consider not only the increased transportation costs, but also the costs for packaging, customs clearance, insurance, stock in transit, higher safety stocks due to the longer lead times, depreciation of product value and scrapping costs, special transport costs, opportunity costs due to lack of flexibility, increased coordination costs (cf Jacob & Meyer 2008: 173; Christodoulou et al. 2007: 29; Palm 2014: 142; Chopra & Meindl 2010: 132; Slack & Lewis 2011: 136). These costs need to be balanced against production costs to define the location with the lowest global landed costs.

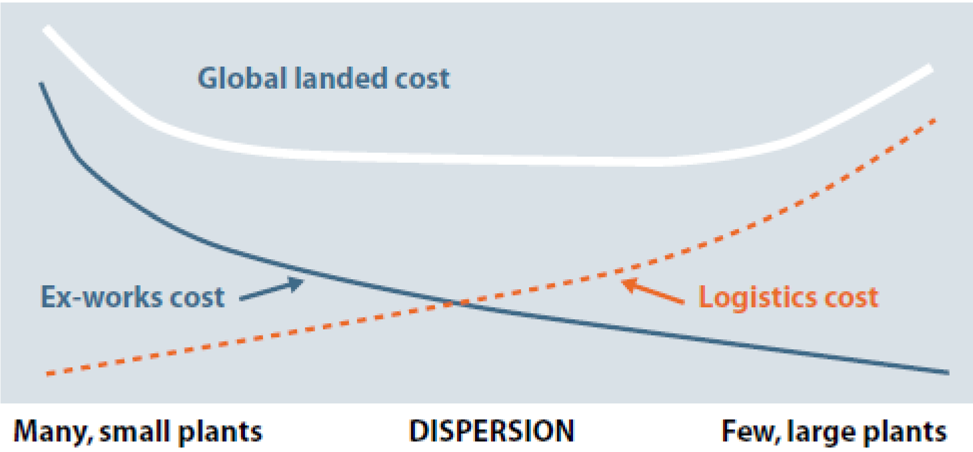

Figure 9: Global landed cost curve (Christodoulou et al. 2007: 29)

Technology

Manufacturing Technology is also an important factor that needs to be considered when designing the production network and can not only influence the decision how but also where to produce. This is illustrated in an example of Shorten et al. (2006: 4). Manual assembly is the preferred solution for low volumes production, automated assembly for high volume production. However, the break-even point when to invest in automated production can significantly differ between countries with high-labour cost and countries with low labour cost (such as Mexico and the U.S. in the example).

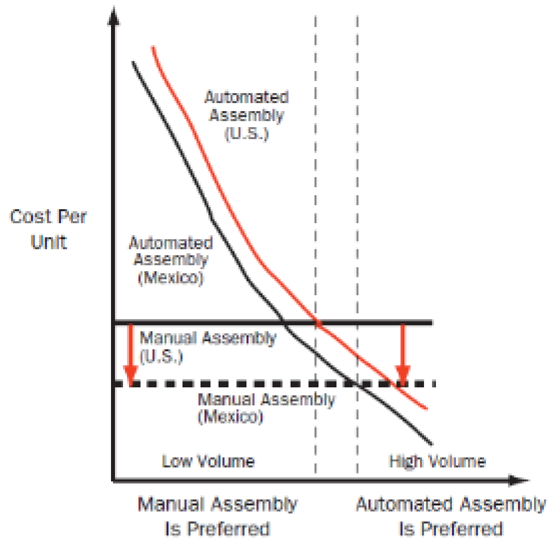

Figure 10: Cost of manual versus automated assembly in different locations (Shorten et al. 2006: 4)

External factors

External factors also have a high impact on a production network structure and need to be evaluated carefully. For example, trade restrictions such as customs duties and non-tariff barriers are highly relevant factors in the automotive industry, particularly in important markets such as China, India and Brazil (see also 2.2). Furthermore the effect of subsidies needs to be considered since they can significantly reduce cost of investments abroad. Currency imbalances and the risk of exchange rate fluctuations also play an important role (cf. Meyer & Jacob 2008: 175). Political, economic and legal stability also are elementary external factors which must be considered. Other important external factors are market potential, availability of personnel and local sourcing potential (cf. Palm 2014a: 144). The PESTLE (Political, Economic, Sociological, Technological, Legal, Environmental) tool can be used to help identifying and structuring the influences impacting the decision on global production locations.

Transition financials

Once all relevant-cost factors have been considered to define the total landed cost of a global production network design, the transition costs to implement the new structure must be evaluated. Some companies simply decide to ignore transition cost with the argument that redesigning the global production network is a strategic imperative and that long-term the implementation or reconfiguration of production sites anyhow would be funded through regular investment capital. However, usually it is preferable to evaluate transition costs so that they can be considered when evaluating different alternatives of production network structures (cf. Christodoulou et al. 2007: 30). The following one-off expenses should be considered when calculating the transition costs (cf. Christodoulou et al. 2007: 30; Meyer 2008: 120):

1. Restructuring expenditure including severance payments
2. Cost of physical production equipment transfer including dismantling of machines, transportation, reassembly and commissioning at the new location
3. Investment cost in new production equipment
4. Production ramp-up costs, including costs for training of new employees, additional costs for expatriates, costs for process-audits (internal and by OEMs), lower productivity in the start-up phase, overtime to produce inventory buffers for relocations, capital costs for increased inventory
5. Opportunity costs of relocation such as capacity losses during production transfer, additional management capacities required to manage the relocation

2.3.2.2.2 Production Network Location Decision

Finally different network alternatives can be evaluated based on these five categories through a quantitative and qualitative scenario analysis to identify the optimum network design and take the location decision. Since many influencing factors are uncertain (especially external factors such as exchange rates, demand fluctuations, inflation and labour cost changes) the robustness of each alternative shall be validated for changes of these uncertainty factors. Such a sensitivity analysis helps to identify the most important influencing factors and reduces the risk to take a wrong decision by underestimating the impact of wrong assumptions or changes of uncertain factors (cf. Neuner & Kwasniok 2010: 14ff). The end result of the evaluation of the alternatives is the decision on the optimized production network and its locations. This decision has to be re-evaluated periodically and the global production network has to be adjusted continuously in case of changes of relevant factors (cf. Shorten et al. 2006: 6).

Once the optimum global production network has been identified and decided, the implementation can be planned and executed.

2.3.2.3 Production Network Migration

2.3.2.3.1 Detailed Location Decision

The result of the Production Network Design is the decision on the geographic target region of the production site(s) at country level (see first two steps of **Fehler! Verweisquelle konnte nicht gefunden werden.** below). Now the detailed location decision has to be taken. Availability of required human resources (workforce availability, education and skills), infrastructure (road and rail network, ports and airports) and costs (land, labour, custom duties, taxes and subventions) can differ significantly between different locations even in close geographical proximity (cf. Simon et al. 2008: 241ff; Christodoulou et al. 2007: p. 38). A systematic selection process, the support of local agencies and government bodies as well as local visits help to speed up the selection process and to take the right decision based on accurate and complete information (see steps three to five of Figure 11).

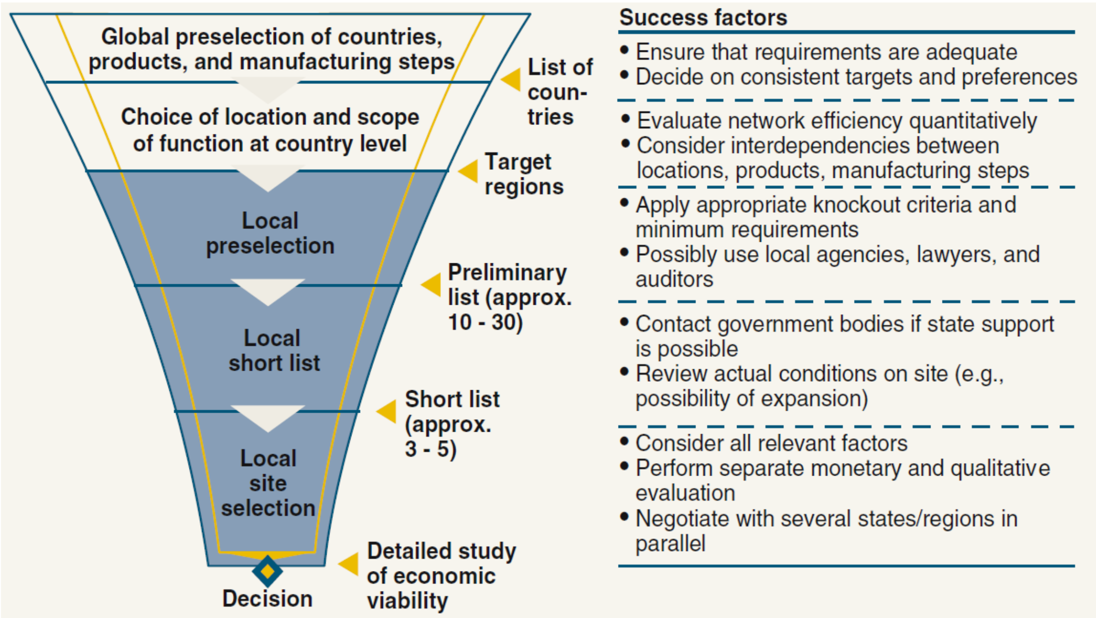

Figure 11: Location Selection Funnel (Simon et al. 2008: 244)

2.3.2.3.2 Organization Changes

The result of a Global Production Network optimization usually is not just the decision to implement a new site but almost always has an impact on the existing production network and its production sites. As result of the production network extension or optimization existing plants very often relocate production lines to new or already existing plants in other locations, expand their existing production lines to increase capacity, introduce new processes or capabilities, implement new production lines to launch new product-process families etc.

Any change of the role of the individual plants and their relationship also lead to changes in the organization structure of a company. These changes have to be reflected in the company’s overall organizational structure (cf. Christodoulou et al. 2007: p. 37). Moreover, given the importance and complexity of a redesign of the production network, companies should install a dedicated organizational function or team in charge to manage and coordinate the production network adjustments. To do so this team must be empowered to access all resources and expertise required to implement the required changes across all functions (cf. Shorten et al. 2006: 7).

2.3.2.3.3 Recruiting and Training

Hiring and training local staff with the required skills and know-how is the key aim when implementing, expanding or changing production sites. For positions requiring specific technical or management and leadership expertise which cannot be found in the market expatriates need to be identified and assigned to support the ramp-up phase and train and develop local resources. The training of local workers and managers to improve their skills and know-how is of highest importance for successful and cost-efficient global production. At the same time, measures must be taken to ensure to retain the trained employees so that the knowledge and skills built are not lost to local competition (cf. Simon et al. 2008: 247ff).

2.3.2.3.4 Ramp-up

Ramp-up planning includes the systematic planning for the transfer of products, materials, equipment, systems, know-how and people. This planning must include all required actions for both, the sending plant and the receiving plant. Timely and complete execution of all required actions must be controlled and documented. Progress and efficiency of the ramp-up phase shall be measure with KPIs. The ramp-up phase only ends once the receiving plant is fully capable to run production smoothly and independently (cf. Christodoulou et al. 2007: p. 38).

2.4 Global Production Relocation in Practice

2.4.1 Relocation motivation

The Frauenhofer ISI institute studied the reasons of German companies to relocate production abroad. The study results identified labor-cost benefits in Eastern European countries as the dominating motivating factor to produce abroad. Market access and proximity to customers are also important factors, although less important than cost of labor benefits (cf. Zanker et al. 2013: 9ff).

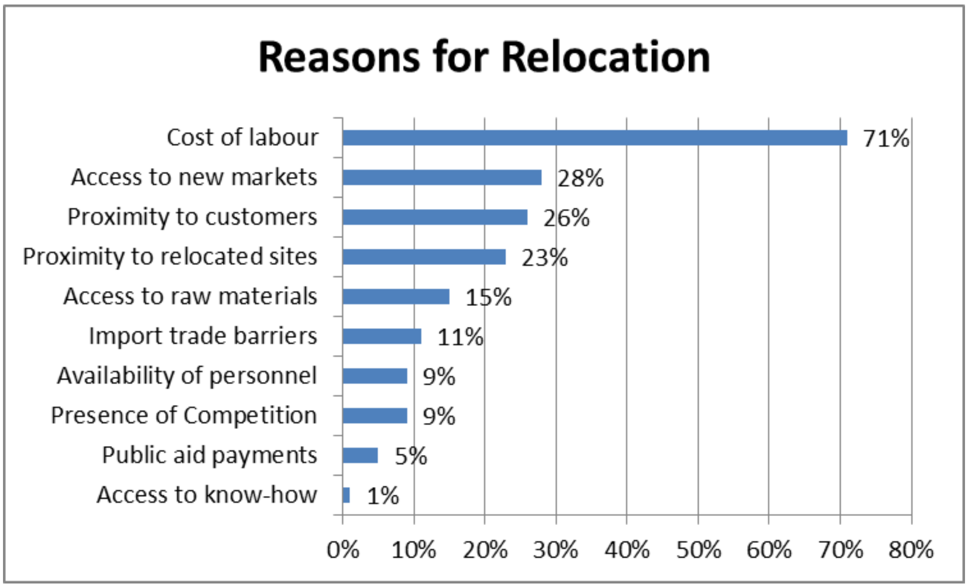

Figure 12: Reasons for Relocation (cf. Zanker et al. 2013: 9)

2.4.2 Relocation problems

The same Frauenhofer ISI study revealed that almost every third relocation project is not successful and companies decided to re-relocate production back to their home-country. The top reasons why these production relocations are not successful are flexibility-losses and quality issues. Other important issues are underutilized capacities, increased transportation costs and coordination efforts. Costs of labor, which was identified as the primary motivation factor to establish production abroad very rarely is a reason to re-relocate production back home (cf. Zanker et al. 2013: 10).

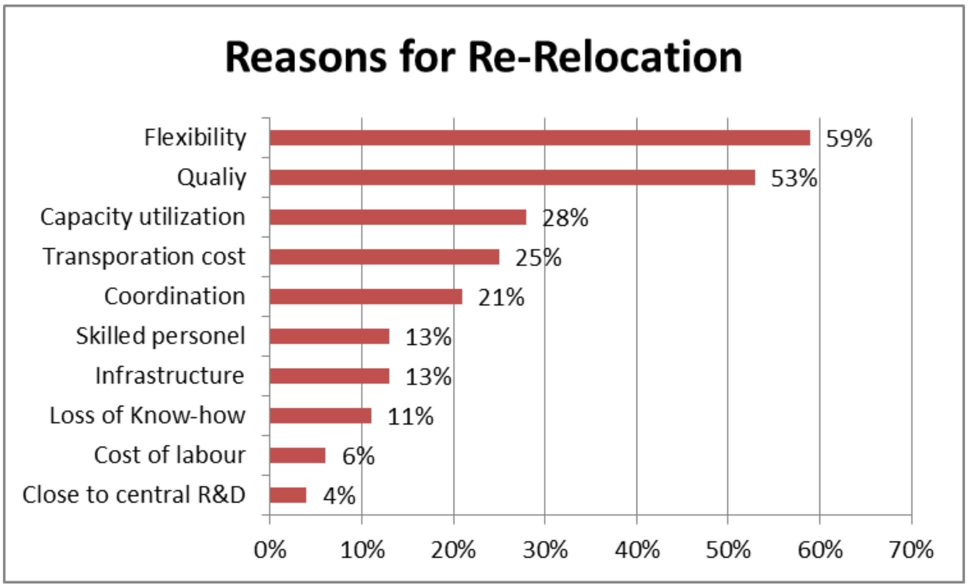

Figure 13: Reasons for Re-Relocation (cg. Zanker et al. 2013: 10)

Summarizing, the study shows that in practice companies mainly consider direct location-specific factor cost[4] (especially labor costs opportunities) when taking their decision to relocate production abroad, but often underestimate the (potential negative) impact of relocated global production sites on flexibility, quality and logistics cost and as a result the performance of the production network is not satisfying (cf. Becker 2010: 7).

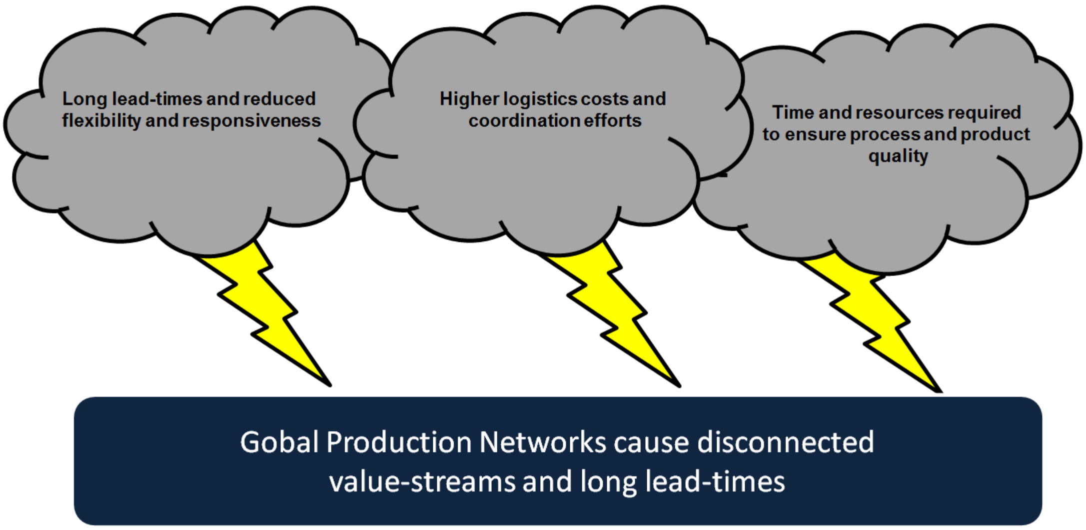

Figure 14: Impact of global production networks on the value-stream

[4] Factor costs are costs for labour, materials, capital (cf. Chopra & Meindl 2010: 132)

This is quite surprising, since the importance to consider customer and quality requirements and logistics costs are defined as important production network location criteria in the traditional production network theory (see 2.3.2.2.1). In practice however companies focus on (direct) cost saving opportunities and underestimate the importance of lean value-streams. As a result value creation becomes more and more fragmented in global multi-organizational networks with value-adding activities distributed around the globe.

Meeting the ever increasing customer's and logistics requirements becomes more and more difficult in these complex networks since remote production always increases coordination efforts, lead-time and response time to fulfill customer requirements (cf. Prinz et al. 2010: 85; Balsliemke 2013: 288). To reduce response-times to fulfill customer requirements and to protect against forecast inaccuracy, demand volatility and disruptions in these complex networks, the global production sites usually build additional inventory and safety buffers, which increases the lead-time of the total value-stream even more and results in even less flexibility or increased inventories in the total value stream.

The objectives to reduce lead-time and remove waste are the guiding principles of the lean philosophy. Lean businesses have characteristics that are mostly the opposite of traditionally managed businesses. Lean management focuses on improving the material and information flow in the entire value stream system. Material and information that flows without interruptions has many benefits such as shorter lead-times, improved quality, low cost and customer satisfaction (cf. Emiliani & Stec 2004; Fujimoto 1999; Womack & Jones 2003). The next chapter will present the concept of Lean Production and study its approach to optimize Global Production Networks.

2.5 Lean Production Network Theory

2.5.1 From the Toyota Production System to Lean Production

Lean production has been derived from the Toyota Production System (TPS), which started its development during the recession period after World War II. Since post-war demands were low and resources were scarce, mass production and its focus on economies of scale was not a viable option. To the opposite, over-production had to be avoided and Toyota was forced to produce solely to the demand of the customers. Toyota recognized that it had to find a way how to economically produce large variety in small volumes and started to develop the TPS by combining selected elements of mass production with their own ingenious systems and ideas (Fujimoto 1999: p. 50). Since then TPS has continuously evolved and was gradually rolled out to the wider Toyota organisation and its suppliers. Nevertheless, the development of TPS was largely unnoticed outside of Japan until the first oil crisis in 1973. Sugimori et al. (1977) published the first article of the Toyota Production System in English and TPS was discovered and started to disseminate to the western world. During the 1980s TPS was transferred out of Japan to the “New United Motor Manufacturing” (NUMMI) automobile manufacturing joint venture between Toyota and General Motors in the USA and a number of writers and consultants started to promote lean methods. In 1990 the best-seller “The Machine that changed the World” was published by Womack et al. and provided exhaustive evidence of the competitive superiority of the “Lean Production” concept (cf. Holweg 2007: 429). “Lean Production” successfully challenged the accepted mass production practices in the automotive industry and led to a rethinking of the high-volume repetitive manufacturing environment (cf. Holweg 2007: 420). Nowadays the philosophy of Lean Management is applied to many industries and even to indirect and administrative areas (cf. Minichmayr 2014: 139).

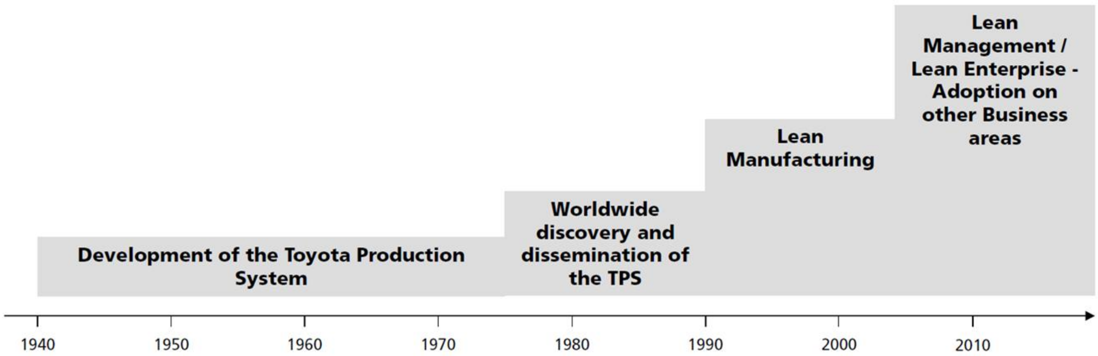

Figure 15: Lean Development phases (Minichmayr 2014: 15)

The philosophies of TPS and Lean Production both share the same guiding principle to eliminate waste. However, they differ in their focus how to achieve these targets. The focus of TPS is on continuous improvement, respect for people through learning and empowerment, and standard work practices (cf. Heizer & Render 2014: 674). Lean Production focuses to optimize the entire value-stream from the customer perspective by identifying customer value and driving out all no-value added activities (cf. Heizer & Render 2014: 676).

2.5.2 The seven categories of waste

Waste is defined as anything that adds cost or time without adding value to the customer or anything that the customer is not willing to pay for. Traditionally lean literature identifies seven categories of waste, also referred to as the “Seven Deadly Wastes” (cf. Tapping et al. 2002: 41f; Minichmayr 2014: 69ff; Balsliemke F. 2015: 2ff)

Overproduction: producing components, products or quantities that are not required for immediate use or sale, often caused by large batches

Inventory: excess stock in form of raw material, work-in-progress and finished goods

Waiting times: idle time between operations or during operations e.g. caused by maintenance, unbalanced lines, scheduling mistakes, missing materials

Defective goods: producing defective goods or mishandling materials, disruption of the process continuity, time and space for analysis, rework and removal

Motion: any movement of workers that is not required or inefficient to successfully perform a value-adding operation including unnecessary movements to search for materials, tools or information

Transportation: moving materials between process steps or to and from warehouses, long transportation ways, intermittent parking of materials, unnecessarily frequent storing in and out

Over-processing: processing more than needed to produce what the customer requires caused by over-dimensioned machinery, wrong or missing equipment, inefficient equipment process etc.

Since the original seven categories of waste were established, further categories were discovered and added such as ***waste in skills*** (not fully utilizing and leveraging the skills of employees), ***design*** (products that fail to meet the customer’s need), ***communication*** (lack of information or sharing of information which leads to misunderstanding or unnecessary repeated communication) or ***unnecessary processes*** not adding value at all (cf. Minichmayr 2014: 69; Pereira R. 2009: 2).

2.5.3 Lean Production Principles

In their book "Lean Thinking" Womack & Jones (2003: 15ff) describe five steps for guiding the implementation of lean techniques to eliminate waste.

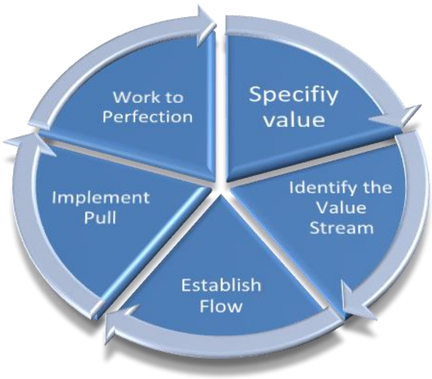

Figure 16: Lean Production Principles (cf. Womack & Jones 2003: 15ff)

Value is the critical starting point of Lean Thinking and can only be defined by the ultimate customer. Value is only meaningful when expressed in terms of a specific product which meets the customer's needs at the right time and appropriate price (cf. Womack & Jones 2003: 16ff).

The **value stream** is the set of all specific actions required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer. Each activity along the value stream has to be identified and muda (Japanese for waste) has to be eliminated (cf. Womack & Jones 2003: 19f).

All activities along the value stream should occur in progressive and tight sequence and without defects so that the product can **flow** smoothly and without interruptions to the customers (cf. Womack & Jones 2003: 21ff).

The **pull** principle means that the whole value stream should be driven by the customer demand, which means that no upstream process should produce until the downstream process asks for it (cf. Womack & Jones 2003: 24f).

Perfection strives for the complete elimination of muda along an entire value stream by the continuous application of the first four lean principles to specify value, identify the entire value stream, make the value steps flow continuously and let the customer pull value (cf. Womack & Jones 2003: 25). Perfection is an aspiration, anything and everything is able to be improved and therefore lean is a never-ending process of continuous improvement.

2.5.4 Lean Production Networks

In lean thinking most of the waste and long lead-times in global production networks result from the need to move products between different facilities and over long distances. The logical step therefore is to re-locate and co-locate value adding steps so that they can be performed faster and with less waste. Jones & Womack (2011: 65) defined three principles to decide on the location of production steps or plants.

Principle 1: Move all production steps together as close as possible, ideally even to the same room

Principle 2: Locate the co-located production steps as close to the customer as possible

Principle 3: If co-locating production steps and customer proximity increases production costs these costs must be weighed against the value of the waste reduction and time saving

2.5.4.1 Lean Production Network Location Scenarios

Jones & Womack (2011: 66) describe four lean production network location scenarios considering the lean production network principles.

Scenario 1: If the customer is located in a high labor cost country and requires high responsiveness and the product has low labor content, concentrate all production steps close to the customer in the high labor cost country.

Scenario 2: If the customer is located in a high labor cost country and does not request high responsiveness and the product has high labor content, concentrate all production steps in a near low-cost country and ship only the Finished Goods to the customer. Ideally this production location should be in a low-cost country within the same area of sales, e.g. Mexico for USA or Eastern Europe for Germany.

Scenario 3: If the customer is located in a high labor cost country and does request high responsiveness and the product has high labor content, the ideal location has to be determined by a detailed cost analysis of different options. These options could vary from producing parts of the product in a distant low labor cost country and delivering it by air to assembly of the product close to the customer in the high labor cost country using automation technology eliminating most of the manual labor.

Scenario 4: If the customer is located in a low labor cost country the product should be produced as close as possible to the customer in the low labor cost country.

The four scenarios can be translated into three Lean Production Network Criteria:

- Labor cost at the customer location,
- labor content of the product and
- customer responsiveness requirement.

Practical examples of the automotive industry for these scenarios are

Scenario 1: a Just in Sequence Supplier of an OEM located in Germany
Scenario 2: a Tier 2 supplier located in Morocco supplying a Tier 1 located in Spain
Scenario 3: a Tier 2 supplier located in Romania using VMI (Vendor Managed Inventory)[5] combined with Consignment stock[6] to supply a Tier 1 located in France
Scenario 4: a Tier 1 supplier located in Mexico supplying an OEM in Mexico.

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[5] With Vendor Managed Inventory the supplier is in charge of managing it materials in the customer's inventory within an agreed inventory corridor (cf. Hellingrath 2014: 14ff).
[6] Consignment means delayed change of ownership, i.e. materials at the customer's location belong to the supplier until the customer withdraws them from the inventory ((cf. Hellingrath 2014: 19).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Labor cost @ customer	High	High	High	Low
Labor content of product	Low	High	High	any
Responsiveness requirement	High	Low	High	any
Lean Location	Concentrate value-stream as close as possible to the customer located in the high labour cost country	Concentrate value-stream in a close low labour cost country and ship Finished Goods to the customer located in the high labour cost country	Design value-stream enabling high responsiveness at lowest Total Cost of Ownership	Concentrate value-stream as close as possible to the customer located in the low labour cost country
Example	JIS Supplier of OEM in Gemany	Tier 2 in Morocco supplying Tier 1 in Spain	Tier 2 in Romania using VMI & consignment for Tier 1 in France	Tier 1 in Mexico supplying OEM in Mexico

Figure 17: Lean Production Network Criteria and Scenarios

2.5.4.2 Lean Production Network Location Decision

The Lean Production Network Location Procedure aims to design the value stream of a production network to achieve the best overall trade-off of costs, responsiveness and quality (through earlier identification of defects). The traditional Production Network Design procedure wants to achieve the same target and calculates the best location option using the total landed costs or total cost of ownership method (see 2.3.2.2.1). The total cost of ownership method addresses the issue to not only consider the direct cost factors manufacturing and material cost, but to consider all cost elements including especially logistics costs to achieve the required customer flexibility, coordination costs to manage the production network, costs for inventory and product write offs as a result of longer lead-times and any other relevant cost factors such as location specific external costs.

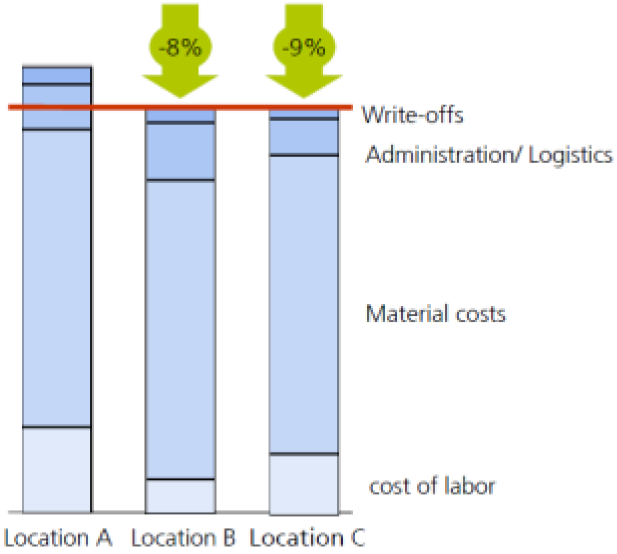

Figure 18: Location decision bases on Total Cost of Ownership Method (Palm 2014: 143)

The total cost of ownership method is a holistic calculation model for companies to evaluate of cost benefits of production relocations and to justify the required investments and expenditures to change the global production network structure. However, basing the decision on the Total Cost of Ownership Method involves three major risks from a lean production network perspective.

Firstly, in practice many companies calculate the sum of the Total Cost of Ownership of the individual production locations in the network rather than the Total Cost of Ownership of the (redesigned) Production Network including all cost to link the different production locations, suppliers and customers within the network.

Secondly, if the costs to link the network sites are calculated, very often only the transport cost to move the materials, parts and products through the network are calculated using costs of planned transports and cost-efficient shipping modes.

Thirdly and most importantly, even if all plannable costs are considered carefully and correctly, companies usually have difficulties to anticipate the additional costs and risks which result from increased complexity, reduced flexibility and longer lead-times in fragmented global production networks.

To take a lean production network decision companies must also consider the indirect and hidden costs which result from managing and connecting the activities along the value stream such as costs of in-transit inventory, costs of safety stock to ensure flexibility, costs of special transports to compensate for disruptions in the complex network, out of stock costs and lost sales caused by long lead-times, write off costs caused by product changes, costs of dead or aging stock which was produced to forecast but never called-off (cf. Womack & Lovejoy 2011: 96ff; Becker 2010: 15).

All of these costs are value-stream related costs, or costs required to link the production network players and to move the materials down the value stream from the suppliers to the customers. The list above should be helpful for companies to consider these important cost factors. However, the problem still remains that most companies do not “see” the costs and risks of global production networks in their cost accounting and balance sheets. This makes it even more difficult to calculate these costs for planned production network relocations. To resolve this issue Lean Production developed Value Stream Mapping as an excellent tool which helps companies to actually really see where value is added and where waste is created. Moreover, it helps companies to reduce waste and to optimize their future value streams.

2.5.5 Value Stream Mapping

“Value Stream Mapping”, known as “Material and Information Flow Mapping” at Toyota, is one of the most powerful methods to implement lean in companies (cf. Rother & Shook 2004; Pavnaskar et al.2003; Manos 2006; Jones & Womack 2011). The method “…is a simple yet very effective method to gain a holistic overview of the status of the value streams in an organization from the supplier to the customer” (Minichmayr 2014: 21). Value stream mapping therefore is focused to improve the total value stream rather than isolated processes or activities. Value stream maps help to identify waste in the value stream that adds costs but does not add value and aims to optimize material- and information flow to flow smoothly and without interruption, improve productivity and competitiveness (cf. Emiliani & Stec 2004: 622).

2.5.5.1 Levels of Value Streams

Before starting the Value Stream Mapping the scope of the value stream that shall be optimized has to be defined (cf. Manos 2006: 64). Originally Value Stream Mapping was focused on the analysis and improvement of disconnected manufacturing flow lines and “door-to-door” production processes, including raw material-supply to the plant and customer-deliveries (cf. Rother & Shook 2004: 3). The method later was further developed and enhanced to also map the value stream of multiple production plants and up-stream and down-stream supply chains, so-called extended value-streams (cf. Jones & Womack 2002; Arbulu et al. 2003). Recently Jones (2011: 100ff) proposed to use extended value-stream mapping to map total supply systems.

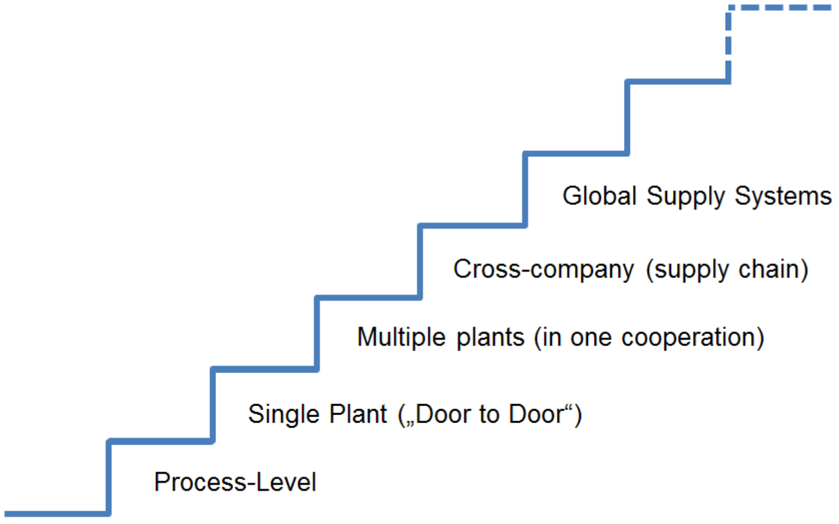

Figure 19: Levels of Value Streams (cf. Minichmayr 2014: 23; Jones 2011)

2.5.5.2 Value Stream Mapping Procedure

The Value Stream Mapping method uses a four-step procedure to analyze and design the Value Stream.

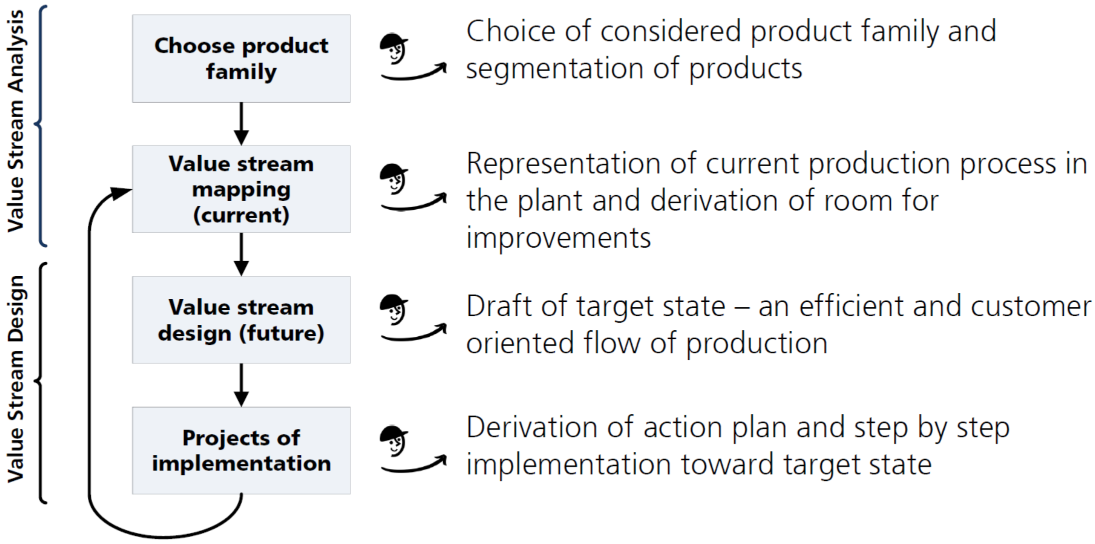

Figure 20: Procedure of the Value Stream Mapping Method (Minichmayr 2014: 25)

2.5.5.2.1 Selecting a Product Family

There are many value-streams in a company, therefore it is essential to define the value-stream to be analyzed and optimized by selecting a product-family (cf. Tapping et al. 2002: 27). Typically a product family includes a group of product variants passing though similar process steps and using common equipment before being shipped to customer(s) (cf. Jones & Womack 2011: 1). Companies may have different reasons for selecting a specific product family and value-stream for optimization, such as

- product routing through similar production processes,
- product characteristics (e.g. function, type of product),
- product demand (quantity and volatility),
- product importance or
- product order type (e.g. make to stock or make to order)

(cf. Minichmayr 2014: 28).

2.5.5.2.2 Mapping the current state

To create the map, all required data and information have to be collected by starting from the customer's perspective and then "walking" upstream along the entire value-stream to be mapped. All following-up processes along the value stream are customers of the pre-delivery-processes. Typical steps to describe the current state of door-to-door value-stream maps are to assess customer data, assess plant data, identify processes, collect process- and stock information, draw the material flow, map the material flow and calculate lead time (cf. Minichmayr 2014: 33).

2.5.5.2.3 Designing the future value stream

The design of the future value stream is guided by the lean principles and aims to reduce lead time and avoid waste in the total value stream. This is quite different to the traditional approach to optimize the value-adding activities (see Figure 21).

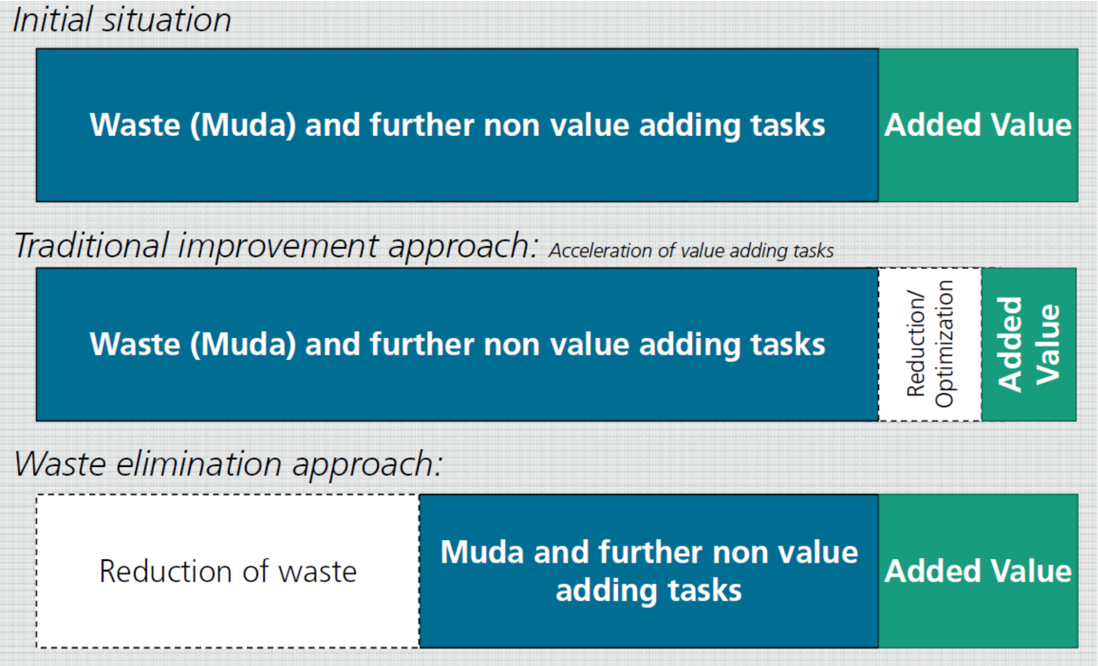

Figure 21: Waste reduction potential versus potential of value creation process optimization (Minichmayr 2014: 68)

Rother & Shook (2004: 52) originally described eight guiding questions to design an optimized future state. These were further discussed, enhanced and categorized by different other authors (cf. Tapping et al. 2002: 107ff, Manos 2006: 68ff). Minichmayr (2014: 76ff) defines 10 guidelines for the design of target door-to-door value streams:

1. **Orientation on customer tact-time:** Customer tact defines how frequently a product must be produced to meet the customer's demand. The customer tact is an excellent tool to synchronize the production and sales rhythm and to adjust production capacity of each production process to the customer demand.

2. **Continuous flow:** Link processes wherever possible to enable continuous flow instead of batch production of each individual process.

3. **FIFO tracks:** Use the FIFO (First In First Out) logic to couple production processes following each other when these processes cannot be directly integrated to enable continuous flow.

4. **Pull-Systems:** Reduce inventories of Raw material, Work in Progress and Finished Goods to reduce the lead-time. Use supermarket-pull systems[7] to link processes requiring batch production.

5. **Pacemaker-process:** Depending on the type of production (e.g. make to order, make to stock, JIT, JIS) the customer order has to be initiated into the value stream at a different point. This order penetration point defines the pacemaker process and the changeover from a (customer) pull to a (production) push system.

6. **Flexibility by balancing production mix:** If multiple products are produced in the same value stream it is important to level the production mix and minimize/optimize lot-sizes. The EPEI (Every Part Every Interval) value defines how long it takes to produce all products and is an excellent indicator about the production flexibility.

7. **Release of small, steady work packages:** Release tact-bound orders to production at the pacemaker process in small and even work packages so that production can react to volatile customer demands.

8. **Improvement of bottlenecks:** Any process with a cycle time or processing time greater than the tact time is a bottleneck or constraint. Such bottlenecks can cause waste (e.g. extra processing time, overtime to meet the demand, overproduction or work in progress in upstream processes)

9. **Separation and adoption of work content:** Eliminate waiting times of staff, e.g. by operating multiple machines in parallel and simplify tact-balancing by grouping work-packages of a process.

10. **Value-stream orientation:** Locate all process steps as close as possible

2.5.5.2.4 Implementing the future state design

Once the ideal design has been set up, it is important to ensure all relevant stake-holders and especially top-management support and approve the implementation. Once decided the implementation should be divided into manageable sub-projects, starting with the pace-maker process.

[7] In a supermarket pull-system the downstream process consumes items from the shelf and the upstream process replenishes them to the supermarket.

2.6 Lean Production Networks in the automotive industry

Ford’s River Rouge plant, which was developed almost a century ago between 1917 and 1928, can be called the pioneer of value stream concentration. The River Rouge complex was an automotive "ore to assembly" plant. Henry Ford’s idea was to achieve “a continuous, nonstop process from raw material to finished product, with no pause even for warehousing or storage”. More than that, the ultimate goal was to achieve a completely vertically integrated value chain by owning, operating and coordinating all the resources needed to produce complete automobiles. Ford’s production network included forests, iron mines and limestone quarries, coal mines and even rubber plants in Brazil. Although Ford’s ambition was never completely realized, no other company has ever come so close (cf. The Henry Ford 2015).

Today’s automotive manufacturer most popular for its lean value streams is Toyota. The Toyota Production System ever since focused on short lead-times through value-stream concentration, waste reduction and customer-proximity. In the beginning Toyota concentrated production of all cars in Japan and shipped the finished cars to the export markets. In the 1980s it established its first assembly plant abroad in the USA (see also 2.5.1), with components still delivered from Japan. This moved production closer to the customers, but increased the value-stream complexity and supply-lead-times. To resolve this issue Toyota started to source materials and components in the local market and to locate and concentrate the production network in the sales market in so called “Toyota Cities” (cf. Becker 2010: 30).

Figure 22: “Toyota City” in Texas (Becker 2010: 29)

Nowadays so-called „Supplier Parks” are state of the art in the automotive industry. Supplier parks are industrial areas including buildings and infrastructure close to an OEM. They are built for strategic reasons and are commonly used by several suppliers of one customer (cf Sihn 2014b: 16). Particularly parts with a high volume and a high number of variants (e.g. seats, door trims, exhaust systems, cockpit modules) which require a lot of space and need to be supplied JIS or JIT to the OEM are suitable for supplier parks. Supplier parks enable a high value stream concentration, low inventories and short lead-times for the OEM. Suppliers can also benefit by consolidating inbound flows of materials with other suppliers, an optimized material flow and shared infrastructure within the supplier-park and very short customer delivery transportation lead time and cost. So-called Multi-OEM Supplier Parks which typically are located in regions with a high concentration of car manufacturers can deliver additional benefits to suppliers, since they enable suppliers to concentrate production for multiple customers in one location (cf Palm 2014b: 221).

However, usually supplier parks are dedicated to a specific OEM close to its production location. By locating production close to the customer in a supplier-park, suppliers can significantly improve their customer responsiveness, but at the same time this increases the suppliers’ own value stream network complexity and limits the suppliers’ potential for value stream concentration and cost reduction, even more when the OEMs plant locations are based in high labour cost countries and the products supplied have a high labour-content (see also 0).

3 Lean Orientation of Global Production Networks

3.1 Lean Orientation of Global Production Network Stereotypes

The traditional production network theory evaluates production networks according to their potential for economies of scale and scope and their potential for local adaptation and low transaction cost (see chapter 2.2). In this chapter the production network stereotypes will be assessed regarding their lean orientation by evaluating them against the lean production network principles.

The stereotypes “World Factory” and “Local for Local” both have a high value stream concentration since they concentrate value adding production steps in either one global site or a production site per local market. However, the models differ in their potential to react fast to changing customer requirements. The “world factory” supplies all customers globally from just one plant and therefore has much lower customer proximity than the “Local for local” stereotype. The “Sequential or Convergent” model has the lowest value stream concentration and also a low proximity to customers since it concentrates every manufacturing step at a different location across the globe. In comparison the “Web structure” with its capability to produce each product in each plant has a better value stream orientation, but since the model aims to optimize production capacity utilization rather than flexibility, responsiveness to customers in this model is also rather low. The “Hub & Spoke” model achieves better customer proximity through close-to-market locations for final product customization or assembly. Value-stream concentration of this model is rather low since parts are shipped between global plants concentrated on economies of scale and local plants concentrated on customer proximity.

“Local for local” model has the highest potential to achieve the lean production network principles value stream concentration and customer proximity. However, as described in 2.2 this stereotype has the clear disadvantage of low economies of scale and scope. The lean production network logic considers the importance of economies of scale and scope with the principle that additional production costs to achieve customer proximity must be compensated by the value of waste reduction and time saving. This can be translated into the requirement to optimize the total cost of ownership. Figure 23 below summarizes the potential of each of the five stereotypes regarding their potential to achieve economies of scale and economies of scope, value stream concentration and customer proximity and responsiveness.

	World Factory	Web Structure	Sequential or convergent	Hub & spoke	Local for Local
Economies of Scale and Scope	High	Low	Medium	High	Low
Proximity to customer/ Responsiveness	Low	Low	Low	High	High
Value Stream Concentration	High	Medium	Low	Low	High

Figure 23: Lean Orientation of Production Network Stereotypes

3.2 Lean Orientation Assessment of the Global Production Network of an automotive supplier

3.2.1 The automotive supplier

To create unique customer and product benefits, the automotive supplier develops innovative solutions in direct collaboration with automotive manufacturers and systems suppliers. With its innovative solutions, the company has become a major producer for automotive connectors and contacting systems, special cable assemblies, wiring harnesses and smart sensor solutions for applications in safety-relevant and highly-stressed vehicle areas. As a result of its successful performance the automotive supplier has developed into a global player, supplying its products to many renowned automotive manufacturers and system suppliers around the world. To produce and deliver its products the company operates a Global Production Network with more than 4000 employees working in seven production plants in six countries on three continents

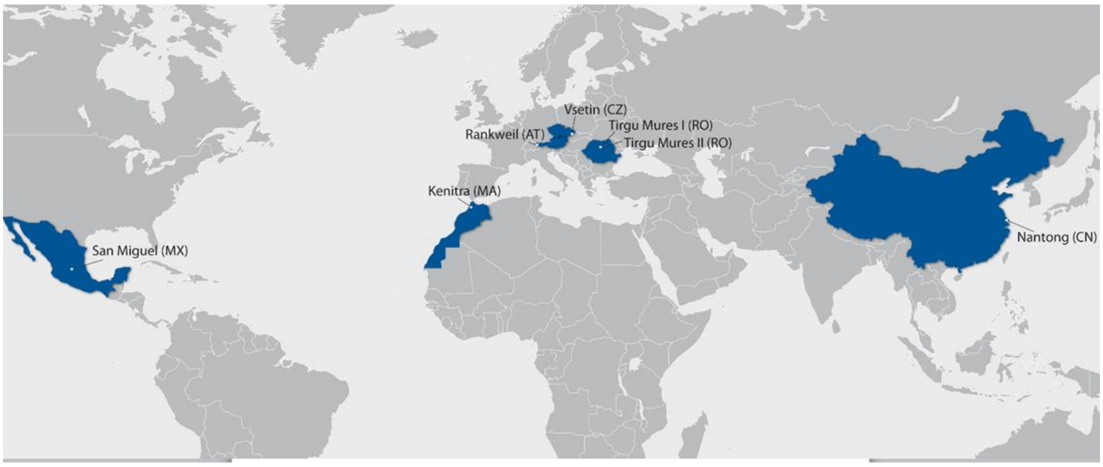

Figure 24: Global Production Network of automotive supplier

3.2.2 Production Network Strategy

A major success factor of the automotive supplier is the consequent execution of its production network strategy:

- maximize efficiency through concentrating production of economies of scale and economies of scope sensitive components and products in centralized production locations
- ensure market access through localizing production within in the major sales regions of the automotive supplier (EMEA, NAFTA, Asia)
- concentrate production of product process families in single plants within the major sales regions
- reduce cost of labour by localizing labour intense production steps in low labour cost countries within the major sales regions

3.2.3 Production Network Design

The **role** of each individual plant within the network is defined in the company's Product – Process – Plant - Matrix (see below). This matrix is continuously reviewed and updated in case of changes to the global production network, e.g. when extending existing production plants, opening new production plants, relocating product-process families between plants, launching new product-process families, introducing new processes or capabilities to the plants.

Product Family	Connectors housings, holder and frames	Connectors housings, holder and frames	Connector systems	Connector systems	Connector systems	Contacting systems	Contacting systems	Sensor Systems	Sensor Systems	Sensor Systems	Special cable assemblies	Special cable assemblies	Wiring harnesses
Process Family	Injection moulding tool-cavities >=8	Injection moulding tool-cavities <=8	Overmoulding Connector modules	Automated assembly of connector systems	Manual assembly of connector systems	Stitching	Insert moulding	Overmoulding Sensor modules	Overmolding Sensor assemblies	Insert moulding	Cable assembling and overmoulding	Cable assembling	Wire assembling and overmoulding
Rankweil	■			■		■		■					
Vsetin		■											
Tirgu Mures I							■		■		■		
Tirgu Mures II			■					■		■		■	■
Kenitra					■								■
Nantong	2016	2016		2016	■								■
San Miguel	Definition ongoing (Planned Start of Production Quarter 2/ 2016)												

Figure 25: Product - Process - Plant Matrix

The **coordination principles** between the global functions and the plants are defined in a Function – Plant – Region Matrix. This matrix defines the responsible leader of each plant and the leaders of each global function. The Managing Directors of the plants are responsible for the production plant performance and to coordinate all local production plant functions. The leaders of the global functions are responsible for coordination, strategy development and execution, business process standardization, performance measurement and continuous improvement of their function across all plants.

Plant / Global Function	Rankweil Managing Director	Vsetin Managing Director	Tirgu Mures Managing Director	Kenitra Managing Director	Nantong Managing Director	San Miguel Managing Director
Global Function Leader		-	-	-		
Global Function Leader		-	-	-		
Global Function Leader		-	-	-		
Global Function Leader						
Global Function Leader						
Global Function Leader						
Global Function Leader						

Figure 26: Function - Plant – Region Matrix

The automotive supplier structures its business operations into three business regions: EMEA, NAFTA, Asia. For each region a so-called regional lead plant is defined. The regional lead plants are responsible for the regional coordination of the material and information flow, regional sales and product and process design adaptation to local market requirements.

The current global production network of the automotive supplier emerged over a period of more than 50 years. The company was founded in 1959 and opened its Headquarter and first production **location** in Rankweil in Austria. In 1980 the company produced its first connector systems for the automotive industry. In 1993 the automotive supplier started the internationalization of production and entered a Joint Venture with a supplier in the Czech Republic. This enabled the automotive supplier to reduce cost by relocating production of labour-intense products from Austria to the Joint Venture in the low cost-country. Ten years later, after a long and successful cooperation, the automotive supplier took over the Joint Venture partner and opened a new production site in Vsetin in the Czech Republic in 2003.

As a result of continued business growth the automotive supplier further extended its production capacity. At the same time the cost reduction pressure in the automotive sector also continued. After a structured location analysis the company decided to install a second production location in Eastern Europe and to relocate production of the most labour-intensive products from the plant in the Czech Republic to a new plant in Romania. Romania was identified as the ideal location offering labour-cost reduction opportunities while also meeting the required market proximity to the customers, which were mainly located in Western and Central Europe. After a detailed location analysis the automotive supplier decided to install the new plant in an industry park in the Romanian city Tirgu Mures and started production at the new plant in 2008. Sales dropped as a result of the 2008 global financial crisis. The automotive supplier swiftly reacted to the reduced demands and adopted its shift models and operating times in all plants, but kept all its installed capacity in the production network. As soon as the economy recovered, the automotive supplier used its innovation strength and production network capacity to grow significantly above market. As a result sales rocketed by 51% in the year 2010 versus 2009 and further increase by 19% in 2011 versus 2010.

Given this growth the automotive supplier decided to further increase its production network capacity by opening a third production plant abroad. Moldavia was identified as the best alternative in Eastern Europe, Morocco as the best alternative in North Africa. Since total cost of ownership for both options were close, the strategic decision was to reduce geographic exposure to Eastern Europe and to build up a new plant on the African continent. Availability of personnel and external facts such as the availability of duty free automotive industry areas, subsidies, a low inflation rate, stable exchange rate and political stability were carefully assessed before taking the final decision. In the course of the detailed location decision process a duty free automotive industry park in Kenitra in the North of Morocco was identified as new plant location. The new plant opened doors in 2012, and several production lines were relocated to the new plant from the Romanian Tirgu Mures site. Business growth further continued and in the end of 2013 the automotive supplier used the opportunity to acquire an empty production plant in Tirgu Mures. Since the plant was located only a few kilometres from the already existing site, this location provided an excellent opportunity to quickly adopt the site and integrate it into the local production plant management.

Figure 27: Location decisions of an automotive supplier

Besides expanding its production footprint in Europe and Africa, the automotive supplier also took the strategic decision to further globalize its production network by opening production sites in China and the NAFTA market. The automotive supplier had supplied its (predominantly localized European) customers plants in the Asian and NAFTA markets from its plants in EMEA. Like most automotive suppliers, also this company was challenged to fulfil ultimate localization requirements. More importantly, the automotive supplier took the strategic decision to further exploit the growth opportunities of the world's two biggest automotive markets China and NAFTA (see 1.2). For the Chinese market, the city of Nantong was identified as production location. The plant started producing for the local Chinese market in 2015. The location decision process performed for the NAFTA market identified San Miguel in Mexico as the best option. The plant is currently under construction and will start production in 2016.

As described in 2.5.4 a lean production network should move the value creating steps together as close as possible, locate the value adding steps as close as possible to the customer and optimize the total costs of the value added network. With the decision to globalize its production footprint, the automotive supplier also restructured its global business operations into three operating business regions: EMEA, Asia and NAFTA. Through the decision to localize production in each of the business regions the automotive supplier has made a major step into the direction of a lean global production network.

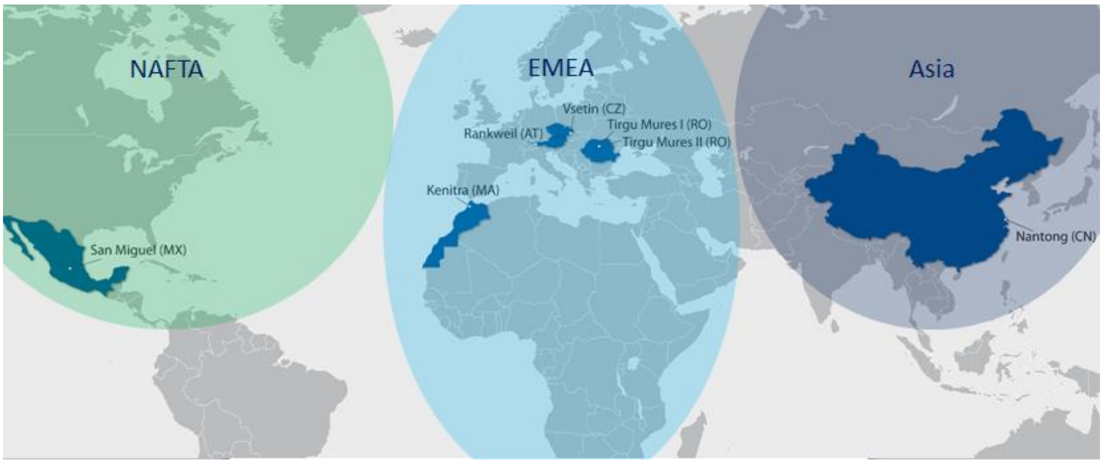

Figure 28: Global Production network of an automotive supplier

3.2.3.1 Regional Production Network EMEA

The regional production network to serve the EMEA region has grown over time and nowadays consists of five production plants, each focused on defined product-process-families (see 3.2.3). Production of economies of scope and economies of scale sensitive and capital intensive components and products is concentrated at the Lead plant in Rankweil (Austria) and at the production plant in Vsetin (Czech Republic). From there components are supplied to the plants in Trigu Mures (Romania) and the plant in Kenitra (Morocco). All suppliers are nominated by the central Procurement team located at the Headquarter in Rankweil, and the same material usually is sourced from the same supplier for all plants within the region, whereas the majority of the suppliers are located in Europe. Raw materials usually are directly supplied from the suppliers to the individual production plants. To improve economies of scale and reduce inbound transportation costs low volume items are sourced centrally by the lead plant Rankweil and are then distributed internally to the other plants.

The strategy is to concentrate suppliers, centralize production of knowledge-intense and economies of scale sensitive and capital intense components, and to focus on product-process-families in the individual production plants to enable economies of scale and scope advantages. Moreover, production costs are continuously optimized by relocating products with relatively higher labor content to a production location with relatively lower labor cost. Summarizing, the decision in which production plant to locate the production of a product-process-family within the EMEA region mainly depends on its sensitivity to economies of scope and economies of scale and capital intensiveness in comparison to the labor content of the product families.

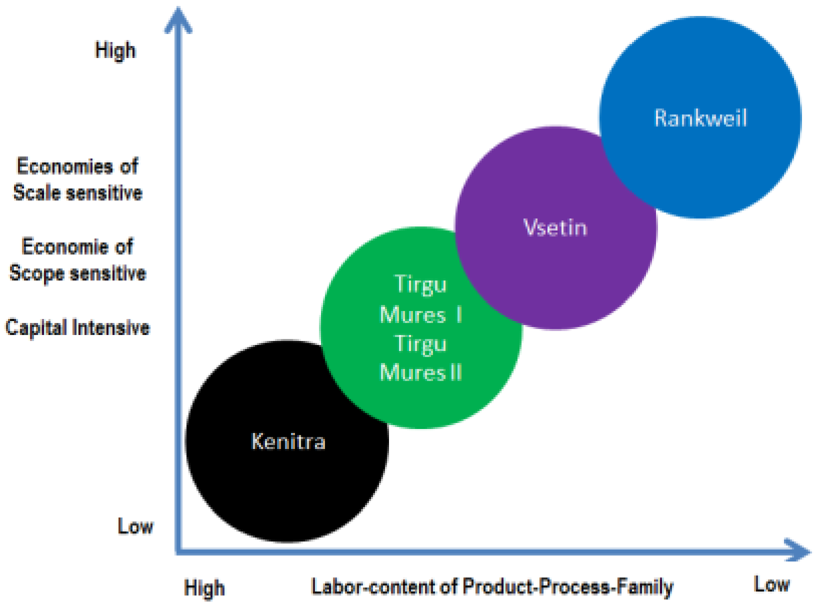

Figure 29: EMEA Production Network Location Criteria

Apparently, customer proximity and value stream concentration are not the major decision criteria when deciding on the production location of a product-process family within the EMEA production network.

Customer proximity is important to achieve the required customer flexibility. All current production locations in Europe and also the plant in Morocco are capable to fulfil the customer flexibility requirement to deliver each customer once a week. In single cases where customers require higher flexibility which cannot be fulfilled by a specific production plant as a result of too long transportation lead-times, products are distributed to customers via a central warehouse in Rankweil, from where all European customers can be reached within their requested lead-times.

Value stream concentration is important to reduce lead-time and logistics and quality costs. The automotive supplier operates multiple plants dedicated on the production of defined process product families, however all plants are located within the market they serve. The efficiency benefits and production cost advantages achieved through concentration of capital intensive component production in these dedicated plants as well as localizing production of labour intensive products in the plants located in low labour cost countries over-compensate the resulting increased cost of logistics, quality and coordination.

3.2.3.2 Regional Production Networks Asia and NAFTA

The new plants in Nantong (China) and San Miguel (Mexico) are located directly within their relevant sales markets. This ensures customer proximity, improved flexibility and reduced logistics costs. Furthermore, cost of labour are a major criterion when deciding on the detailed plant location within the geographic areas due to the high labour content of many products. The automotive supplier decided to locate production for the NAFTA market in Mexico. San Miguel was identified as the best production location due to its proximity to existing Mexican customers and suppliers and good availability of qualified personnel. For the Asian market the strategic decision was to localize production in China due to ultimate localization requirements and the still high growth potential of the local Chinese market. Availability of qualified personnel and a good balance between cost of labour and logistics costs to serve major customers located in China were the main reasons to decide on Nantong for the production location within China.

When taking the decision to localize production in Asia and the NAFTA market, the automotive supplier took the decision to concentrate production and the value-stream for the relevant product-process families in the relevant markets. Total production lines are localized in the new plants in Nantong and San Miguel. Whenever possible, raw materials are sourced from suppliers located within the same business region, and as close as possible to the plants to reduce inventory, lead-times and quality problems.

The decision whether or not and when to relocate production of product-process-families from the existing plants in the EMEA region to the newly established plants in China and Mexico to serve customers locally is based on a Total Cost of Ownership evaluation (see 2.3.2.2.1). New product-families for local customers are directly launched in the local plants. Only production of extremely knowledge-intensive, economies of scope sensitive and capital intensive components and products remains at the Headquarter location in Austria and are delivered from there to the global production plants or customers.

3.2.3.3 Global Region for Region Production Network

Summarizing, while before the value creation process of the global production network was concentrated in production plants in Europe and Northern Africa to produce and deliver all products for the global market, the new global production network design target is to localize and concentrate production within the relevant sales regions.

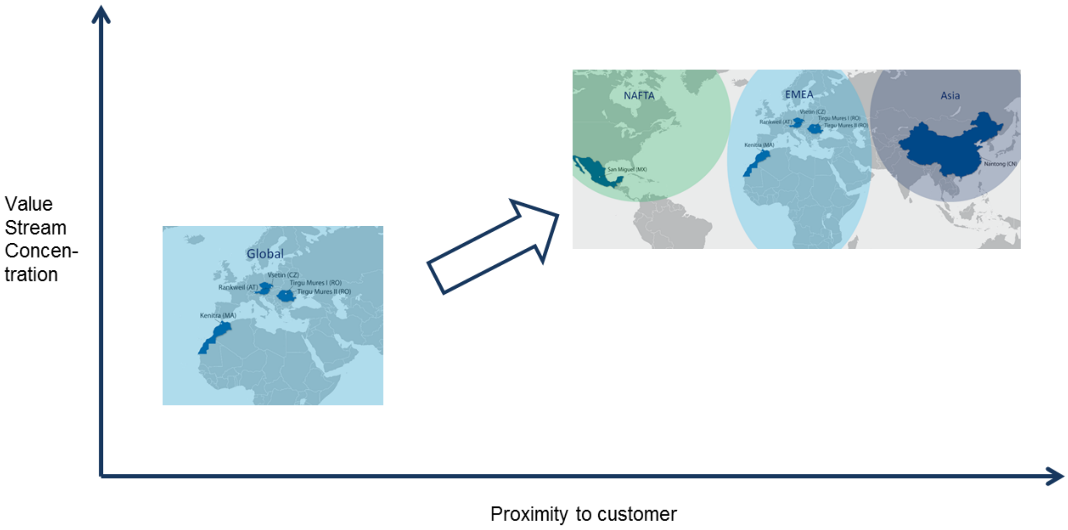

Figure 30: Region for Region Production Network

The global production network of the automotive supplier can be named as "Region for Region" Production Network. The "Region for Region" Production Network targets to enable global growth and to fulfill all three lean production network principles: value stream concentration, customer proximity and optimization of total cost of ownership (see also 2.5.4).

The next chapter will introduce Global Production Relocation Mapping as a lean tool to see, analyze and optimize the impact of global production relocations on lead-time, inventory, transportation requirements and logistics costs.

4 Global Production Relocation Mapping

"When you have learned to see value in individual facilities, it's time to see and then optimize entire value streams, from raw materials to customers" (Jones & Womack 2011). Extended value-stream maps can be used to track the path of all important parts that go into a product being delivered to a customer. The power of the extended value stream maps firstly comes from its visualization, making the consequence of global production and sourcing networks transparent. Secondly, it can be used to analyze the current state network and to design an optimized network (cf. Jones 2011: 100).

An important first decision before mapping the extended Value Stream map is to decide on its scope (see also 2.5.5.1). An extended value stream map focuses on the main features of the total production network, showing the main time lines needed for each of the extended value streams in the system and the main information flows triggering these activities. These times are summed up to the total lead-time for each extended value stream (cf. Jones 2011: 101).

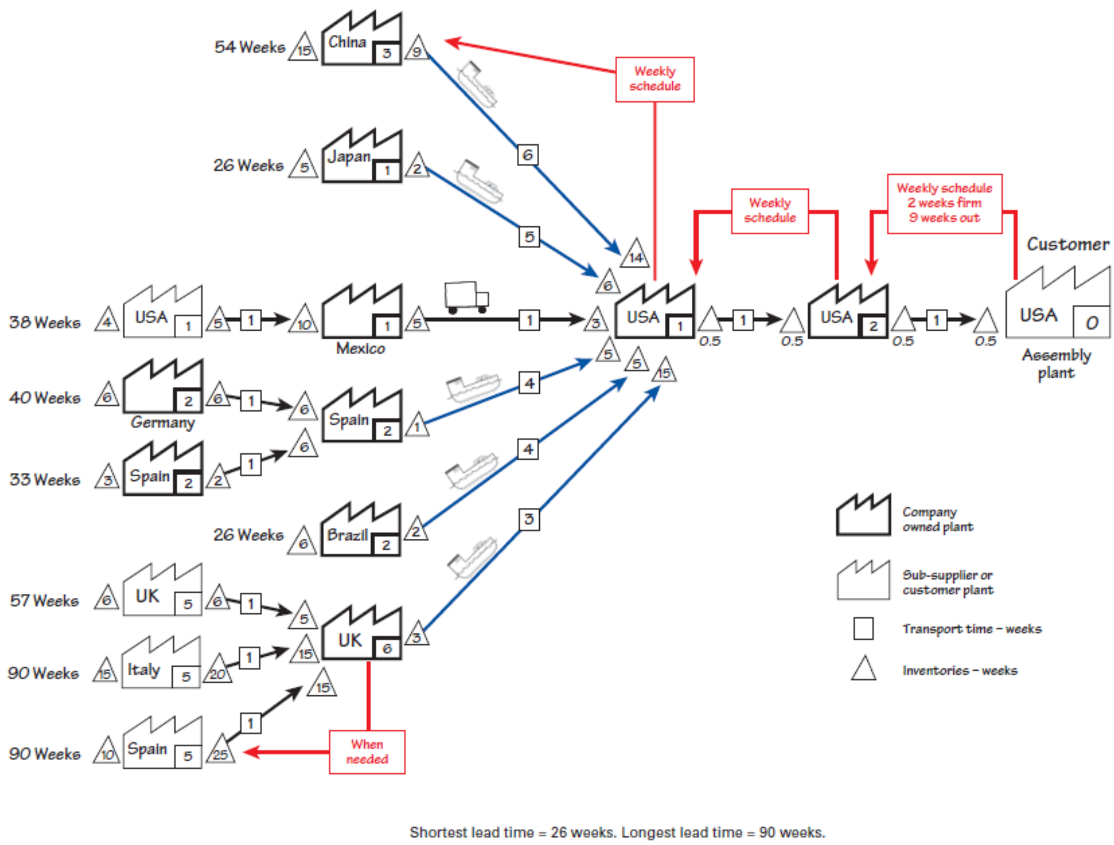

Figure 31: Current-State extended value stream map of a Supply System (cf. Jones 2011: 101)

An ideal whole value stream map would start with the end customer using or consuming the product and then go all the way upstream to the basic elements of the raw materials. However, this would be a more than overwhelming exercise. To limit complexity and to ensure focus Jones & Womack (2011: 4) propose to look one or two production plants or suppliers upstream from the customer location. This works for companies who want to analyze and optimize the value creation supply system of a product-process family delivered to a single customer. The challenge for automotive suppliers is to optimize their global production network considering the location of the own plants, their supplier's locations and the locations of their **multiple global customers** (see also definition of production networks in 2.1). This makes the whole exercise much more complex and requires further enhancement of the extended value stream mapping.

4.1 The Global Production Relocation Mapping method

The author of this thesis proposes to use ***Global Production Relocation Mapping*** as a lean method to visualize, analyze, simulate and optimize complex global production networks. Since a global production network includes multiple customers the mapping starts from the production plant producing the final finished product to be delivered to the customers. From there, first all value-streams **downstream** have to be mapped to all customer ship-to locations and production locations of the customers. The customer ship-to location is defined as the customer dictated place of delivery for finished products to the customer. Depending on the customer, the customer ship-to location can either be a named customer cross-dock location or directly the customer plant location. The producer of the finished product is responsible to deliver the right products in the right quantity and quality to the customer ship-to location. At the customer ship to location the customer takes over risk, cost and ownership for the products and all subsequent storage or transport operations.

Afterwards the **upstream** value-stream including company-owned production plants, facilities providing logistics services (such as warehousing) and the suppliers of raw materials have to be mapped.

In order to improve visualization of such complex global production networks, some of the standard value stream mapping symbols have been modified and enhanced. The Global Production Relocation Mapping symbols presented in Figure 32 use color coding to actually better see the different production network participants and the material- and information flow between them. Furthermore information fields have been added to the symbols to visualize the most important production network data:

- number of raw materials supplied per supplier
- throughput-time to produce materials at suppliers
- number of stored materials and/ or products at warehouses
- number of produced components and products per production plant
- throughput-time to produce components and products at production-plants
- number of demanded products and volume share of each customer
- transportation distances, Incoterms, transportation modes and frequency
- all stock and transportation lead-times

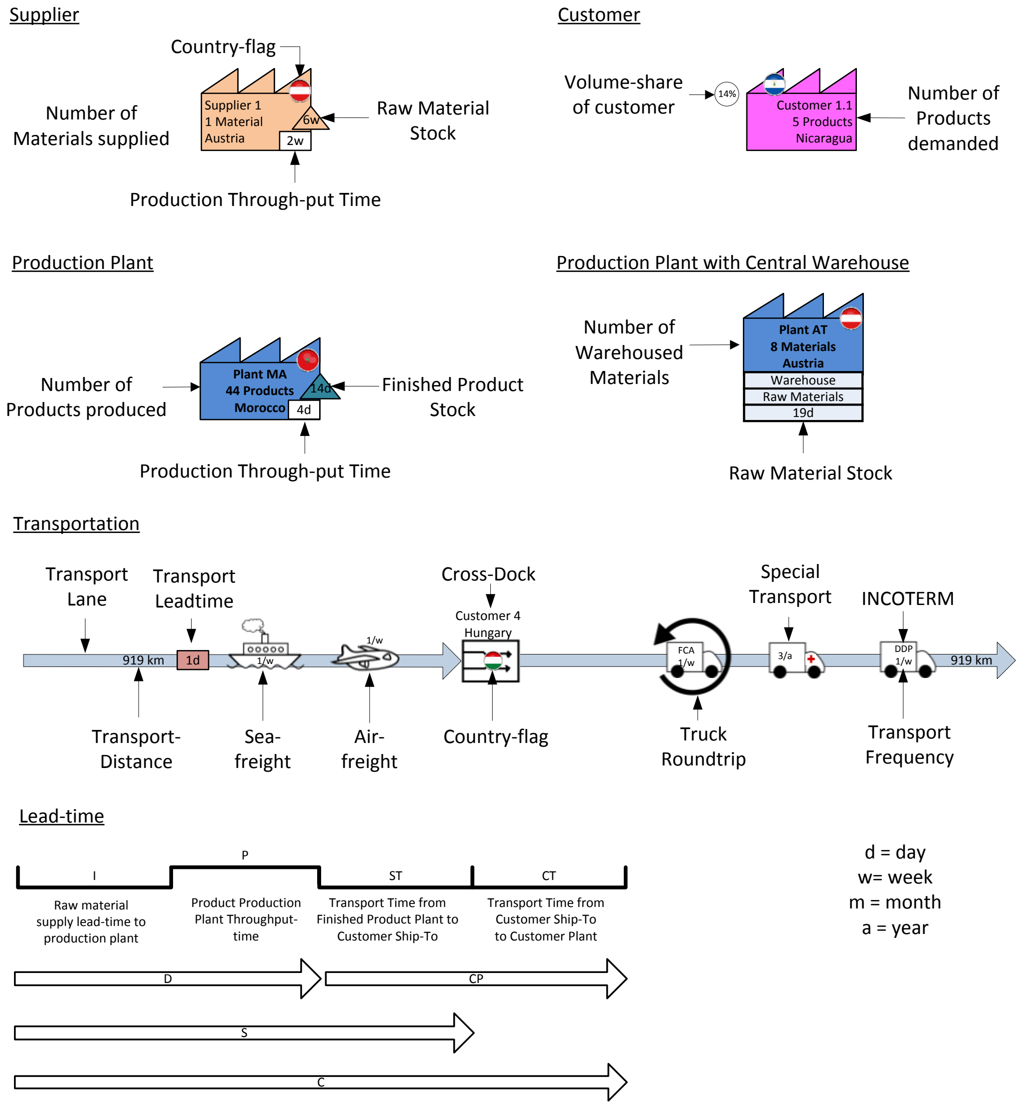

Figure 32: Global Production Relocation Mapping Symbols

Once all the value streams and information flows are visualized and all relevant data have been added, the lead-time of all individual value-streams and the total lead-time of the global production network can be calculated and visualized. Given the complexity of a global production network with multiple supplier and customer relationships, it is proposed to calculate and visualize not only the total lead-time of the global production network, but to also describe the different lead-times of the different value-stream steps:

I: Raw materials supply lead-time to production plant

P: Product production plant through-put time

D: Lead-time until despatch of finished products

ST: Transport-time from finished product plant to customer ship-to location

CT: Customer transport time customer ship-to location to customer plant (including lead-time for cross-docking)

CP: Total transport-time finished product plant to customer plant

S: Lead-time until product receipt at customer ship-to location

C: Global Production Network lead-time to product receipt at customer plant

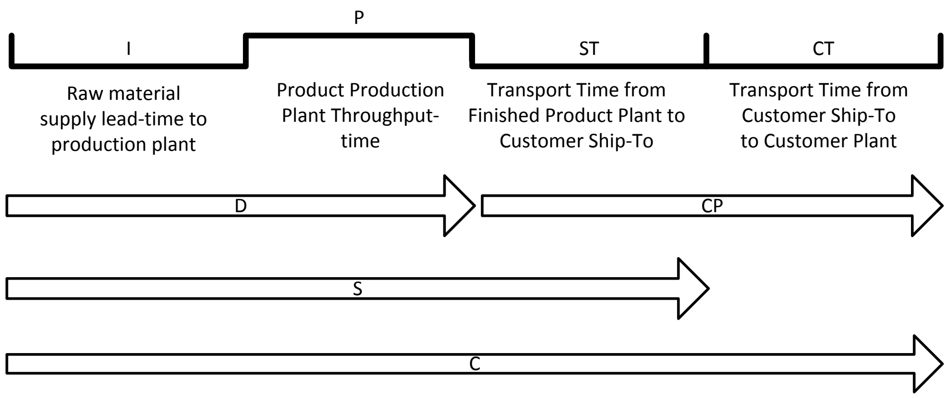

Figure 33: Lead-times of Global Production Network

Putting these lead-time data in the Global Production Relocation Map enables to exactly understand …

….the lead-time of each raw-material from processing to receipt at the production plants (I)

… the production plant through-put time (lead-time for raw-material inventory at production plant + product production processing time + product inventory) (P)

… the lead-time from processing of raw materials until finished product despatch to customers (D = I+ P)

… the transport time to ship the finished products from the finished product production plant to the customer ship to location (ST)

… the transport time for the customer to transport the products from the customer ship to location to the customer production plant including lead-time for cross-docking (where relevant) (CT)

… the total transport time to ship the finished products from the finished product plant to the customer production plant (CP = ST + CT)

… lead-time from processing of raw materials until finished product receipt at the customer ship to location (S = I + P + ST= D+ ST)

… the total production network lead-time from raw material processing to receipt of finished products at the customer plant (C = D + CP = I + P + ST + CT)[8]

The Global Production Relocation Mapping method will be applied to map the relocation of a global production network of a product – process family of the automotive supplier in the next chapter.

4.2 Defining the Product Line to relocate

As described earlier, to enable its continued successful growth, the automotive supplier follows the strategy to concentrate production of all product–process-families in single to maximize economies of scale and scope advantages and to locate production within each business region of the company to enable customer proximity. The decision in which regional production plant to locate the production of a product-process-family depends on its sensitivity to economies of scope and economies of scale, the capital intensiveness and labor content to produce the product-process family.

Following this strategy, the automotive supplier decided to relocate all Wiring Harnesses from one of its plants in Tirgu Mures in Romania to its plant in Kenitra in Morocco. The primary reason for this relocation is the need for additional capacity and space at the Romanian plant to accommodate further growth. Since the Wiring harness product family has a very high product variety and high labor content, the decision has been taken to relocate this family to the production plant in Morocco.

The wiring harness family consists of several product lines which are produced on different production lines. As it is also visible from the Product – Process – Plant Matrix (see Figure 25), some lines of the wiring harness family already have been relocated to Kenitra, others currently are still produced in Tirgu Mures. In order to manage complexity and to minimize the relocation risk, the lines are relocated sequentially one after the other until the total wire harness family is relocated to Kenitra. This thesis introduces Global Production Relocation Mapping as a lean method to visualize, analyze, simulate and optimize global production relocations.

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[8] When customer ship to and customer production plant location are the same, the lead-times (ST) and (CP) as well as (S) and (C) are also equal since there is no further customer transport (CT = 0).

The method will be demonstrated using a planned relocation of a product line of the wiring harness family of the automotive supplier: the door handle harness line.

Today's cars door handles are important for the styling of a car and must fulfill functional, safety and increased comfort requirements. Especially the door handles of premium cars offer light concepts and comfort access systems which are integrated into the door handles. The automotive supplier develops door handle harnesses as innovation partner of the OEM to easily connect and assemble the electronic systems of door-handles.

Figure 34: Door Handle System (Huf Group 2015)

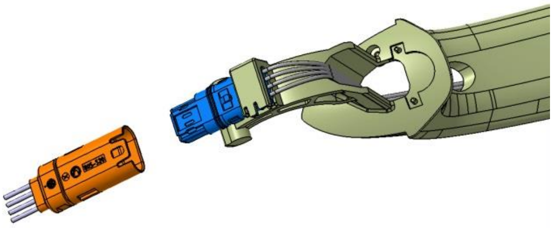


Figure 35: Door Handle Harness

The OEM defined the automotive supplier as directed part supplier to produce these door handle harnesses and to deliver them to defined Tier 1 and Tier 2 suppliers of the OEM. Currently the company produces 44 product variants which are delivered to thirteen different Tier 1 and Tier 2 production plants. These Tier 1 and Tier 2 suppliers produce and assemble the door handle systems or total door trims for the different car models of the OEM. The OEMs Production Program and Forecast defines the capacity requirements and consumption rate for the entire production network of the OEM. This plan is communicated by the OEM to all its suppliers, including the automotive supplier and its customers (Tier 1 and Tier 2s of the OEM). The automotive supplier bases its mid- and long-term production capacities and material supply planning mainly on the Production Program Plan and Forecast of the OEM. Short-term production planning, material requirement planning as well as delivery scheduling is based on the direct customer forecasts and delivery schedules. As it can be seen in Figure 36 below, customer forecasts and delivery-schedules are only accurate and relevant for the short-term period of up to eight weeks.

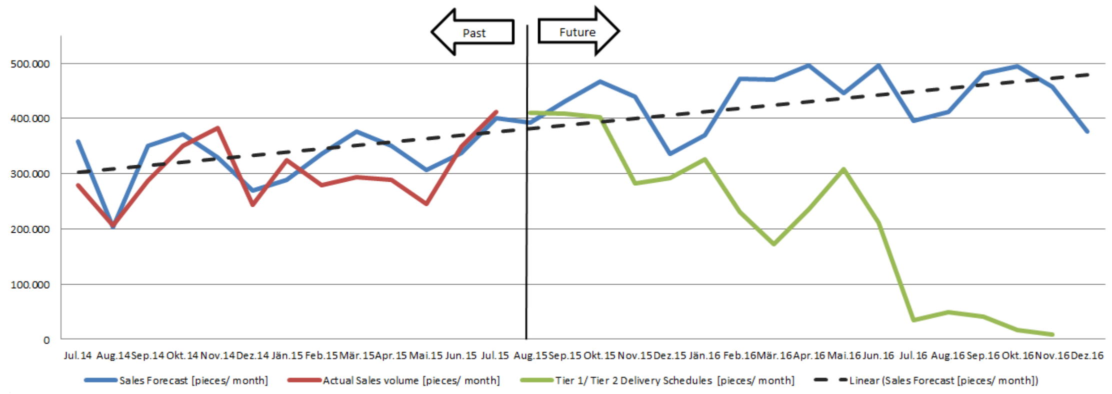


Figure 36: Door Handle Harness Product Line Sales Volume and Forecast

Based on actual sales and current sales forecast the product family volume will grow 18% in 2015 (versus 2014) and further increase by 26% in 2016 (versus 2015). To manufacture the increased volumes the company is already in the progress to further increase the line capacity.

4.3 Mapping the current state

With the help of Global Production Relocation Mapping it becomes easy to see the material and information flow of complex global production networks. Figure 37 visualizes the current state of the production network of the automotive supplier‘s door handle harness product line.

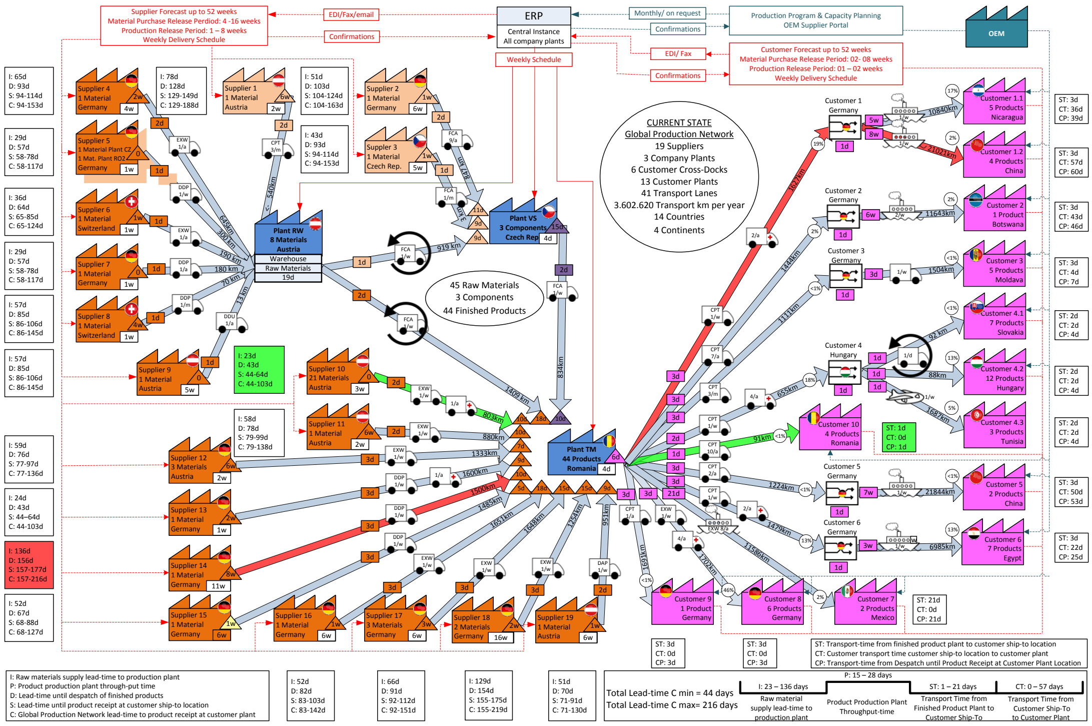


Figure 37: Current state map[9]

Current state company-internal value-stream analysis

The production plant in Vsetin produces three components and delivers them to the production plant Tirgu Mures which produces the final products. The Production plant Rankweil operates as a central Raw Material warehouse for low volume and low-consumption raw materials in this production network. The three company-owned production plants are connected through weekly full truck load transports to move materials, components, products and other goods between the plants. The transport-connections between the plant in Rankweil and the production plants in Vsetin and Tirgu Mures are operated in weekly round-trips, the transport from Vsetin to Tirgu Mures is operated as a weekly one-way transport.

The total plant throughput-time (P) of the production plant Tirgu Mures to produce the finished products is between 15 to 28 days. This includes the time for inventory storage of raw materials and components (9-18 days), the production processing time (4days) and the finished product inventory storage time (6 days). The plant throughput-time of the component production plant Vsetin is between 28 days and

[9] See **Fehler! Verweisquelle konnte nicht gefunden werden.** for the full-size map in A3 ormat.

30 days. Average raw material storage time for the low consumption materials stored in the central raw material warehouse in Rankweil is 19 days.

Current state outbound value-stream analysis

The products are delivered to thirteen customer plants located in eleven different countries across the globe (five in Europe, two in America, three in Asia, three in Africa). Only four of the customers are delivered directly from the automotive supplier to their production plant. For all other customers the automotive supplier delivers the products to customer cross-dock locations. Germany is the major logistics hub of the customers of this network. The major reason for this is that also many of their other suppliers are located in or around Germany. Locating a cross-docking platform in Germany enables a short distance and lead-time from these suppliers to the customer cross-dock locations, where the customers consolidate the inbound-deliveries and transport the consolidated shipments to their production plants abroad. Most of the customers use sea freight to transport products over long distances from their cross-docks to their sites located on different continents. One customer uses an interesting alternative approach by consolidating supplies in a cross-dock location in Hungary, close to its production plants in Slovakia and Hungary. The distance between these plants and the Hungarian cross-dock location is very close, so that all three locations can be connected via daily roundtrips by truck. The same customer also operates a plant in Tunisia, but different to the other customers this customer uses daily airfreight to transport products from the cross-dock location to the plant in Tunisia. The use of a daily rather than a weekly transport frequency significantly reduces lead-time and improves flexibility for this customer, plus also the transport cost to the plants in Slovakia and Hungary are optimized through close distance and the utilization of round-trips. For the plant in Tunisia the higher costs for air freight are taken into consideration to enable lower stock levels and higher flexibility.

As discussed earlier, the outbound transport lead-times are also measured and visualized in the current state map. The customers are positioned on the map considering their real physical distance to the automotive supplier’s finished product production location. Transport distances and lead-times are displayed for each transport-lane.

The transportation lead-time to ship products from the production plant in Tirgu Mures to the customer’s ship to locations (ST) varies between just one day and 21 days. The additional transit-time to transport the products from the customer cross-docks to the customer production plants (CT) is between zero days (for customers delivered directly to the plant) and 57 days. Total outbound lead-time (CP) is between one to 60 days.

Current state inbound value-stream analysis

When analyzing the inbound value stream of the production network it becomes visible, that the automotive supplier sources its raw materials from suppliers in relatively close proximity to its lead plant and headquarter location in Rankweil. Especially Germany offers a wide range of automotive suppliers. In total 45 different raw materials are sourced from 19 external suppliers to produce the door handle harness family. The majority of the raw materials (35) are sourced directly by the production plant Tirgu Mures from the external suppliers. A limited number of raw materials (6) are sourced by Tirgu Mures from the central raw material warehouse located at the production plant in Rankweil. The component production plant Vsetin purchases two materials directly from the external suppliers, two raw materials are also sourced from the central raw material warehouse in Rankweil.

All inbound lead-times are visualized on the current state map. Same as for the customers also the suppliers are positioned on the map considering their physical distance to the production plants they supply. Transportation distances and lead-times are displayed for each transport-lane. Furthermore, production throughput-time at the suppliers to manufacture the raw materials, raw material stock at the suppliers, and raw material stock at the automotive supplier’s production plants are visualized.

The shortest inbound lead-time (I) to supply a production plant (raw material production time + storage time at the supplier + transport time to the production plant) is 23 days, the longest 136 days.

Current state total global production network value stream analysis

The minimum total lead-time of the current state global production network from raw material processing to receipt of finished products at the customer (S=C) is 44 days. The maximum total lead-time to a customer ship-to location (S) is 177 days and 216 days to the customer plant with the longest outbound lead-time (C).

The shortest global production network lead-time is visualized in the current state map in green color, the longest total lead-time, which at the same time is the critical path, in red color.

With the help of the current state map, all transport distances in the total network get visible and can be calculated. For the current state the minimum distance between the closest raw material supplier and the closest customer ship-to location is 894 Kilometers. The longest distance between raw material supplier and customer production location is 25.361 kilometers. The annual total transportation distance under control of the automotive supplier to move all materials and components and finished products through the global production network to the customer ship to locations is 1.306.211 kilometers. Considering the customer-managed transportation from the customer cross-docks to the customer plants the total annual transportation distance of the current state global production network is 3.602.620 kilometers. Figure 38 below summarizes the results of the current state analysis. These results will be compared with the result of the relocated state in the next chapter.

	Current State	
Global Production Network Leadtime	MIN	MAX
Total Lead-time Raw Materiel Supplier to Customer Ship-To Location (S)	44	177
Total Lead-time Raw Material Supplier to Customer Plant Location (C)	44	216
Production Network Value Stream Leadtimes	MIN	MAX
Inbound Lead-time Supplier to Production Plant (I)	23	136
Finished Product Production Plant Through-put Time (P)	15	28
Outbound Lead-time Production Plant to Customer Ship To Location (ST)	1	21
Customer Lead-time Customer Ship-To to to Customer Plant Location (CT)	0	57
Total Outbound Lead-time from Production Plant to Customer Plant Location (CP)	1	60
Global Production Network Transportation Distance	MIN	MAX
Transportation Distance Supplier to Customer Ship-To Location	894	13.879
Transportation Distance Supplier to Customer Plant Location	894	25.361
Annual Production Network Transportation Kilometers to Customer Ship Tos	1.306.211	kilometers
Annual Production Network Transportation Kilometers to Customer Plants	3.602.620	kilometers
Production Network Value Stream Transportation Distances	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plant	803	2.293
Outbound Transport Lane Distance Production Plant to Customer Ship-To	91	11.586
Customer Transport Lane Distance Customer Ship-To to Customer Plant	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	858.654	kilometers
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-Tos	447.557	kilometers
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plants	2.296.409	kilometers

Figure 38: Current state lead-time and transportation requirements

4.4 Mapping the relocated state

Once the current state mapping has been completed, the relocated state can be mapped. The automotive supplier plans to move the complete production line from the current plant Tirgu Mures in Romania to the plant Kenitra in Morocco, whereas all Raw Material Suppliers and Customers remain unchanged.

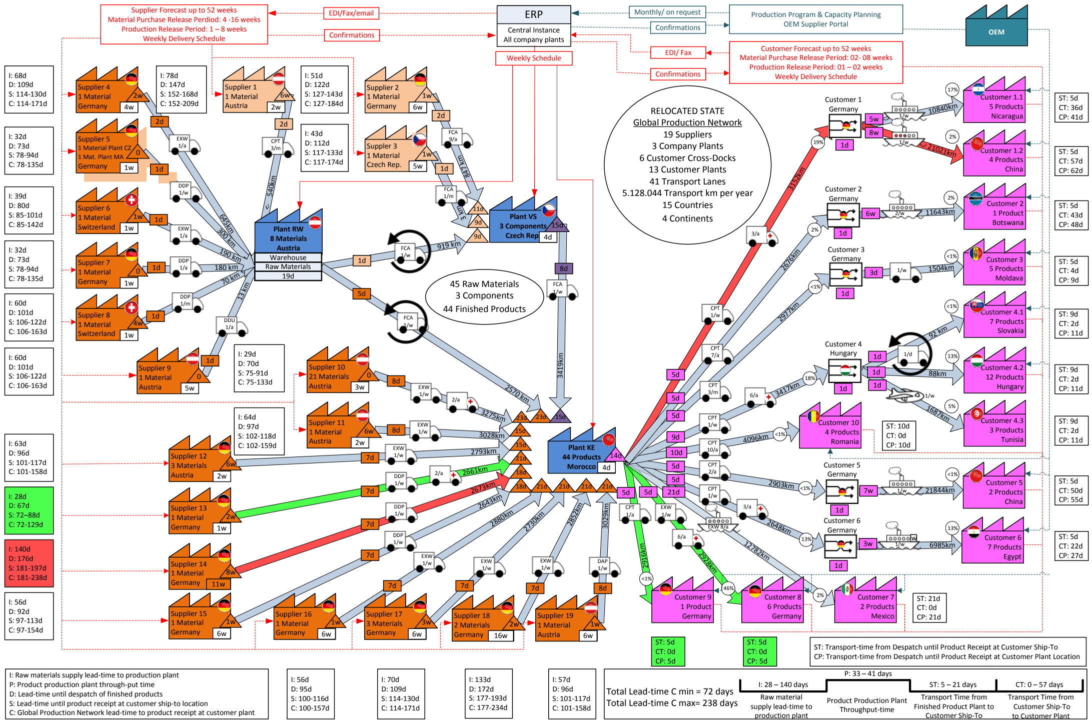


Figure 39: Relocated state map[10]

Relocates state company-internal value-stream analysis

After relocation the finished product is produced at the production plant in Kenitra. The roles of the company plants Vsetin as component-producer, and Rankweil as central raw material warehouse remain the same in the relocated network. The lead-time and distance to supply the raw materials from Rankweil to Kenitra increases from 2 days to 5 days and from 1.409 km to 2.570 km. The lead-time and distance to supply components from Vsetin to Kenira increases from 2 days to 8 days and from 834 km to 3.419 km.

The complete production-line shall be transferred from Tirgu Mures to Keintra. All process steps, equipment and machines used in production therefore remain exactly

[10] See Appendix 14 for the full-size map in A3 format.

the same. Consequently, the production throughput-time to manufacture the finished products (four days) shall remain the same after relocation to Kenitra. Engineers, technicians and operators are trained in the current production plant in Tirgu Mures directly at the production line before relocation. During the ramp-up in Kenitra the operators are supported on-site by experienced workers from Tirgu Mures. The ramp-up phase only ends once Kenitra is fully capable to run production efficiently and independently.

Nevertheless, the total plant throughput-time (P) significantly increases to 33-41 days after relocation. This is the result of significantly higher raw material and component inventory (15-23 days) and increased finished product inventory (14days). The higher inventory levels are required to cover for the longer inbound lead-times to replenish raw materials from the suppliers to the production plant and to maintain the required customer-flexibility despite the longer outbound lead-times to the customers.

Relocated state outbound value-stream analysis

The distance and lead-time to reach the customer ship-to locations increases for all outbound-lanes. The shortest transport lead-time to reach a customer ship-to location (ST) in the relocated production network is 5 days (versus one day before relocation), the maximum remains 21 days. Minimum transport distance from Kenitra to the closest customer ship-to location is 2.648 km (versus only 91km before relocation), maximum distance 12.782 km (versus 11.586 km). The transit time of customers to forward the products to their plants (CT) remains the same as before relocation. Total outbound lead-time (CP) increases to 5-62 days.

Relocated state inbound value-streams analysis

Similar to the outbound value-streams, also the distance and lead-time to supply raw materials and components to Kenitra increases. The shortest inbound lead-time (I) increases from 23 to 28 days, the longest from 136 days to 140 days. Minimum inbound transport distance from the closest supplier to Kenitra is 2.583 km (versus 803 km before relocation), maximum distance 4.878 km (versus 2.293 km).

Relocated state total global production network value stream analysis

The minimum total lead-time of the relocated state global production network (S=C) from raw material processing to receipt of finished products at the customer is 72 days. This is 28 days or four weeks longer than before relocation. The maximum total lead-time to a customer ship-to location (S) increases to 197 days and even to 238 days to reach the customer plant with the longest outbound lead-time (C).

The minimum distance between the closest raw material supplier and the closest customer ship-to location increases to 5.231 km, this is almost six times the distance versus before relocation. The longest distance between raw material supplier and customer production location in the network goes up to 29.625 km. The total transportation distance under control of the automotive supplier to move all materials and components and finished products through the global production network to the customers' ship to locations is 2.831.635 km per year, more than double compared to before relocation. When also considering the customer-managed transportation from the customer cross-docks to the customer plants, the total annual transportation distance of the relocated state reaches 5.128.044 kilometers transportation distance. Figure 40 below compares the results of the relocated state analysis with the current state analysis.

	Current State		Relocated State	
Global Production Network Leadtime	MIN	MAX	MIN	MAX
Total Lead-time Raw Materiel Supplier to Customer Ship-To Location (S)	44	177	72	197
Total Lead-time Raw Material Supplier to Customer Plant Location (C)	44	216	72	238
Production Network Value Stream Leadtimes	MIN	MAX	MIN	MAX
Inbound Lead-time Supplier to Production Plant (I)	23	136	28	140
Finished Product Production Plant Through-put Time (P)	15	28	33	41
Outbound Lead-time Production Plant to Customer Ship To Location (ST)	1	21	5	21
Customer Lead-time Customer Ship-To to Customer Plant Location (CT)	0	57	0	57
Total Outbound Lead-time from Production Plant to Customer Plant Location (CP)	1	60	5	62
Global Production Network Transportation Distance	MIN	MAX	MIN	MAX
Transportation Distance Supplier to Customer Ship-To Location	894	13.879	5.231	17.660
Transportation Distance Supplier to Customer Plant Location	894	25.361	5.499	29.625
Annual Production Network Transportation Kilometers to Customer Ship Tos	1.306.211	kilometers	2.831.635	kilometers
Annual Production Network Transportation Kilometers to Customer Plants	3.602.620	kilometers	5.128.044	kilometers
Production Network Value Stream Transportation Distances	MIN	MAX	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plant	803	2.293	2.583	4.878
Outbound Transport Lane Distance Production Plant to Customer Ship-To	91	11.586	2.648	12.782
Customer Transport Lane Distance Customer Ship-To to Customer Plant	0	21.844	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	858.654	kilometers	1.866.783	kilometers
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-Tos	447.557	kilometers	964.852	kilometers
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plants	2.296.409	kilometers	2.296.409	kilometers

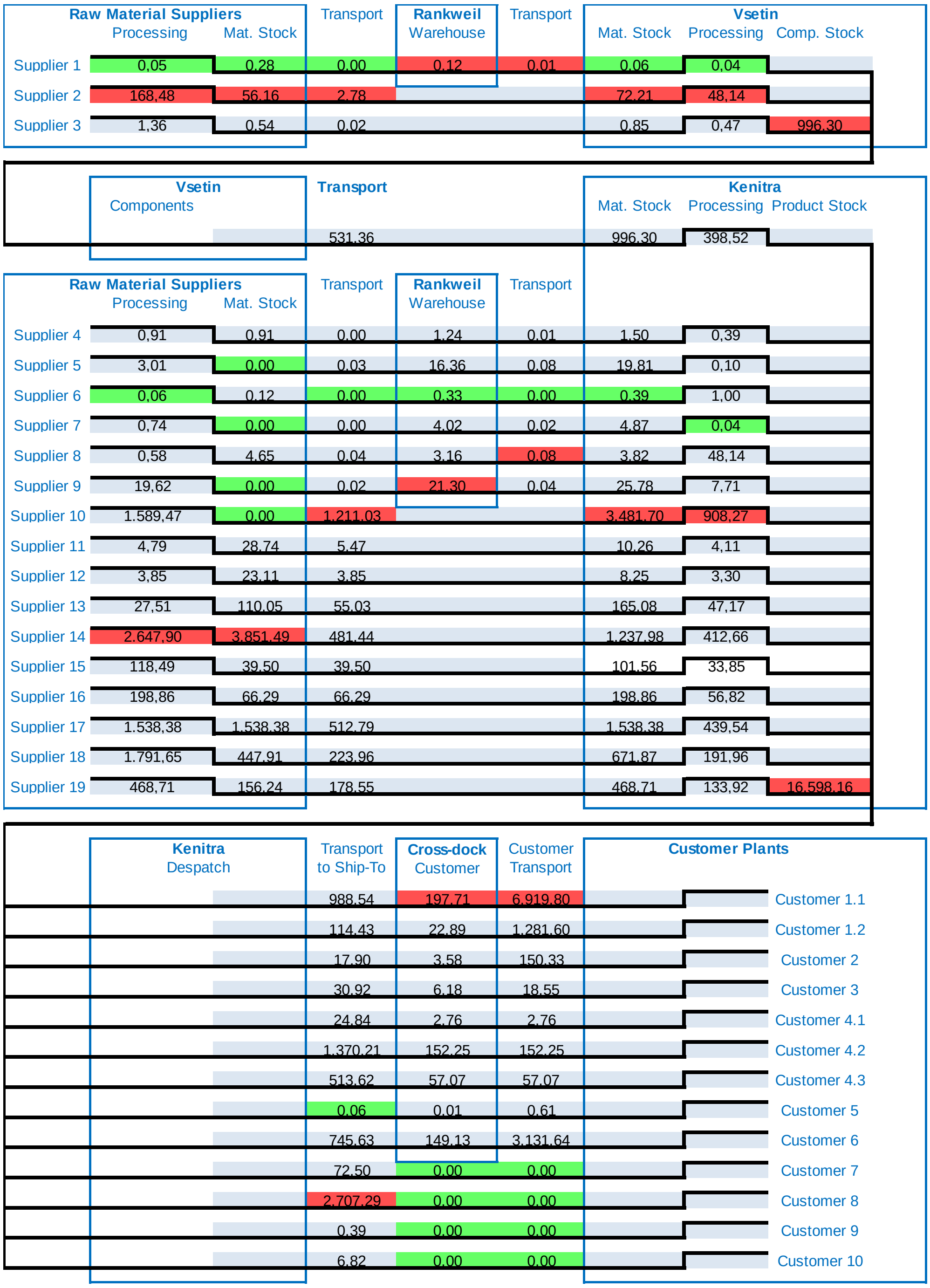
Figure 40: Comparison current state and relocated state lead-time and transportation requirements

The relocated state analysis shows a negative impact of the relocation on lead-time and transportation distances. Inventories of raw materials and finished products have to be increased to cover for the longer material-replenishment lead-times and to protect against forecast inaccuracy, demand volatility and disruptions to sustain the required customer flexibility despite the longer outbound lead-times. But even with higher inventories, the flexibility to react on short-term customer requirements or material shortages remains reduced. As a consequence, additional special transports are expected to secure material supply and customer responsiveness. The increased special transports, the increased transportation distances and the increased inventories lead to additional logistics costs of the relocated production network. These additional costs have to be overcompensated by labor cost reduction benefits to make the relocation economically sensible. The Frauenhofer ISI study presented in 2.4.2 identified that companies very often underestimate the impact of global production relocations on flexibility, quality and logistics costs and do not consider these cost factors carefully enough when taking their decision to relocate production abroad. As demonstrated above, global production relocation mapping is an excellent tool to make the impact of increased lead-timed and transport-distances visible. The next chapter will introduce a lean calculation tool to also visualize and simulate the logistics costs caused by production relocations.

4.5 Visualizing and simulating inventory and transportation costs

The visualization and simulation tool presented in this chapter has been developed to make transportation and inventory costs visible for each step along the whole production network. By doing so, it gets very easy to calculate and simulate the total logistics costs impact of complex production relocations. Moreover, it can be used as a useful tool to calculate and simulate all individual lead-times and transportation-distances in the whole system. The usage of the tool will be explained based on the inventory cost visualization and simulation of the relocated state (see Figure 41)[11].

[11] The visualisation and simulation of all production network lead-times, transportation distances, inventory costs, and transportation costs for the current state production network, the relocated state production network and the optimized relocated production network can be found in the appendix.



Global Production Network Inventory Costs (€/ year)	2014	2015	2016
Inventory Costs Total Production Network Suppliers to Customer Plants	66.506	76.100	93.095
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	54.200	62.018	75.869
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,0150	0,0146	0,0141
Production Network Value Streams Inventory Costs (€/ year)	2014	2015	2106
Inventory Costs Suppliers	14.909	17.059	20.869
Inventory Costs Raw Material Stock in Transit to Production Plants	3.312	3.790	4.637
Inventory Costs Company Production Plants and Warehouses	29.385	33.624	41.134
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	6.593	7.544	9.229
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	12.306	14.081	17.226

Figure 41: Relocated state inventory costs visualization and simulation

The tool visualizes the material flow using the value stream mapping timeline segment symbol. The flow of materials, components and products is visualized horizontally from left to right. Vertically the tool is structured into four segments: raw material to component value-stream, component and raw-material to finished product value-streams, finished product to customer value-stream, and a fact box summarizing the results.

The different production network-steps are defined as time-line-segments. The inventory costs for each step are displayed in the relevant timeline-segment. With the help of this method now it’s easy to see and compare the inventory costs of all global production-network steps. The visualization is further supported by highlighting the lowest inventory cost steps in green color and the highest inventory cost steps in red color. Obviously, the first focus should be on these steps when trying to improve the inventory costs in the production network.

When calculating the inventory costs it is very important to consider the cost of inventory along the whole value-streams. Moreover, additional storage cost, increased depreciation of stock value and scrapping costs caused by product changes and deadstock caused by longer lead-times have to be included in the inventory costs (see also 2.3.2.3.1 and 2.5.4.2).

The fact box in the bottom of the tool summarizes the total inventory cost results. The costs are calculated for the past year (based on actuals 2014), the current year (based on actuals and Forecast 2015) and the next year (based on Forecast 2016). It is very important to quantify not only historical and current but also future cost, since any production relocation must deliver benefits in the long-term.

Figure 42 below compares the results of the inventory costs and transportation costs calculation of the current state and the relocated state. Also for the calculation of transportation costs it is important to consider not only the increased transportation costs, but also the additional costs caused by relocation for customs clearance, handling and packaging and potential transportation damages as well as the costs of special transports to compensate for longer lead-times and disruptions in the complex network (see also 2.3.2.3.1 and 2.5.4.2).

	Current State 2014	Current State 2015	Current State 2016	Relocated State 2014	Relocated State 2015	Relocated State 2016	Delta 2016 Absolut	Delta 2016 Relativ
Global Production Network Inventory Costs (€/ year)								
Inventory Costs Total Production Network Suppliers to Customer Plants	47.487	54.337	66.473	66.506	76.100	93.095	26.623	40%
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	35.181	40.256	49.246	54.200	62.018	75.869	26.623	54%
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,010	0,009	0,009	0,015	0,015	0,014	0	54%
Production Network Value Streams Inventory Costs (€/ year)								
Inventory Costs Suppliers	14.909	17.059	20.869	14.909	17.059	20.869	0	0%
Inventory Costs Raw Material Stock in Transit to Production Plants	1.077	1.233	1.508	3.312	3.790	4.637	3.129	207%
Inventory Costs Company Production Plants and Warehouses	15.935	18.234	22.306	29.385	33.624	41.134	18.828	84%
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	3.260	3.730	4.563	6.593	7.544	9.229	4.666	102%
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	12.306	14.081	17.226	12.306	14.081	17.226	0	0%
Global Production Network Transportation Costs (€/ year)								
Total Transportation Costs Suppliers to Customer Ship-To Locations	80.879	95.408	120.326	171.529	202.343	255.188	134.863	112%
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,022	0,022	0,022	0,048	0,048	0,048	0	112%
Production Network Value Stream Transportation Costs (€/ year)								
Inbound Transportation Costs Suppliers to Production Plants	30.608	36.106	45.536	63.531	74.944	94.516	48.980	108%
Outbound Transportation Costs Production Plant to Customer Ship-To Locations	50.271	59.302	74.790	107.998	127.399	160.672	85.882	115%
Global Production Network Inventory and Transportation Costs (€/ year)								
Logistics Costs Production Network Suppliers to Customer Ship-To Locations	116.060	135.664	169.572	225.728	264.361	331.057	161.485	95%
Logistics costs / Product (Suppliers to Customer Ship-To Locations)	0,032	0,032	0,032	0,063	0,062	0,062	0,030	95%

Figure 42: Comparison current state and relocated state inventory and transportation costs

Total annual inventory and transportation costs are steadily increasing as a result of the sales growth in the current and relocated production network. Total current state inventory and transportation costs 2016 are 169.572 €. In the relocated state the total logistics costs of 331.057 € are almost twice as high mainly caused by significantly higher transportation costs. The transportation cost increase results from both, inbound and outbound transportation. Inventory costs are 26.623 € higher in the relocated state. The increased inventory costs mainly are caused by increased stocks at the production plant in Kenitra. Total logistics costs per product increase by 95% from 0.032 € to 0.062 €. This means that the costs to manufacture a product have to be reduced by at least 0.030€ per piece to reach the break-even between increased logistics costs and reduced production costs. In the next chapter the global production relocation mapping method will be used to optimize the relocated global production network.

4.6 Mapping the optimized relocated state

Jones & Womack (2011: 44) defined six key criteria to consider when mapping future state extended value stream maps. These criteria will be used in the following to design the optimized relocated state map.

1. **Every participant in the entire value stream should be aware of the customer consumption rate of the product at the end of the value stream.** The customer consumption rate is communicated to the automotive supplier and

its customers through the OEM portal. The OEM's production program defines the planned car production volume and time for each car model in each OEM assembly plant. This plan is the common platform for the capacity planning of the automotive supplier and its customers. However, production volume and production content of the different production network partners significantly differs depending on the product portfolio delivered to the OEM. In fact, the customers of the automotive suppliers are competitors and produce door handle modules for the different car models of the OEM. The automotive supplier is currently producing 44 different product variants, which are required for door handles of multiple different car models assembled in the world-wide production plants of the OEM. While knowing the OEMs consumption volume and fluctuation at the end of the value stream is extremely important for the planning of capacity, mid-term tactical production planning and short-term production scheduling of the automotive supplier is primarily based on the demand of its direct customers. The customer demand is communicated by the Tier 1s and Tier 2s to the automotive supplier through forecasts and firm delivery schedules. The automotive supplier currently produces in 15 shifts which for the current product demand results in an actual internal tact time of 4.5 seconds.

$$\text{Customer tact} = \frac{\text{Available operating time per shift} = 28.800\text{ s}}{\text{Customer demand per shift} = 6.350\text{ pcs}} = 4.5\text{ s}$$

As already presented in 4.2, the demanded volume is constantly increasing, which will require to further reduce tact time and to increase the number of working shifts and / or install additional capacity.

2. **Minimize inventory in the total value stream network.**
   As described in 4.4, higher raw material inventory levels are required at the relocated production plant in Kenitra to cover for the longer inbound lead-times to replenish raw materials from the suppliers to the production plant. Considering the customer demand variability and longer outbound lead-times, also finished product inventories have to be increased to maintain the required customer-flexibility. Ensuring customer satisfaction and meeting customer requirements is the leading guideline when starting to explore inventory reduction opportunities. Any relocation can only be successful, when customers either benefits from it or at least are not negatively impacted by it. Therefore the higher finished product

inventories cannot be reduced and must be kept to maintain current customer satisfaction.

As discussed in 3.2, the automotive supplier has the strategy to supply customers located in the NAFTA and Asia region directly from its plants in Mexico and China in the future. The customers with a production location in Nicaragua[12], Mexico and China will benefit from this strategy in the future. However, the decision if and when to install a local production line for the door handle harness family in the plants San Miguel and Nantong to serve these customers locally has not yet been taken. This decision depends on future business growth opportunities of the product line in these markets. At the moment only 2 % of the volume is supplied to the two customers in China, 14 % to the customer in Nicaragua and 2% to the customer in Mexico.

But there still remains the opportunity to reduce inventories of raw materials. The automotive supplier decided to focus on localizing supply of the raw materials with the highest consumption- and inventory level and to use local supply opportunities for all other materials as far as available. The automotive supplier succeeded to qualify a local supplier (Supplier A), ideally located in the same automotive industry park in Kenitra. This local supplier will replace the major current state supplier for wires (Supplier 10). Furthermore, the automotive supplier contracted a local supplier located in Casablanca (Supplier B) to deliver packaging materials from its local production. This supplier replaces the current state Supplier 11 and Supplier 12. Finally, supplier 13 offered the opportunity to supply the plant in Kenitra from its local warehouse in Tanger after relocation (Supplier C). Figure 43 below shows the financial impact of these improvements on the inventory cost.

[12] Nicaragua is no member of the NAFTA region but has a free trade agreement with Mexico.

	Relocated state	Relocated optimized state	Relocated optim. vs. relocated state Absolut	Relativ
Global Production Network Inventory Costs 2016 (€/ year)				
Inventory Costs Total Production Network Suppliers to Customer Plants	93.095	89.256	-3.839	-4%
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	75.869	72.030	-3.839	-5%
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,014	0,013	-0,001	-5%
Production Network Value Streams Inventory Costs 2016 (€/ year)				
Inventory Costs Suppliers	20.869	22.391	1.522	7%
Inventory Costs Raw Material Stock in Transit to Production Plants	4.637	2.748	-1.889	-41%
Inventory Costs Company Production Plants and Warehouses	41.134	37.662	-3.472	-8%
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	9.229	9.229	0	0%
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	17.226	17.226	0	0%

Figure 43: Comparison relocated optimized and relocated state inventory costs

An annual inventory cost reduction of 3.839€ compared to the relocated state does not impress in the first place. However, the reason for the relatively low monetary saving is mainly caused by three strategic decisions. First, finished product stock levels will be kept at the same high level as in the relocated state to ensure customer satisfaction. Second, it was decided to install one week safety stock at the new local wire supplier (Supplier A) in addition to 10 days stock at the production plant Kenitra. Once the new supplier will have demonstrated its capabilities, this safety buffer can be reduced or eliminated. Third, a price premium was agreed with Supplier C for making its raw materials available at its local warehouse in Tanger.

3. **Minimize the transportation requirements in the value stream network.**
Transportation is a non-value adding activity that adds costs and lead-time and therefore shall be eliminated or at least reduced wherever possible. Also for the optimized relocated production network, all customers request to be delivered with the same delivery frequency, performance and without additional costs to the same customer-ship to locations as before relocation. Except for two customers, the automotive supplier delivers the products CPT to the customer ship-to addresses and the automotive supplier directly has to cover for the increased transportation costs. For the two customers with EXW condition, the cost difference for the increased transportation costs to their ship-to locations will have to be compensated by the automotive supplier through a corresponding product price reduction. As a conclusion, the higher outbound transportation cost to the customer ship to location cannot be reduced versus the relocated scenario.

However, the implementation of local suppliers described earlier enables a significant reduction of transportation distance, lead-time and costs to transport the raw materials from these suppliers to the production plant in Kenitra. In addition to this the company decided to install a Cross-dock hub in Germany to reduce transportation costs and improve inbound visibility for raw material suppliers where no local source could be found. Instead of delivering directly to Kenitra, the suppliers will deliver their raw materials to this Cross-dock. At the Cross-docking location the raw material deliveries are consolidated by a third party logistics provider and transported to Kenitra by weekly full truck loads. These improvements lead to a significant optimization of the inbound transportation-requirements compared to the relocated state. The shortest inbound transportation lane is reduced to just one kilometer versus 2.583 km before optimization. Total yearly inbound transportation requirements are reduced from 1.866.783 kilometers to 597.662 kilometers in the optimized relocated state.

	Relocated State		Optimized Relocated	
Global Production Network Transportation Distance	MIN	MAX	MIN	MAX
Transportation Distance Supplier to Customer Ship-To Location	5.231	17.660	2.649	17.660
Transportation Distance Supplier to Customer Plant Location	5.499	29.625	2.917	29.625
Annual Production Network Transportation Kilometers to Customer Ship Tos	2.831.635	kilometers	1.562.514	kilometers
Annual Production Network Transportation Kilometers to Customer Plants	5.128.044	kilometers	3.858.923	kilometers
Production Network Value Stream Transportation Distances	MIN	MAX	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plant	2.583	4.878	1	4.878
Outbound Transport Lane Distance Production Plant to Customer Ship-To	2.648	12.782	2.648	12.782
Customer Transport Lane Distance Customer Ship-To to Customer Plant	0	21.844	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	1.866.783	kilometers	597.662	kilometers
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-Tos	964.852	kilometers	964.852	kilometers
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plants	2.296.409	kilometers	2.296.409	kilometers

Figure 44: Comparison relocated optimized and relocated state transportation requirements

The total transportation distance under control of the automotive supplier to move all materials, components and finished products through the global production network to the customer ship to locations can be drastically reduced in the optimized relocated state to 1.562.514 km per anno, this is 45% less than in the relocated state. Including the customer-managed transportation from the customer cross-docks to the customer plants the total yearly transportation distance of the optimized relocated state is 3.858.923 kilometers transportation distance.

As a result of the inbound optimization the total annual transportation costs are reduced by 54.346€ per year versus the relocated state.

	Relocated state	Relocated optimized state
Global Production Network Transportation Costs 2016 (€/ year)		
Total Transportation Costs Suppliers to Customer Ship-To Locations	255.188	200.842
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,048	0,037
Production Network Value Stream Transportation 2016 Costs (€/ year)		
Inbound Transportation Costs Suppliers to Production Plants	94.516	40.170
Outbound Transportation Costs Production Plant to Customer Ship-To Locations	160.672	160.672

Figure 45: Comparison relocated optimized and relocated state transportation costs

4. **Limit information processing to the minimum.**

   The automotive supplier is operating a ERP system on a central instance. All customer forecasts and delivery requirements are received electronically or entered manually to this system as soon as they are received. Customers normally update their requirements weekly. These requirements usually include material purchase and production release period, as well as weekly delivery quantity requirements.

   The automotive supplier uses a make to stock strategy to produce the door handle harness family. The order-penetration point is the finished product inventory in Kenitra. The entire production network value stream is controlled from this point upwards. Information processing within and between the automotive supplier’s production plants is performed fully automated through the integrated system. Raw material forecasts and weekly delivery requirements including material purchase and production release period are sent automatically once a week to each supplier.

5. **Design value-stream to achieve shortest possible lead-time.**

   The shorter the lead-time, the more responsive is the value stream. Short lead-times enable to detect defects, process variations and other problems early and therefore reduce the risk to produce significant waste. As already explained above, until a potential further future relocation of the door handle harness product line to the new plants in Mexico and China, the outbound lead-times cannot be improved in the optimized relocated state versus the relocated state. However, the localization of suppliers enables to reduce the inbound lead-time for two of these suppliers, for the other two localized suppliers the inbound-lead time remains on the same level due to the decision to install safety stock at these suppliers until they confirm their reliability. The decision to install these local suppliers and to keep raw material stock upstream enables to reduce the total plant through-put time (P) from 33 – 41 days in the relocated state to 21 – 41 days in the optimized relocated state. The installation of a Cross-dock for European suppliers has no impact on the lead-time, since the additional lead-time required for handling and consolidation at the cross-dock location is compensated by shorter transportation lead-times to and from the cross-dock location.

	Relocated State		Optimized Relocated	
Global Production Network Leadtime	MIN	MAX	MIN	MAX
Total Lead-time Raw Materiel Supplier to Customer Ship-To Location (S)	72	197	62	197
Total Lead-time Raw Material Supplier to Customer Plant Location (C)	72	238	62	238
Production Network Value Stream Leadtimes	MIN	MAX	MIN	MAX
Inbound Lead-time Supplier to Production Plant (I)	28	140	29	140
Finished Product Production Plant Through-put Time (P)	33	41	21	41
Outbound Lead-time Production Plant to Customer Ship To Location (ST)	5	21	5	21
Customer Lead-time Customer Ship-To to to Customer Plant Location (CT)	0	57	0	57
Total Outbound Lead-time from Production Plant to Customer Plant Location (CP)	5	62	5	62

Figure 46: Comparison relocated optimized and relocated state lead-time requirements

The minimum total lead-time of the global production network for the shortest raw material supply lead-time, plant throughput-time and transport-time to the closest customer ship-to (S) and customer production plant (C) in the optimized relocated state can be reduced to 62 days versus 72 days in the relocated state. The maximum total lead-time from raw-material supplier to the customer ship-to (S) remains at 197 days and at 238 days to reach the customer plant with the longest outbound lead-time (C).

6. **The change to introduce a smooth flow, eliminate excess inventories and transportation and reduce lead time should require as low costs as possible**.

The optimized relocated state is visualized in the optimized relocated state map.

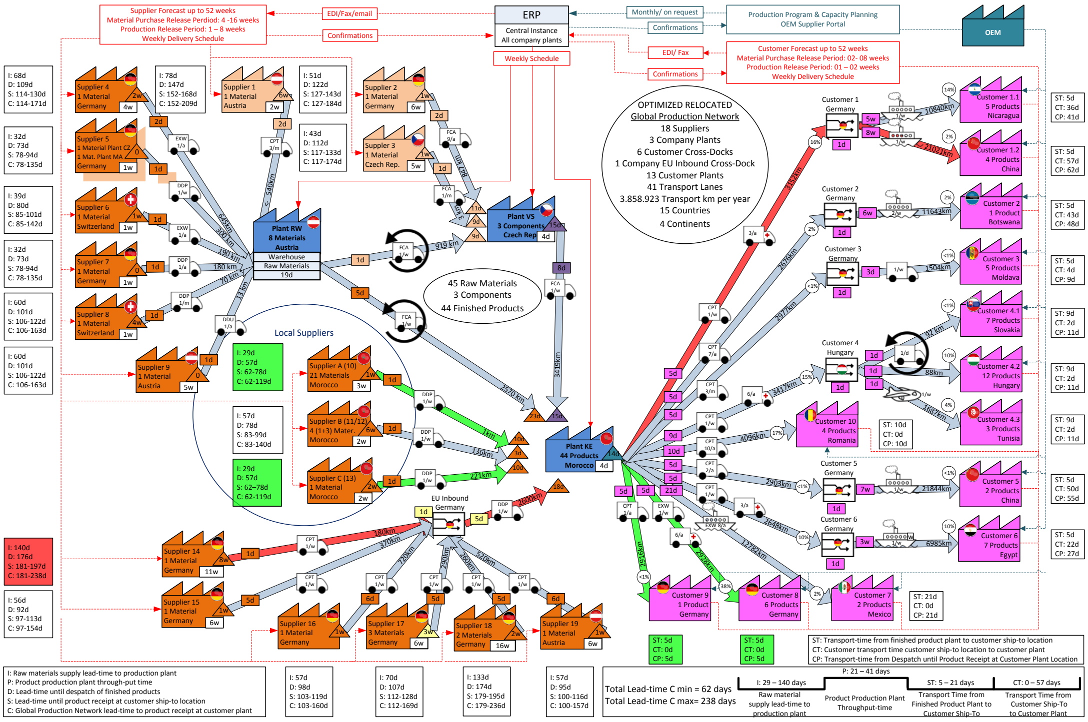


Figure 47: Optimized relocated state map[13]

Figure 48 below summarizes and compares lead-time and transportation requirements of the global production network in the current state, relocated state and optimized relocated state.

	Current State		Relocated State		Optimized Relocated	
Global Production Network Leadtime	MIN	MAX	MIN	MAX	MIN	MAX
Total Lead-time Raw Materiel Supplier to Customer Ship-To Location (S)	44	177	72	197	62	197
Total Lead-time Raw Material Supplier to Customer Plant Location (C)	44	216	72	238	62	238
Production Network Value Stream Leadtimes	MIN	MAX	MIN	MAX	MIN	MAX
Inbound Lead-time Supplier to Production Plant (I)	23	136	28	140	29	140
Finished Product Production Plant Through-put Time (P)	15	28	33	41	21	41
Outbound Lead-time Production Plant to Customer Ship To Location (ST)	1	21	5	21	5	21
Customer Lead-time Customer Ship-To to to Customer Plant Location (CT)	0	57	0	57	0	57
Total Outbound Lead-time from Production Plant to Customer Plant Location (CP)	1	60	5	62	5	62
Global Production Network Transportation Distance	MIN	MAX	MIN	MAX	MIN	MAX
Transportation Distance Supplier to Customer Ship-To Location	894	13.879	5.231	17.660	2.649	17.660
Transportation Distance Supplier to Customer Plant Location	894	25.361	5.499	29.625	2.917	29.625
Annual Production Network Transportation Kilometers to Customer Ship Tos	1.306.211	kilometers	2.831.635	kilometers	1.562.514	kilometers
Annual Production Network Transportation Kilometers to Customer Plants	3.602.620	kilometers	5.128.044	kilometers	3.858.923	kilometers
Production Network Value Stream Transportation Distances	MIN	MAX	MIN	MAX	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plant	803	2.293	2.583	4.878	1	4.878
Outbound Transport Lane Distance Production Plant to Customer Ship-To	91	11.586	2.648	12.782	2.648	12.782
Customer Transport Lane Distance Customer Ship-To to Customer Plant	0	21.844	0	21.844	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	858.654	kilometers	1.866.783	kilometers	597.662	kilometers
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-Tos	447.557	kilometers	964.852	kilometers	964.852	kilometers
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plants	2.296.409	kilometers	2.296.409	kilometers	2.296.409	kilometers

Figure 48: Comparison of lead-times and transportation requirements for all scenarios

[13] See Appendix 15 for the full-size map in A3 format.

Total optimized relocated state inventory and transportation costs 2016 are 272.872 € compared to 331.057 € in the relocated state without optimization. This cost saving is achieved through localization of suppliers and implementing a cross-dock platform in Germany consolidating inbound transportation from European suppliers to Kenitra. Total logistics costs per product can be reduced by 18% from 0.062 € to 0.051 € in the optimized relocated state.

	Current state	Relocated state	Relocated optimized state
Global Production Network Inventory Costs 2016 (€/ year)			
Inventory Costs Total Production Network Suppliers to Customer Plants	66.473	93.095	89.256
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	49.246	75.869	72.030
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,009	0,014	0,013
Production Network Value Streams Inventory Costs 2016 (€/ year)			
Inventory Costs Suppliers	20.869	20.869	22.391
Inventory Costs Raw Material Stock in Transit to Production Plants	1.508	4.637	2.748
Inventory Costs Company Production Plants and Warehouses	22.306	41.134	37.662
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	4.563	9.229	9.229
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	17.226	17.226	17.226
Global Production Network Transportation Costs 2016 (€/ year)			
Total Transportation Costs Suppliers to Customer Ship-To Locations	120.326	255.188	200.842
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,022	0,048	0,037
Production Network Value Stream Transportation 2016 Costs (€/ year)			
Inbound Transportation Costs Suppliers to Production Plants	45.536	94.516	40.170
Outbound Transportation Costs Production Plant to Customer Ship-To Locations	74.790	160.672	160.672
Global Production Network Inventory and Transportation Costs 2016 (€/ year)			
Logistics Costs Production Network Suppliers to Customer Ship-To Locations	169.572	331.057	272.872
Logistics costs / Product (Suppliers to Customer Ship-To Locations)	0,032	0,062	0,051

Figure 49: Comparison of inventory and transportation costs all scenarios

Total logistics cost per product in the current state are 0.032€ versus 0.051€ in the optimized relocated state. Therefore the factor cost per piece in the optimized relocated state still have to be reduced by at least 0.021€ per piece in Kenitra to reach the break-even between increased logistics costs and reduced production costs.

The automotive supplier is confident to achieve this target. Going forward, future relocations shall be visualized, quantified, simulated and optimized using global production network relocation mapping before deciding on relocations. The simulation of the relocated state and the optimized relocated state enables to set clear factor cost reduction targets that must be achieved to make relocations viable. For relocations within the EMEA region, the proposal is that the production cost reduction in the relocated production plant must meet the logistics costs increase of the relocated state without optimization while the optimized relocated state is nevertheless implemented. This strategy ensures that production relocations still remain financially beneficial, even when optimization programs cannot be implemented on time or at all. At the same time all optimizations implemented directly lead to cost savings versus current state. In parallel the company will focus on rolling out its global region for region network strategy by localizing product-process families in its plants in Mexico and China. This will have a very positive impact on optimizing the value stream networks of not only the NAFTA and Asia regional production network, but also for the EMEA regional production network since Asian and American customers will be supplied more and more often directly from the local plants San Miguel and Nantong within their region.

5 Summary and conclusion

This master thesis researched how automotive suppliers can meet the competing targets to grow their business, reduce costs and improve customer responsiveness in global production networks.

In the theoretical foundation of this master thesis the strategies and methods to optimize global production networks were introduced. The literature study identified two different schools of thoughts offering strategies and methods to optimize global production networks. In the traditional production network theory, derived from Operations Management, global production networks are optimized through a periodic strategic process defining the production network strategy, production network design and production network migration to the optimized target structure. The lean production network theory defines three principles to optimize global production networks: value stream concentration, customer proximity and optimization of total cost of ownership. The lean production tool value stream mapping was described as method to gain a holistic overview of the status of the value streams in an organization from the supplier to the customer.

Labor cost reduction potential in emerging countries is still the dominating motivation for many companies to relocate production abroad. Furthermore growth opportunities in the developing markets and the need to fulfill customer proximity and responsiveness requirements play a major role for automotive suppliers to globalize production network.

In practice many companies focus on direct location-specific factor cost opportunities (mainly low labor cost) when taking their decision to relocate production abroad. The total cost of ownership method addresses this issue and considers all cost elements to decide on the best production location, including logistics costs to achieve the required customer responsiveness. However, very often companies have difficulties to identify and calculate the additional costs and risks which result from the increased complexity, reduced flexibility and longer lead-times in fragmented global production networks. As a result the performance of the production network often is not satisfying. This confirms the first part of the hypothesis statement that companies often underestimate the (potentially negative) impact of global production relocations on the value stream.

The global production network stereotypes and their strengths and weaknesses to achieve economies of scope and economies of scale and market proximity were described. The evaluation was extended to also assess the lean orientation of the different models. This assessment revealed that none of the production network stereotypes can fulfil all lean production network principles. Next the lean production network orientation of an automotive supplier was described and the “Region for Region” model was identified as a global production network design with the target to exploit global growth opportunities and to fulfill the three lean production network principles: value stream concentration, customer proximity and optimization of total cost of ownership.

Finally extended value stream mapping was enhanced to the global production relocation mapping method as lean tool to visualize, analyze, simulate and optimize the impact of global production relocations on lead-time, inventory, transportation requirements and logistics costs. In the global production relocation mapping method the first step is to define the product line to relocate. The second step is to map the current state. The global production relocation map enables to visualize complex networks with the multiple customers, production plants and suppliers and their value-stream connections. Global production relocation mapping symbols were introduced for improved visualization of the material- and information flow of the global production network. In the third step relocated state of the global production network is visualized and the impact of the relocation on transportation-requirements, inventories and lead-times is analyzed. Next a tool was introduced to visualize and simulate the impact of relocations on inventory and transportation costs. In the last step the relocated state is optimized using six optimization criteria. Finally the current state, relocated state and optimized relocated state are compared and a production cost reduction target is defined that must be met to compensate the increased logistics costs in the (optimized) relocated production network. The second part of the hypothesis statement that the impact of global production network relocations on the value stream can be can be identified, quantified, evaluated and optimized through visualization and simulation has been confirmed through the development and successful application of the global production relocation method.

Concluding, most companies have a very good understanding of the direct factor cost changes when relocating productions abroad. However, many companies have difficulties to anticipate and quantify the impact of global production relocations on the value-stream. Global production relocation mapping enables companies to perform a holistic evaluation of global production relocations. The method enables companies to identify and understand the qualitative and quantitative impact of global production relocations on the value stream, specifically on customer proximity, flexibility, inventories, transportation requirements and logistics costs. Moreover, using the global production relocation maps and its visualization and simulation tool enables companies to identify opportunities for improvement before relocation. The method also defines a direct production cost saving target that must be met to compensate increased logistics costs in the (optimized) relocated global production network. Summarizing the method supports companies to take the right relocation decision and to optimize the global production network to ensure that the relocation will deliver sustainable financial benefits.

6 Bibliography

Abele E., Reinhart G. (2011): Zukunft der Produktion. Carl Hanser Verlag, München

Achterholt U. (2009): KPMG Global Location Strategy For Automotive Suppliers. KPMG International Cooperative, Switzerland

Arbulu R., Tommelein I., Walsh K., Hershauer J. (2003): Value stream analysis of a re-engineered construction supply chain. In: Building Research & Information, Vol. 31, No. 2, pp. 161-171

Balsliemke F. (2015): Kostenorientierte Wertstromplanung. Spinger Gabler, Wiesbaden

Balsliemke F. (2013): Mit kostenorietierter Wertstromplanung zu schlanker Logistik. In: Göpfert I., Braun D., Schulz M. (2013): Automobillogistik. Springer Gabler, Wiesbaden, pp 287-304

Becker M. (2010): Global Footprint. Das Wertschöpfungsnetzwerk nach Prinzipien der Lean Community gestalten. Schulungsunterlagen, Staufen AG, Köngen

Bürstner H. (2011): Strategic Impact of Global Production – How to Fond the Success Measures. In: ElMaraghy H. (Ed.): Enabling Manufacturing Competitiveness and Economic Sustainability. Springer, Berlin, pp.397-402

Chopra S., Meindl P. (2010): Supply Chain Management. 4th ed., Pearson, New Jersey

Christodoulou P., Fleet D., Hanson P., Phaal R., Probert D., Shi Y. (2007): Making the right things in the right places. University of Cambridge Institute for Manufacturing, Cambridge

Christopher M. (2005): Logistics and Supply Chain Management. 3rd ed., Pearson Education, Harlow

Colotla I., Shi Y., Gregory M. (2003): Operation and performance of international manufacturing networks. In: International Journal of Operations & Production Management, Vol. 23, No. 10, pp. 1184-1206

Delfmann W., Klaas-Wissing T. (Ed.): Strategic Supply Chain Design. Kölner Wisseschaftsverlag, Köln, pp. 3-36

Emiliani M.L., Stec D.J. (2004): Using value-stream maps to improve leadership. In: Leadership & Organizational Development Journal, Vol. 25, No.8, pp. 622-645

Friedli T., Thomas S., Mundt A. (2013): Management globaler Produktionsnetzwerke. Carl Hanser Verlag, München

Fujimoto, T. (1999): The evolution of manufacturing systems at Toyota. Oxford University Press, New York

Heizer J., Render B. (2014): Operations Management. 11th ed., Pearson Education Limited, Harlow

Hellingrath B. (2014): Supply Chain Management. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Holweg M. (2007): The genealogy of lean production. In: Journal of Operations Management, Vol. 25, No. 2, pp. 420-437

Huf Group (2015): Our products lead the pack. http://www.huf-group.com/products/products/door-handle-systems.html - accessed on: 2nd of July 2015

Jacob F., Strube G. (2008): Why Go Global? The Multinational Imperative. In: Abele E., Meyer T., Näher U., Strube G., Sykes R. (Ed.): Global production. A handbook for strategy and implementation. Springer, Berlin, pp 2-33

Jones D. (2011): Seeing a Whole Supply System Across the Globe (2011): In: Jones D., Womack J. (2011): Seeing the Whole Value Stream. 2nd ed., Lean Enterprise Institute, Cambridge MA, pp. 100-105

Jones D., Womack J. (2002): Seeing the Whole Value Stream. Lean Enterprise Institute, Cambridge MA

Jones D., Womack J. (2011): Seeing the Whole Value Stream. 2nd ed., Lean Enterprise Institute, Cambridge MA

Kampker A., Schuh G., Schittny B., Kupke D. (2010): An Approach for Systematic Production Network Configuration. In: Sihn W., Kuhlang P. (Ed.): Sustainable Production and Logistics in Global Networks. Neuer Wissenschaftlicher Verlag, Vienna Graz, pp 45-52

Kinkel S., Maloca S. (2009): Produktionsverlagerung und Rückverlagerung in Zeiten der Krise. In: Modernisierung der Produktion – Mitteilungen aus der ISI Erhebung, No. 52, pp. 1-12

Manos T. (2006): Value Stream Mapping – an Introduction. In: Quality Progress, Vol. June, pp. 64-69

Meyer M. (2013): KPMG's Global Automotive Executive Summary 2013. KPMG International Cooperative, Switzerland

Meyer M. (2014): KPMG's Global Automotive Executive Summary 2014. KPMG International Cooperative, Switzerland

Meyer T., Jacob F. (2008): Network Design: Optimizing the Global Production Footprint. In: Abele E., Meyer T., Näher U., Strube G., Sykes R. (Ed.): Global production a handbook for strategy and implementation. Springer, Berlin, pp 140-191

Meyer T. (2008): Investment Abroad: Using the Right Evaluation Techniques. In: Abele E., Meyer T., Näher U., Strube G., Sykes R. (Ed.): Global production a handbook for strategy and implementation. Springer, Berlin, pp 102-139

Minichmayr J. (2014): Value Stream Design. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Neuner C., Kwasniok T. (2010): Global Footprint Redesign. Roland Berger Strategy Consultants, Munich

Palm D. (2014a): Automotive Business. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Palm D. (2014b): Logistics Fundamentals. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Reichl V., Krys C., Dengler K. (2014): Roland Berger Trend Compendium 2030. Roland Berger Strategy Consultants, Munich

Palm D., Sihn W. (2010): Impact of influence factors on logistics planning in the Automotive Industry. In: Sihn W., Kuhlang P. (Ed.): Sustainable Production and Logistics in Global Networks. Neuer Wissenschaftlicher Verlag, Vienna, Graz, pp 77-84

Pereira R. (2009): The Seven Wastes. In: iSixSigma Magazine, Vol. 5, No. 5, pp. 1-2

Ponton P., Jaehne M., Mueller E. (2011): Relocation in Production networks of a Multi-National Enterprise. In: ElMaraghy H. (Ed.): Enabling Manufacturing Competitiveness and Economic Sustainability. Springer, Berlin, pp 488-492

Prinz A., Ost S., Mandel J. (2010): Improving the distribution of value-added activities in complex business networks considering qualitative factors. In: Sihn W., Kuhlang P. (Ed.): Sustainable Production and Logistics in Global Networks. Neuer Wissenschaftlicher Verlag, Vienna, Graz, pp 85-92

Rother M., Shook J. (2004): Sehen Lernen: mit Wertstromdesign die Wertschöpfung erhöhen und Verschwendung beseitigen. Lean Management Institut, Aachen

Pavnaskar, S., Gershenson, J., & Jambekar, A. (2003): Classification scheme for lean manufacturing tools. International Journal of Production Research, Vol. 41, No. 13, pp. 3075-3090.

Pümpin C., Amann W. (2005): SEP - Strategische Erfolgspositionen: Kernkompetenzen aufbauen und umsetzen, Haupt Verlag, Bern

Schönsleben P. (2011): Integrales Logistikmanagement. 5th ed., Springer, Berlin

Shorten D., Pfitzmann M., Mueller C. (2006): Taking the right Steps: Manufacturing Footprint as a Competitive Imperative. Booz Allen Hamilton, Chicago

Shi Y., Gregory M. (1998): International manufacturing networks – to develop competitive capabilities. In: Journal of Operations Management, Vol. 16, pp. 195-214

Shi Y. (2005): Global Manufacturing Network. In: The Blackwell encyclopedia of management: Operations management, Vol. 10, pp.100-101

Sihn W. (2014a): Operations Management. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Sihn W. (2014b): Introduction to Automotive Industry. Class 2013-2105 ed., Professional MBA Automotive Industry, CEC TU Vienna, Vienna

Simon S., Dervisopoulos M., Jacob F., Näher U. (2008): Implementation: Ramping up new facilities for top performance. In: Abele E., Meyer T., Näher U., Strube G., Sykes R. (Ed.): Global production a handbook for strategy and implementation. Springer, Berlin, pp 236-269

Slack N., Lewis M. (2011): Operations Strategy. 3rd ed., Pearson Education, Harlow

Spindelndreier D., Bauernhansl T., Beck M., Lesmeister F. (2015): The proximity paradox. The Boston Consulting Group & Frauenhofer IPA, Boston, Stuttgart

Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977). Toyota production system and kanban system materialization of just-in-time and respect-for-human system. In: *The International Journal of Production Research, 15*(6), 553-564.

Sydow J. (1992): Strategische etzwerke. Evolution und Organisation, Gabler, Wiesbaden

Tapping D., Luyster T., Shuker T. (2002): Value Stream Management. Productivity Press, New York

The Henry Ford (2015): History of the Rouge. http://www.thehenryford.org/rouge/historyofrouge.aspx - accessed on August 6th 2015

The Library of Congress (2011): Today in History. http://memory.loc.gov/ammem/today/jul30.html - accessed on: 24th of June 2015

Thomas Stefan (2013): Produktionsnetzwerksysteme – Ein Weg zu effizienten Produktionsnetzwerken. Dissertation Nr. 4187, Univesität St. Gallen

Walters, D. (2002): Operations Strategy. Palgrave Macmillan, New York

Walter S., Wolf J. (2007): More than a Buzzword – Supply Chain Management as a science revolution? Outlines of a Supply Chain Management Paradigm. In: Wildemann H. (1996b): Management von Produktions- und Zulieferernetzwerken. In: Wildemann H. (Ed.): Produktions- du Zuliefernetzwerke, TCW Transfer-Centrum-Verlag, München, pp 13-45

Wildemann H. (1996a): Entwicklungsstrategien für Zulieferunternehmen. Transfer-Centrum-Verlag, München

Womack J., Jones D., Roos D. (1990): The Machine that changed the World. Free Press, New York

Womack J., Jones D. (2003): Lean Thinkig. Free Press, New York

Womack J., Lovejoy M (2011): The Cost of Location. In: Jones D., Womack J. (2011): Seeing the Whole Value Stream. 2nd ed., Lean Enterprise Institute, Cambridge MA, pp. 96-99

Zanker C., Kinkel S., Maloca S. (2013): Globale Produktion von einer stabilen Heimbasis aus. In: Modernisierung der Produktion – Mitteilungen aus der ISI Erhebung, No. 63, pp. 1-12

7 List of Figures

Figure 1: Development of globalization in three phases (Jacob & Strube 2008: 4)... 8
Figure 2: Most important free trade zones worldwide (Reichl et al. 2014: 7) 10
Figure 3: Suppliers are shifting plants from the USA and Europe to Emerging Markets (Spindelndreier et al. 2015: 7) 12
Figure 4: Structure of the master thesis 15
Figure 5: Global production – network stereotypes (Meyer & Jacob 2008: 164)......17
Figure 6: Three phases to optimize Production Networks 22
Figure 7: Location Criteria (Meyer & Jacob 2008: 172) 24
Figure 8: Impact of moving to a low labor cost country (Christodoulou et al. 2007: 29) 25
Figure 9: Global landed cost curve (Christodoulou et al. 2007: 29) 26
Figure 10: Cost of manual versus automated assembly in different locations (Shorten et al. 2006: 4) 27
Figure 11: Location Selection Funnel (Simon et al. 2008: 244) 29
Figure 12: Reasons for Relocation (cf. Zanker et al. 2013: 9) 31
Figure 13: Reasons for Re-Relocation (cg. Zanker et al. 2013: 10)....................32
Figure 14: Impact of global production networks on the value-stream....................32
Figure 15: Lean Development phases (Minichmayr 2014: 15) 34
Figure 16: Lean Production Principles (cf. Womack & Jones 2003: 15ff) 36
Figure 17: Lean Production Network Criteria and Scenarios....................39
Figure 18: Location decision bases on Total Cost of Ownership Method (Palm 2014: 143) 40
Figure 19: Levels of Value Streams (cf. Minichmayr 2014: 23; Jones 2011) 42
Figure 20: Procedure of the Value Stream Mapping Method (Minichmayr 2014: 25) 42
Figure 21: Waste reduction potential versus potential of value creation process optimization (Minichmayr 2014: 68) 44
Figure 22: “Toyota City” in Texas (Becker 2010: 29)....................47
Figure 23: Lean Orientation of Production Network Stereotypes....................49
Figure 24: Global Production Network of automotive supplier 50
Figure 25: Product - Process - Plant Matrix....................51
Figure 26: Function - Plant – Region Matrix 52
Figure 27: Location decisions of an automotive supplier 53
Figure 28: Global Production network of an automotive supplier....................54

Figure 29: EMEA Production Network Location Criteria..55
Figure 30: Region for Region Production Network 57
Figure 31: Current-State extended value stream map of a Supply System (cf. Jones 2011: 101) 59
Figure 32: Global Production Relocation Mapping Symbols...................................61
Figure 33: Lead-times of Global Production Network 62
Figure 34: Door Handle System (Huf Group 2015) 64
Figure 35: Door Handle Harness 64
Figure 36: Door Handle Harness Product Line Sales Volume and Forecast 65
Figure 37: Current state map 66
Figure 38: Current state lead-time and transportation requirements.......................69
Figure 39: Relocated state map 70
Figure 40: Comparison current state and relocated state lead-time and transportation requirements 72
Figure 41: Relocated state inventory costs visualization and simulation 74
Figure 42: Comparison current state and relocated state inventory and transportation costs 76
Figure 43: Comparison relocated optimized and relocated state inventory costs 79
Figure 44: Comparison relocated optimized and relocated state transportation requirements..80
Figure 45: Comparison relocated optimized and relocated state transportation costs 81
Figure 46: Comparison relocated optimized and relocated state lead-time requirements..82
Figure 47: Optimized relocated state map...83
Figure 49: Comparison of lead-times and transportation requirements for all scenarios 83
Figure 50: Comparison of inventory and transportation costs all scenarios 84

8 List of Appendixes

Appendix 1: Visualization and simulation current state: lead-time 97
Appendix 2: Visualization and simulation current state: transportation distances 98
Appendix 3: Visualization and simulation current state: transportation costs 99
Appendix 4: Visualization and simulation current state: inventory costs 100
Appendix 5: Visualization and simulation relocated state: lead-time......................101
Appendix 6: Visualization and simulation relocated state: transportation distances 102
Appendix 7: Visualization and simulation relocated state: transportation costs 103
Appendix 8: Visualization and simulation relocated state: inventory costs 104
Appendix 9: Visualization and simulation optimized relocated state: tool: lead-time 105
Appendix 10: Visualization and simulation optimized relocated state: transportation distances 106
Appendix 11: Visualization and simulation optimized relocated state: transportation costs 107
Appendix 12: Visualization and simulation optimized relocated state: inventory costs 108
Appendix 13: Global Production Relocation Map - current state 109
Appendix 14: Global Production Relocation Map - relocated state........................110
Appendix 15: Global Production Relocation Map - optimized relocated state........111

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse	Transport	Vsetin: Mat. Stock	Vsetin: Processing	Vsetin: Comp. Stock
Supplier 1	14	42	2	19	1	9	4	15
Supplier 2	42	7	2			11	4	15
Supplier 3	35	7	1			9	4	15

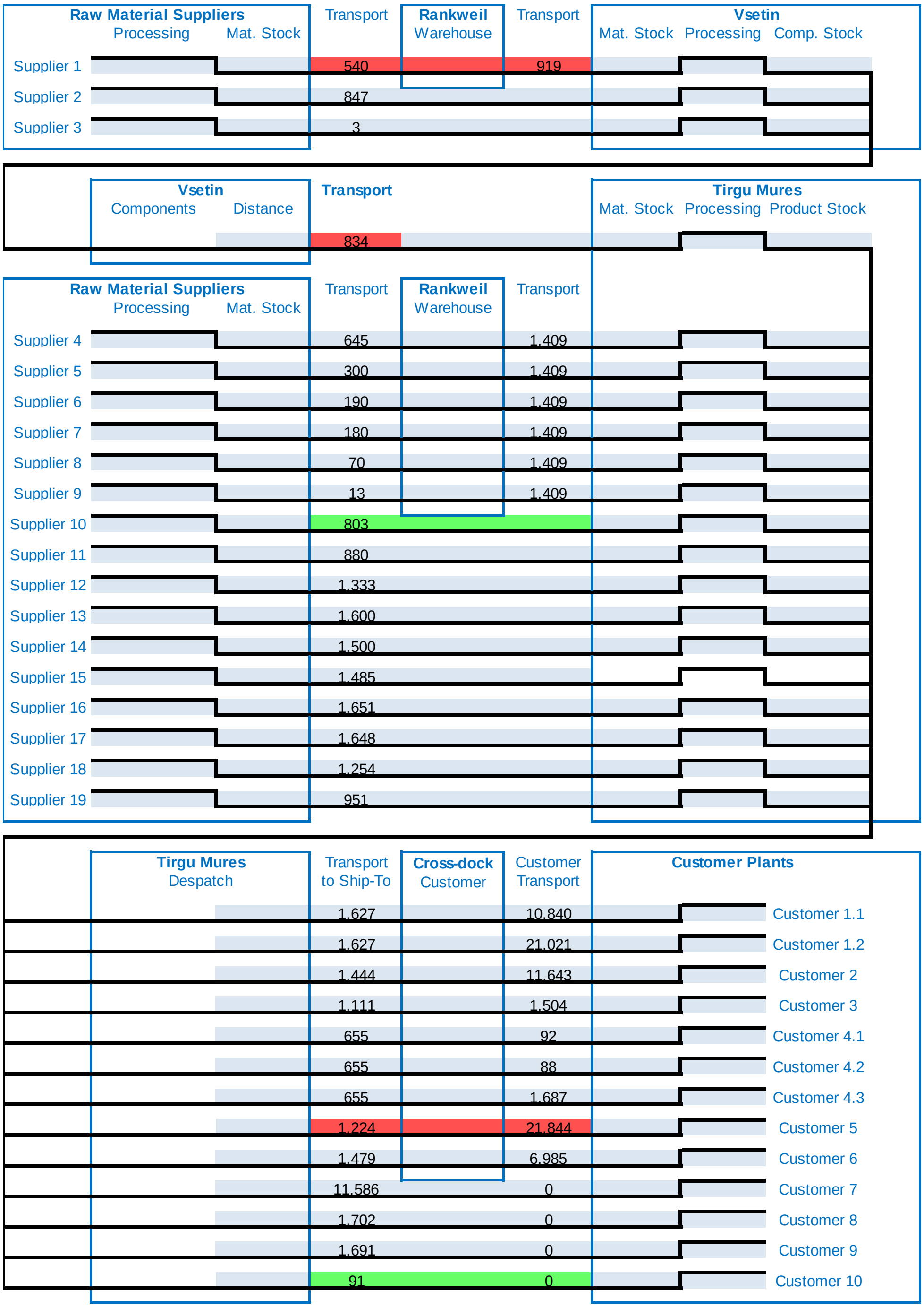
Vsetin: Components Leadtime	Transport	Tirgu Mures: Mat. Stock	Tirgu Mures: Processing	Tirgu Mures: Product Stock
106	2	10	4	6

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse	Transport	Tirgu Mures: Mat. Stock	Tirgu Mures: Processing	Tirgu Mures: Product Stock
Supplier 4	28	14	2	19	2	18	4	6
Supplier 5	7	0	1	19	2	18	4	6
Supplier 6	7	7	1	19	2	18	4	6
Supplier 7	7	0	1	19	2	18	4	6
Supplier 8	7	28	1	19	2	18	4	6
Supplier 9	35	0	1	19	2	18	4	6
Supplier 10	21	0	2			10	4	6
Supplier 11	14	42	2			10	4	6
Supplier 12	14	42	3			7	4	6
Supplier 13	7	14	3			9	4	6
Supplier 14	77	56	3			10	4	6
Supplier 15	42	7	3			5	4	6
Supplier 16	42	7	3			18	4	6
Supplier 17	42	21	3			15	4	6
Supplier 18	112	14	3			15	4	6
Supplier 19	42	7	2			9	4	6

Tirgu Mures Despatch	Transport to Ship-To	Cross-dock Customer	Customer Transport	Customer Plants
	3	1	35	Customer 1.1
	3	1	56	Customer 1.2
	3	1	42	Customer 2
	3	1	3	Customer 3
	2	1	1	Customer 4.1
	2	1	1	Customer 4.2
	2	1	1	Customer 4.3
	3	1	49	Customer 5
	3	1	21	Customer 6
	21	0	0	Customer 7
	3	0	0	Customer 8
	3	0	0	Customer 9
	1	0	0	Customer 10

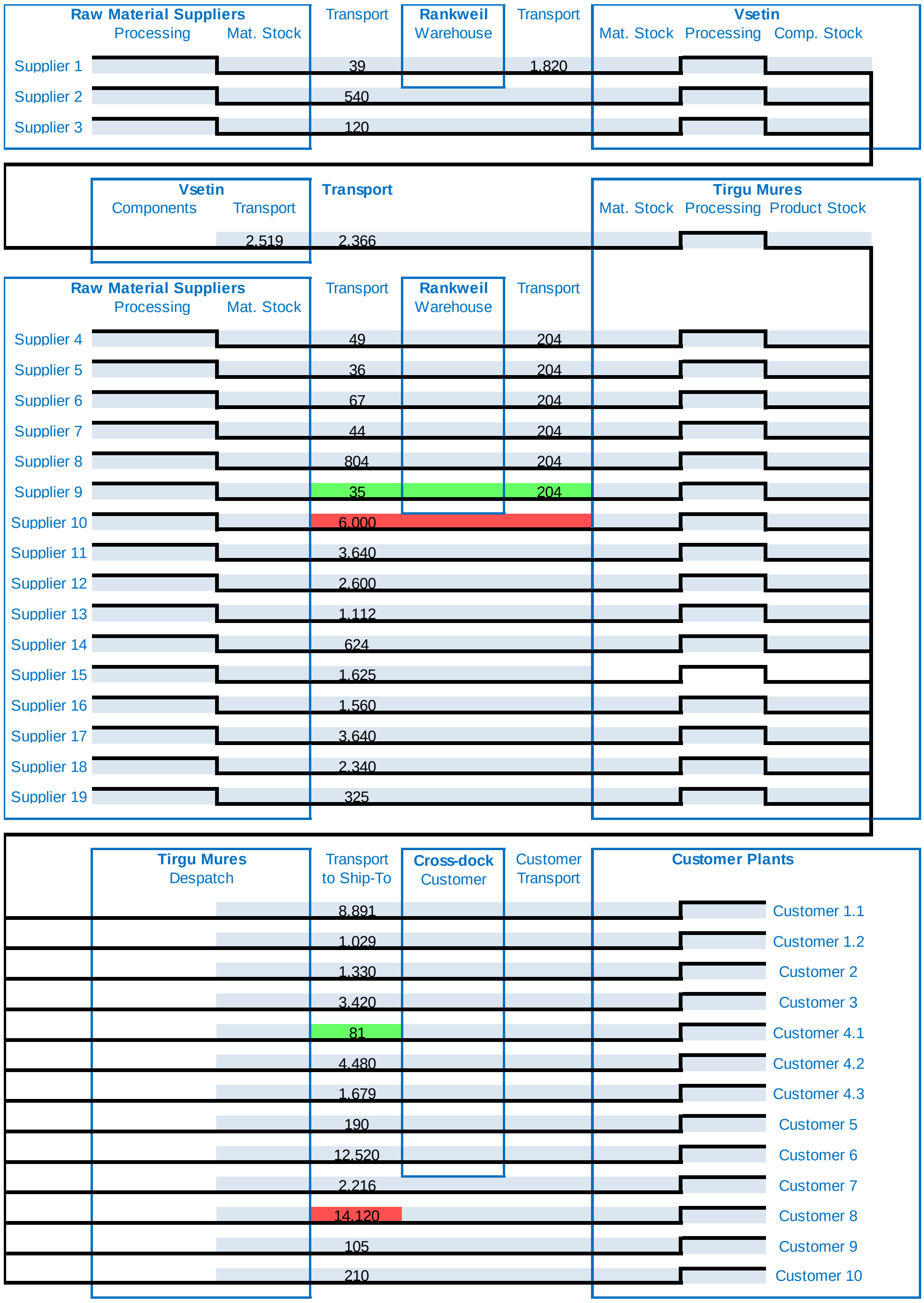
Global Production Network Leadtime	MIN	MAX
Total Leadtime to Customer Ship-To Location	44	177
Total Leadtime to Customer Plant Location	44	216
Production Network Value Stream Leadtimes	MIN	MAX
Inbound Leadtime Suppliers to Production Plant	23	136
Production Plant Through-put Time	15	28
Outbound Leadtime to Customer Ship To Location	1	21
Customer Leadtime Customer Ship-To to to Customer Plant Location	0	57
Total Outbound Leadtime from Production Plant to Customer Plant Location	1	60

Appendix 1: Visualization and simulation current state: lead-time



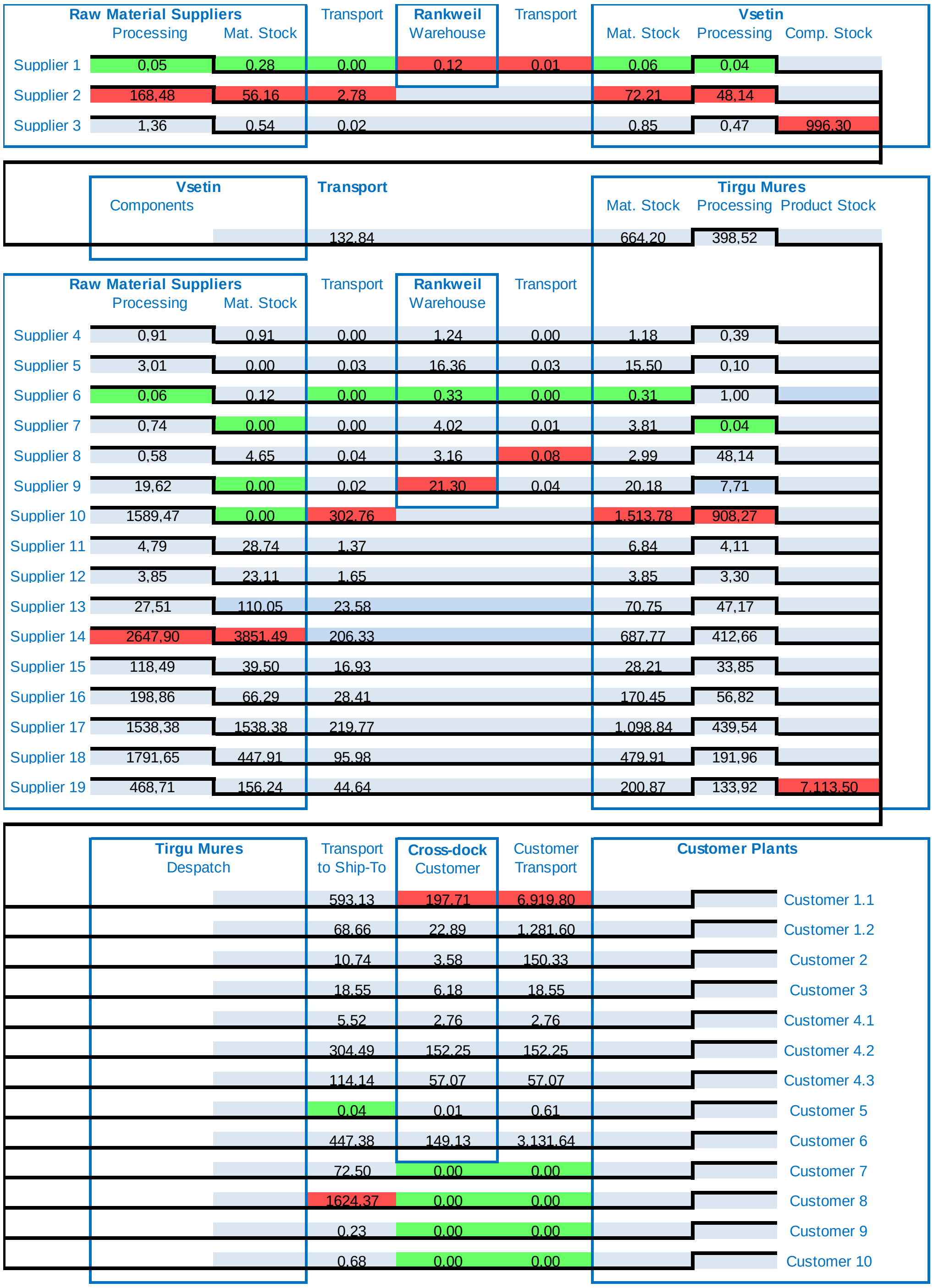
Global Production Network Transportation Distance	MIN	MAX
Total Transport Distance Suppliers to Customer Ship-To Locations	894	13.879
Total Transport Distance Suppliers to Customer Plant Locations	894	25.361
Annual Production Network Transportation Kilometers to Customer Sip To Locations	1.306.211	km
Annual Total Production Network Transportation Kilometers to Customer Plants	3.602.620	km
Production Network Value Stream Transportation Distances	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plants	803	2.293
Outbound Transport Lane Distance Production Plant to Customer Ship-To Locations	91	11.586
Customer Transport Lane Distance Customer Ship-Tos to Customer Plant Locations	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	858.654	km
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-To Locations	447.557	km
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plant Locations	2.296.409	km

Appendix 2: Visualization and simulation current state: transportation distances



Global Production Network Transportation Costs (€/ year)			
Total Transportation Costs Suppliers to Customer Ship-To Locations	80.879	95.408	120.326
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,0224	0,0224	0,0224
Production Network Value Stream Transportation Costs (€/ year)			
Inbound Transportation Costs Suppliers to Production Plants	30.608	36.106	45.536
Outbound Transportation Costs Production Plant to Customer Ship-To Loc.	50.271	59.302	74.790

Appendix 3: Visualization and simulation current state: transportation costs



Global Production Network Inventory Costs (€/ year)	2014	2015	2016
Inventory Costs Total Production Network Suppliers to Customer Plants	47.487	54.337	66.473
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	35.181	40.256	49.246
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,0098	0,0095	0,0092
Production Network Value Streams Inventory Costs (€/ year)	2014	2015	2106
Inventory Costs Suppliers	14.909	17.059	20.869
Inventory Costs Raw Material Stock in Transit to Production Plants	1.077	1.233	1.508
Inventory Costs Company Production Plants and Warehouses	15.935	18.234	22.306
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	3.260	3.730	4.563
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	12.306	14.081	17.226

Appendix 4: Visualization and simulation current state: inventory costs

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse	Transport	Vsetin: Mat. Stock	Vsetin: Processing	Vsetin: Comp. Stock
Supplier 1	14	42	2	19	1	9	4	15
Supplier 2	42	7	2			11	4	15
Supplier 3	35	7	1			9	4	15

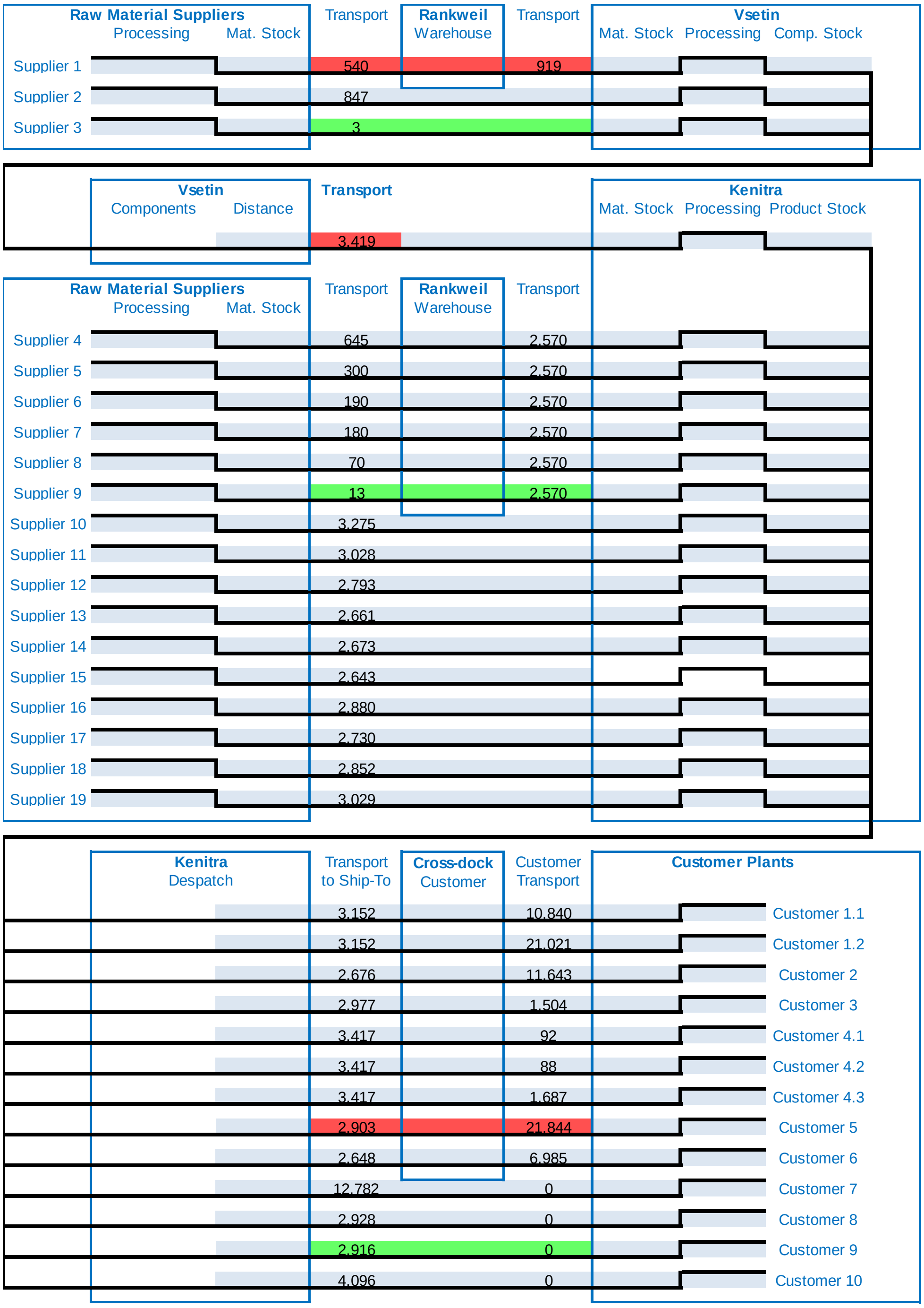
Vsetin: Components Leadtime	Transport	Kenitra: Mat. Stock	Kenitra: Processing	Kenitra: Product Stock
106	8	15	4	14

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse	Transport	Kenitra: Mat. Stock	Kenitra: Processing	Kenitra: Product Stock
Supplier 4	28	14	2	19	5	23	4	14
Supplier 5	7	0	1	19	5	23	4	14
Supplier 6	7	7	1	19	5	23	4	14
Supplier 7	7	0	1	19	5	23	4	14
Supplier 8	7	28	1	19	5	23	4	14
Supplier 9	35	0	1	19	5	23	4	14
Supplier 10	21	0	8			23	4	14
Supplier 11	14	42	8			15	4	14
Supplier 12	14	42	7			15	4	14
Supplier 13	7	14	7			21	4	14
Supplier 14	77	56	7			18	4	14
Supplier 15	42	7	7			18	4	14
Supplier 16	42	7	7			21	4	14
Supplier 17	42	21	7			21	4	14
Supplier 18	112	14	7			21	4	14
Supplier 19	42	7	8			21	4	14

Kenitra Despatch	Transport to Ship-To	Cross-dock Customer	Customer Transport	Customer Plants
	5	1	35	Customer 1.1
	5	1	56	Customer 1.2
	5	1	42	Customer 2
	5	1	3	Customer 3
	9	1	1	Customer 4.1
	9	1	1	Customer 4.2
	9	1	1	Customer 4.3
	5	1	49	Customer 5
	5	1	21	Customer 6
	21	0	0	Customer 7
	5	0	0	Customer 8
	5	0	0	Customer 9
	10	0	0	Customer 10

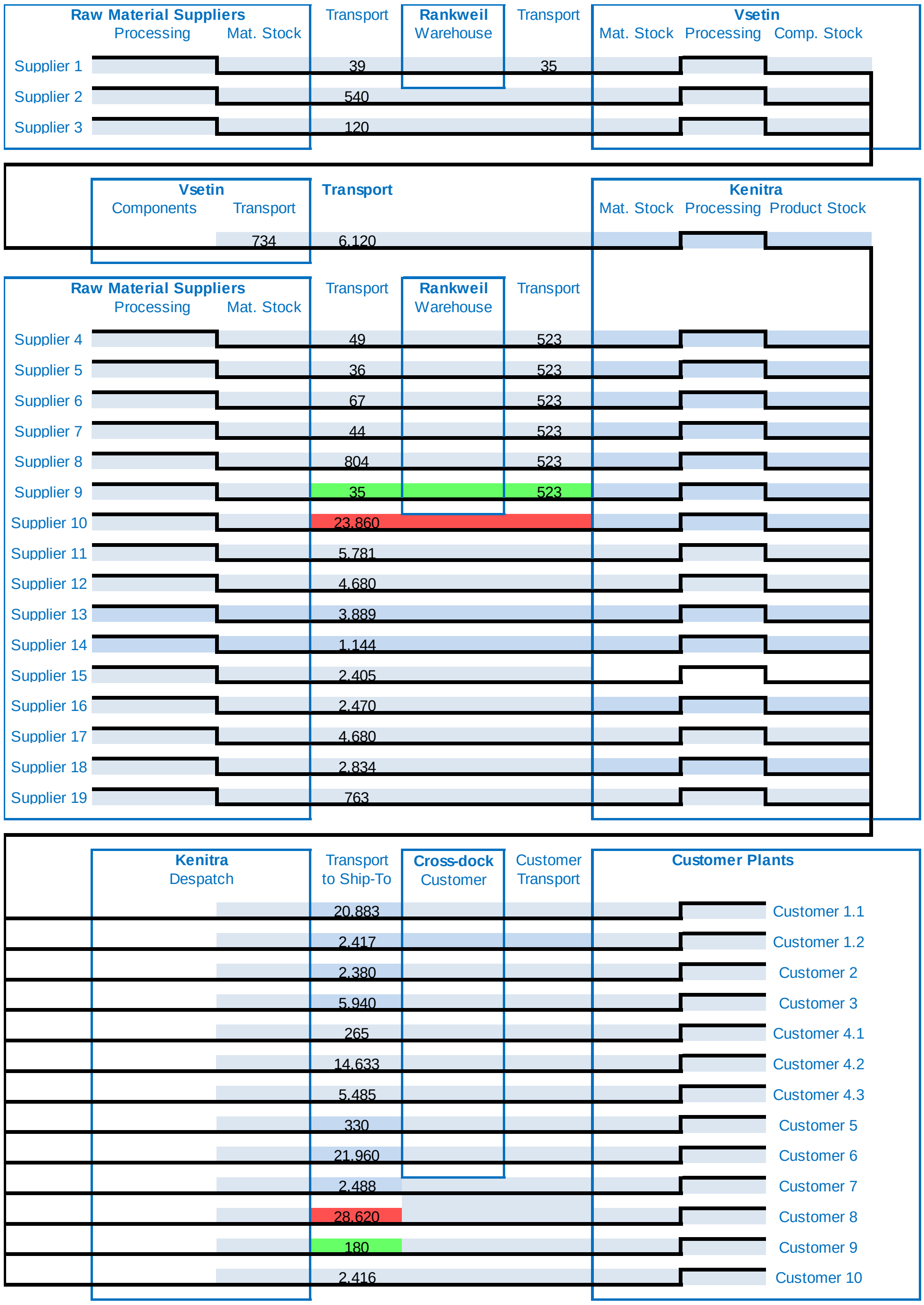
Global Production Network Leadtime	MN	MAX
Total Leadtime to Customer Ship-To Location	72	197
Total Leadtime to Customer Plant Location	72	238
Production Network Value Stream Leadtimes	MIN	MAX
Inbound Leadtime Suppliers to Production Plant	28	140
Production Plant Through-put Time	33	41
Outbound Leadtime to Customer Ship To Location	5	21
Customer Leadtime Customer Ship-To to to Customer Plant Location	0	57
Total Outbound Leadtime from Production Plant to Customer Plant Location	5	62

Appendix 5: Visualization and simulation relocated state: lead-time



Global Production Network Transportation Distance	MIN	MAX
Total Transport Distance Suppliers to Customer Ship-To Locations	5.231	17.660
Total Transport Distance Suppliers to Customer Plant Locations	5.499	29.625
Annual Production Network Transportation Kilometers to Customer Sip To Locations	2.831.635	km
Annual Total Production Network Transportation Kilometers to Customer Plants	5.128.044	km
Production Network Value Stream Transportation Distances	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plants	2.583	4.878
Outbound Transport Lane Distance Production Plant to Customer Ship-To Locations	2.648	12.782
Customer Transport Lane Distance Customer Ship-Tos to Customer Plant Locations	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	1.866.783	km
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-To Locations	964.852	km
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plant Locations	2.296.409	km

Appendix 6: Visualization and simulation relocated state: transportation distances



Global Production Network Transportation Costs (€/ year)			
Total Transportation Costs Suppliers to Customer Ship-To Locations	171.529	202.343	255.188
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,0476	0,0476	0,0476
Production Network Value Stream Transportation Costs (€/ year)			
Inbound Transportation Costs Suppliers to Production Plants	63.531	74.944	94.516
Outbound Transportation Costs Production Plant to Customer Ship-To Loc.	107.998	127.399	160.672

Appendix 7: Visualization and simulation relocated state: transportation costs

	Raw Material Suppliers – Processing	Raw Material Suppliers – Mat. Stock	Transport	Rankweil Warehouse	Transport	Vsetin – Mat. Stock	Vsetin – Processing	Vsetin – Comp. Stock
Supplier 1	0,05	0,28	0,00	0,12	0,01	0,06	0,04	
Supplier 2	168,48	56,16	2,78			72,21	48,14	
Supplier 3	1,36	0,54	0,02			0,85	0,47	996,30

Vsetin Components	Transport	Kenitra – Mat. Stock	Kenitra – Processing	Kenitra – Product Stock
	531,36	996,30	398,52	

	Raw Material Suppliers – Processing	Raw Material Suppliers – Mat. Stock	Transport	Rankweil Warehouse	Transport	Kenitra – Mat. Stock	Kenitra – Processing	Kenitra – Product Stock
Supplier 4	0,91	0,91	0,00	1,24	0,01	1,50	0,39	
Supplier 5	3,01	0,00	0,03	16,36	0,08	19,81	0,10	
Supplier 6	0,06	0,12	0,00	0,33	0,00	0,39	1,00	
Supplier 7	0,74	0,00	0,00	4,02	0,02	4,87	0,04	
Supplier 8	0,58	4,65	0,04	3,16	0,08	3,82	48,14	
Supplier 9	19,62	0,00	0,02	21,30	0,04	25,78	7,71	
Supplier 10	1.589,47	0,00	1.211,03			3.481,70	908,27	
Supplier 11	4,79	28,74	5,47			10,26	4,11	
Supplier 12	3,85	23,11	3,85			8,25	3,30	
Supplier 13	27,51	110,05	55,03			165,08	47,17	
Supplier 14	2.647,90	3.851,49	481,44			1.237,98	412,66	
Supplier 15	118,49	39,50	39,50			101,56	33,85	
Supplier 16	198,86	66,29	66,29			198,86	56,82	
Supplier 17	1.538,38	1.538,38	512,79			1.538,38	439,54	
Supplier 18	1.791,65	447,91	223,96			671,87	191,96	
Supplier 19	468,71	156,24	178,55			468,71	133,92	16.598,16

Kenitra Despatch	Transport to Ship-To	Cross-dock Customer	Customer Transport	Customer Plants
	988,54	197,71	6.919,80	Customer 1.1
	114,43	22,89	1.281,60	Customer 1.2
	17,90	3,58	150,33	Customer 2
	30,92	6,18	18,55	Customer 3
	24,84	2,76	2,76	Customer 4.1
	1.370,21	152,25	152,25	Customer 4.2
	513,62	57,07	57,07	Customer 4.3
	0,06	0,01	0,61	Customer 5
	745,63	149,13	3.131,64	Customer 6
	72,50	0,00	0,00	Customer 7
	2.707,29	0,00	0,00	Customer 8
	0,39	0,00	0,00	Customer 9
	6,82	0,00	0,00	Customer 10

Global Production Network Inventory Costs (€/ year)	2014	2015	2016
Inventory Costs Total Production Network Suppliers to Customer Plants	66.506	76.100	93.095
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	54.200	62.018	75.869
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,0150	0,0146	0,0141
Production Network Value Streams Inventory Costs (€/ year)	2014	2015	2106
Inventory Costs Suppliers	14.909	17.059	20.869
Inventory Costs Raw Material Stock in Transit to Production Plants	3.312	3.790	4.637
Inventory Costs Company Production Plants and Warehouses	29.385	33.624	41.134
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	6.593	7.544	9.229
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	12.306	14.081	17.226

Appendix 8: Visualization and simulation relocated state: inventory costs

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse	Transport	Vsetin: Mat. Stock	Vsetin: Processing	Vsetin: Comp. Stock
Supplier 1	14	42	2	19	1	9	4	15
Supplier 2	42	7	2			11	4	15
Supplier 3	35	7	1			9	4	15

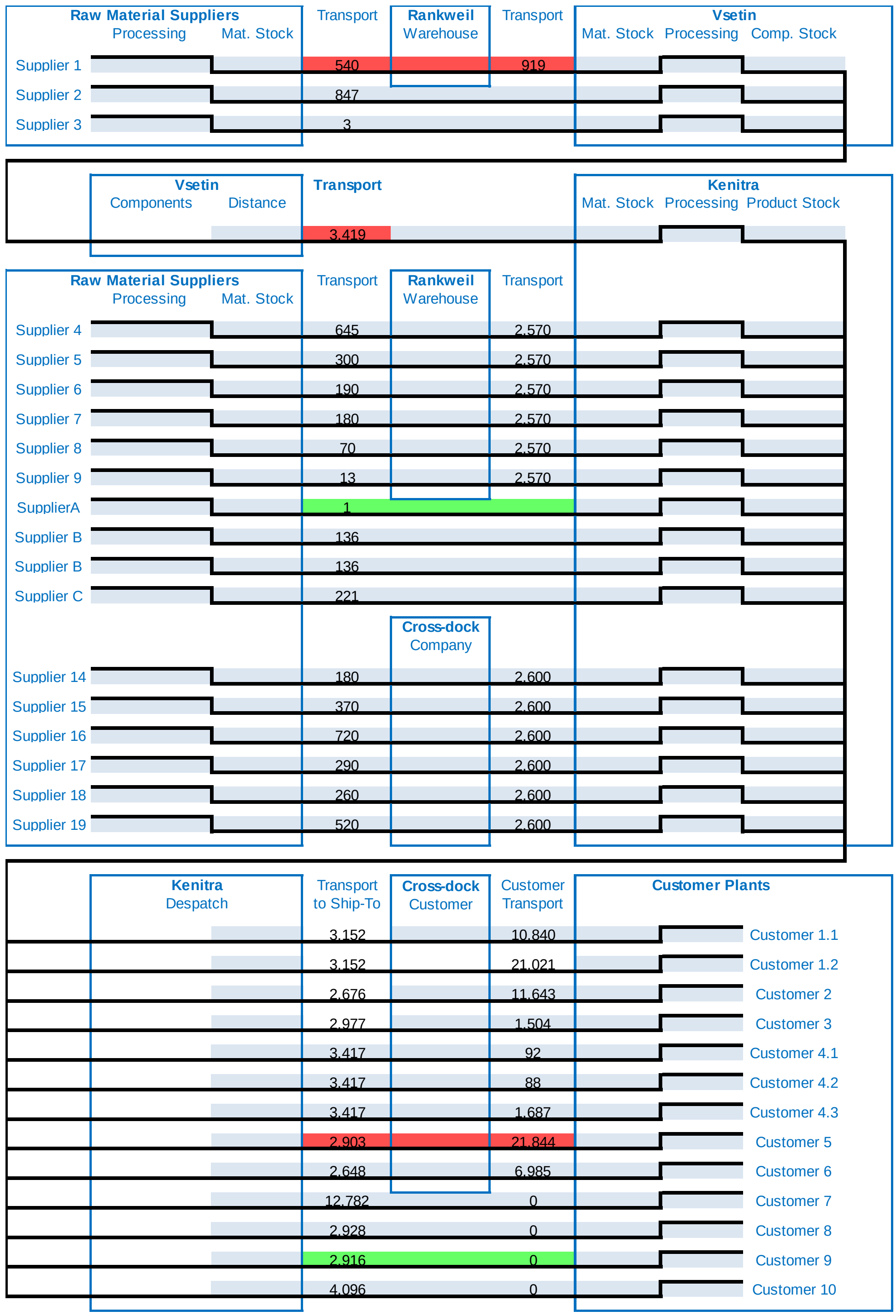
Vsetin: Components	Vsetin: Leadtime	Transport	Kenitra: Mat. Stock	Kenitra: Processing	Kenitra: Product Stock
	106	8	15	4	14

	Raw Material Suppliers: Processing	Raw Material Suppliers: Mat. Stock	Transport	Rankweil Warehouse / Cross-dock Company	Transport	Kenitra: Mat. Stock	Kenitra: Processing	Kenitra: Product Stock
Supplier 4	28	14	2	19	5	23	4	14
Supplier 5	7	0	1	19	5	23	4	14
Supplier 6	7	7	1	19	5	23	4	14
Supplier 7	7	0	1	19	5	23	4	14
Supplier 8	7	28	1	19	5	23	4	14
Supplier 9	35	0	1	19	5	23	4	14
Supplier A	21	7	1			10	4	14
Supplier B	14	42	1			3	4	14
Supplier B	14	42	1			3	4	14
Supplier C	14	14	1			10	4	14
				Cross-dock Company				
Supplier 14	77	56	1	1	5	18	4	14
Supplier 15	42	7	1	1	5	18	4	14
Supplier 16	42	7	2	1	5	18	4	14
Supplier 17	42	21	1	1	5	18	4	14
Supplier 18	112	14	1	1	5	18	4	14
Supplier 19	42	7	2	1	5	18	4	14

Kenitra Despatch	Transport to Ship-To	Cross-dock Customer	Customer Transport	Customer Plants
	5	1	35	Customer 1.1
	5	1	56	Customer 1.2
	5	1	42	Customer 2
	5	1	3	Customer 3
	9	1	1	Customer 4.1
	9	1	1	Customer 4.2
	9	1	1	Customer 4.3
	5	1	49	Customer 5
	5	1	21	Customer 6
	21	0	0	Customer 7
	5	0	0	Customer 8
	5	0	0	Customer 9
	10	0	0	Customer 10

Global Production Network Leadtime	MIN	MAX
Total Leadtime to Customer Ship-To Location	62	197
Total Leadtime to Customer Plant Location	62	238
Production Network Value Stream Leadtimes	MIN	MAX
Inbound Leadtime Suppliers to Production Plant	29	140
Production Plant Through-put Time	21	41
Outbound Leadtime to Customer Ship To Location	5	21
Customer Leadtime Customer Ship-To to to Customer Plant Location	0	57
Total Outbound Leadtime from Production Plant to Customer Plant Location	5	62

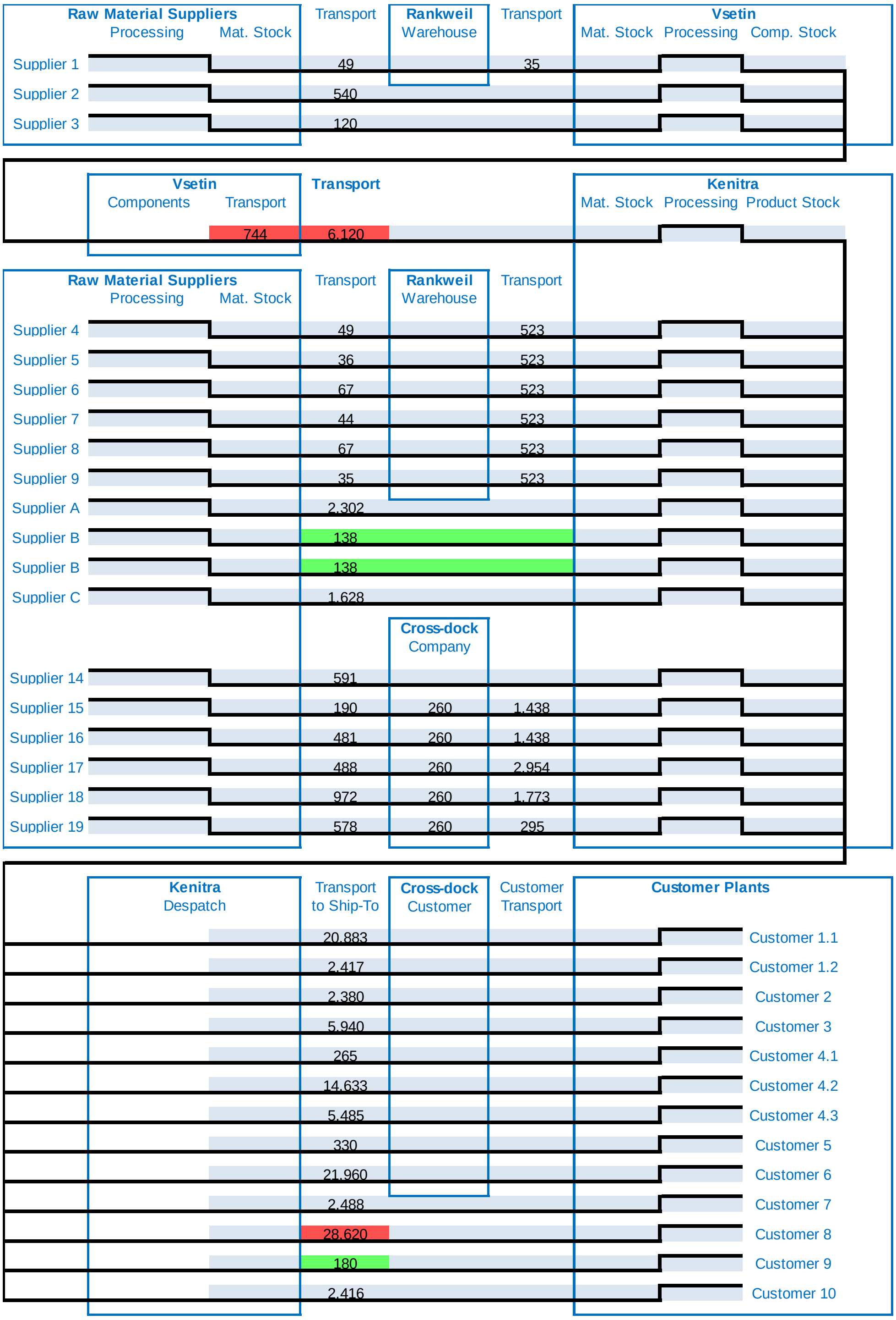
Appendix 9: Visualization and simulation optimized relocated state: tool: lead-time



Global Production Network Transportation Distance	MIN	MAX
Total Transport Distance Suppliers to Customer Ship-To Locations	2.649	17.660
Total Transport Distance Suppliers to Customer Plant Locations	2.917	29.625
Annual Production Network Transportation Kilometers to Customer Sip To Locations	1.562.514	km
Annual Total Production Network Transportation Kilometers to Customer Plants	3.858.923	km

Production Network Value Stream Transportation Distances	MIN	MAX
Inbound Transport Lane Distance Supplier to Production Plants	1	4.878
Outbound Transport Lane Distance Production Plant to Customer Ship-To Locations	2.648	12.782
Customer Transport Lane Distance Customer Ship-Tos to Customer Plant Locations	0	21.844
Annual Inbound Transportation Kilometers Suppliers to Production Plants	597.662	km
Annual Outbound Transportation Kilometers Production Plant to Customer Ship-To Locations	964.852	km
Annual Customer Transportation Kilometers Customer Ship-To to Customer Plant Locations	2.296.409	km

Appendix 10: Visualization and simulation optimized relocated state: transportation distances



Global Production Network Transportation Costs (€/ year)			
Total Transportation Costs Suppliers to Customer Ship-To Locations	134.999	159.251	200.842
Total Transportation Costs / Product (Suppliers to Customer Ship-To Locations)	0,0374	0,0374	0,0374
Production Network Value Stream Transportation Costs (€/ year)			
Inbound Transportation Costs Suppliers to Production Plants	27.001	31.852	40.170
Outbound Transportation Costs Production Plant to Customer Ship-To Loc.	107.998	127.399	160.672

Appendix 11: Visualization and simulation optimized relocated state: transportation costs

Raw Material Suppliers	Processing	Mat. Stock	Transport	Rankweil Warehouse	Transport	Vsetin Mat. Stock	Vsetin Processing	Vsetin Comp. Stock
Supplier 1	0,05	0,28	0,00	0,12	0,01	0,06	0,04	
Supplier 2	168,48	56,16	2,78			72,21	48,14	
Supplier 3	1,36	0,54	0,02			0,85	0,47	996,30

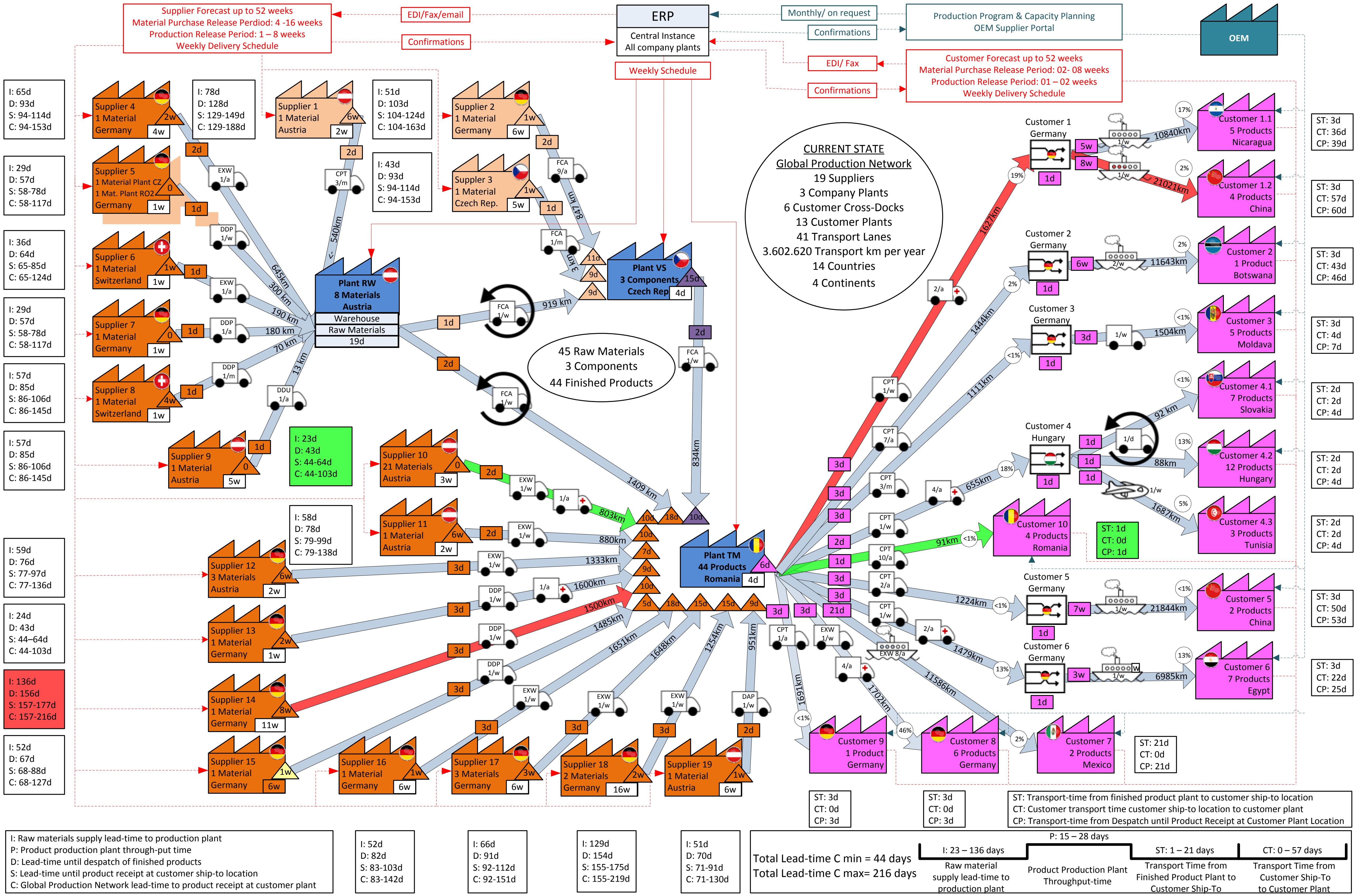
Vsetin Components	Transport	Kenitra Mat. Stock	Kenitra Processing	Kenitra Product Stock
	531,36	996,30	398,52	

Raw Material Suppliers	Processing	Mat. Stock	Transport	Rankweil Warehouse / Cross-dock Company	Transport	Kenitra Mat. Stock	Kenitra Processing	Kenitra Product Stock
Supplier 4	0,91	0,91	0,00	1,24	0,01	1,50	0,39	
Supplier 5	3,01	0,00	0,03	16,36	0,08	19,81	0,10	
Supplier 6	0,06	0,12	0,00	0,33	0,00	0,39	1,00	
Supplier 7	0,74	0,00	0,00	4,02	0,02	4,87	0,04	
Supplier 8	0,58	4,65	0,00	3,16	0,08	3,82	48,14	
Supplier 9	19,62	0,00	0,02	21,30	0,04	25,78	7,71	
Supplier A	1589,47	1059,65	151,38			1513,78	908,27	
Supplier B	4,79	28,74	0,34			2,05	4,11	
Supplier B	3,85	23,11	0,28			1,65	3,30	
Supplier C	55,03	110,05	7,86			78,61	47,17	
				Cross-dock Company				
Supplier 14	2647,90	3851,49	68,78	68,78	343,88	1237,98	412,66	
Supplier 15	118,49	39,50	5,64	5,64	28,21	101,56	33,85	
Supplier 16	198,86	66,29	18,94	9,47	47,35	170,45	56,82	
Supplier 17	1538,38	1538,38	73,26	73,26	366,28	1318,61	439,54	
Supplier 18	1791,65	447,91	31,99	31,99	159,97	575,89	191,96	
Supplier 19	468,71	156,24	44,64	22,32	111,60	401,75	133,92	16598,16

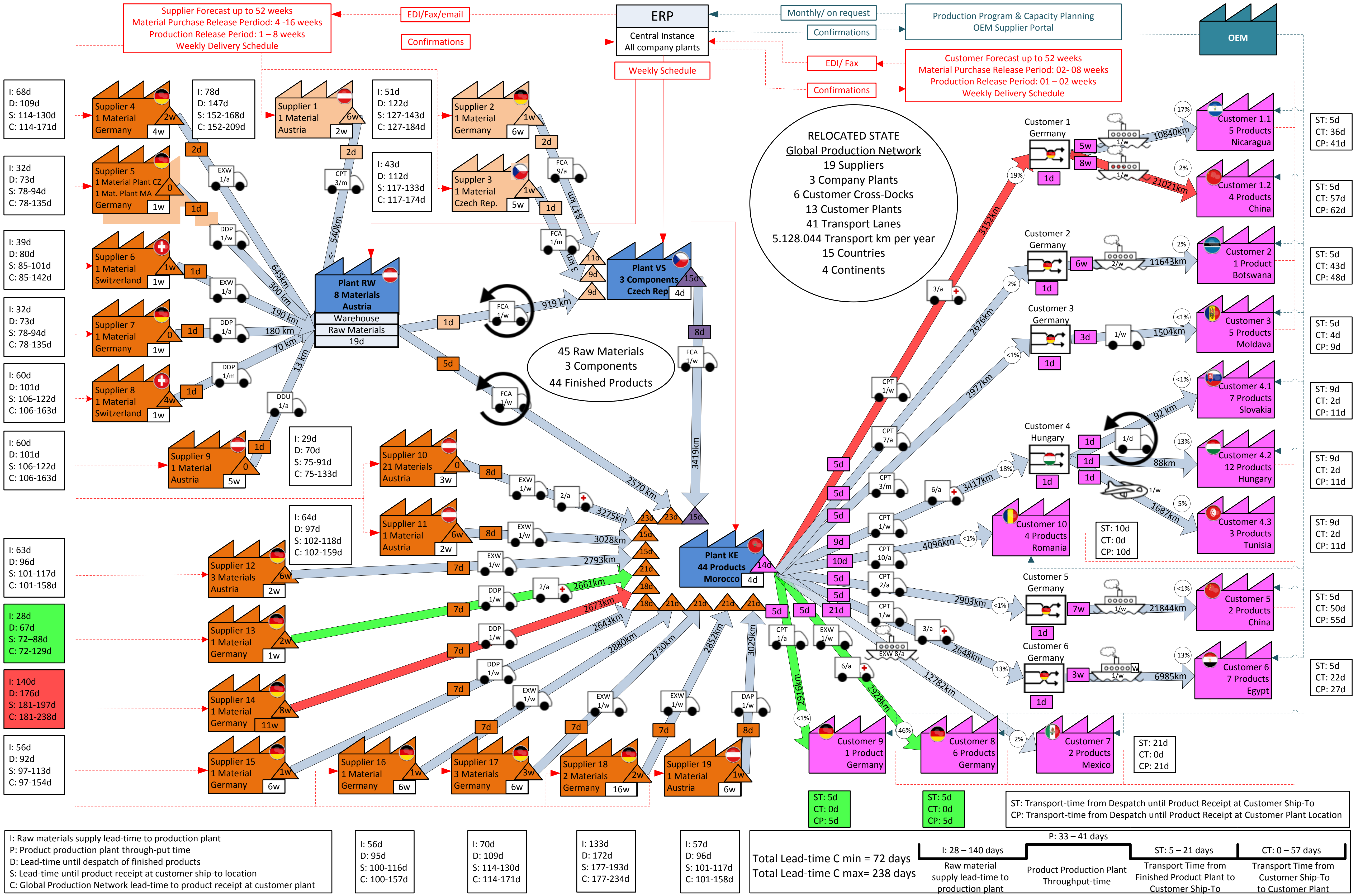
Kenitra Despatch	Transport to Ship-To	Cross-dock Customer	Customer Transport	Customer Plants
	988,54	197,71	6919,80	Customer 1.1
	114,43	22,89	1281,60	Customer 1.2
	17,90	3,58	150,33	Customer 2
	30,92	6,18	18,55	Customer 3
	24,84	2,76	2,76	Customer 4.1
	1370,21	152,25	152,25	Customer 4.2
	513,62	57,07	57,07	Customer 4.3
	0,06	0,01	0,61	Customer 5
	745,63	149,13	3131,64	Customer 6
	72,50	0,00	0,00	Customer 7
	2707,29	0,00	0,00	Customer 8
	0,39	0,00	0,00	Customer 9
	6,82	0,00	0,00	Customer 10

Global Production Network Inventory Costs (€/ year)	2014	2015	2016
Inventory Costs Total Production Network Suppliers to Customer Plants	63.763	72.962	89.256
Inventory Costs Total Production Network Suppliers to Customer Ship-To Locations	51.457	58.880	72.030
Inventory Costs/ Product (Suppliers to Customer Ship-To Locations)	0,0143	0,0138	0,0134
Production Network Value Streams Inventory Costs (€/ year)	2014	2015	2106
Inventory Costs Suppliers	15.996	18.303	22.391
Inventory Costs Raw Material Stock in Transit to Production Plants	1.963	2.246	2.748
Inventory Costs Company Production Plants and Warehouses	26.905	30.786	37.662
Inventory Costs Finished Product Stock in Transit to Customer Ship-To Locations	6.593	7.544	9.229
Customer Inventory Costs Finished Products Stock in Transit to Customer Plants	12.306	14.081	17.226

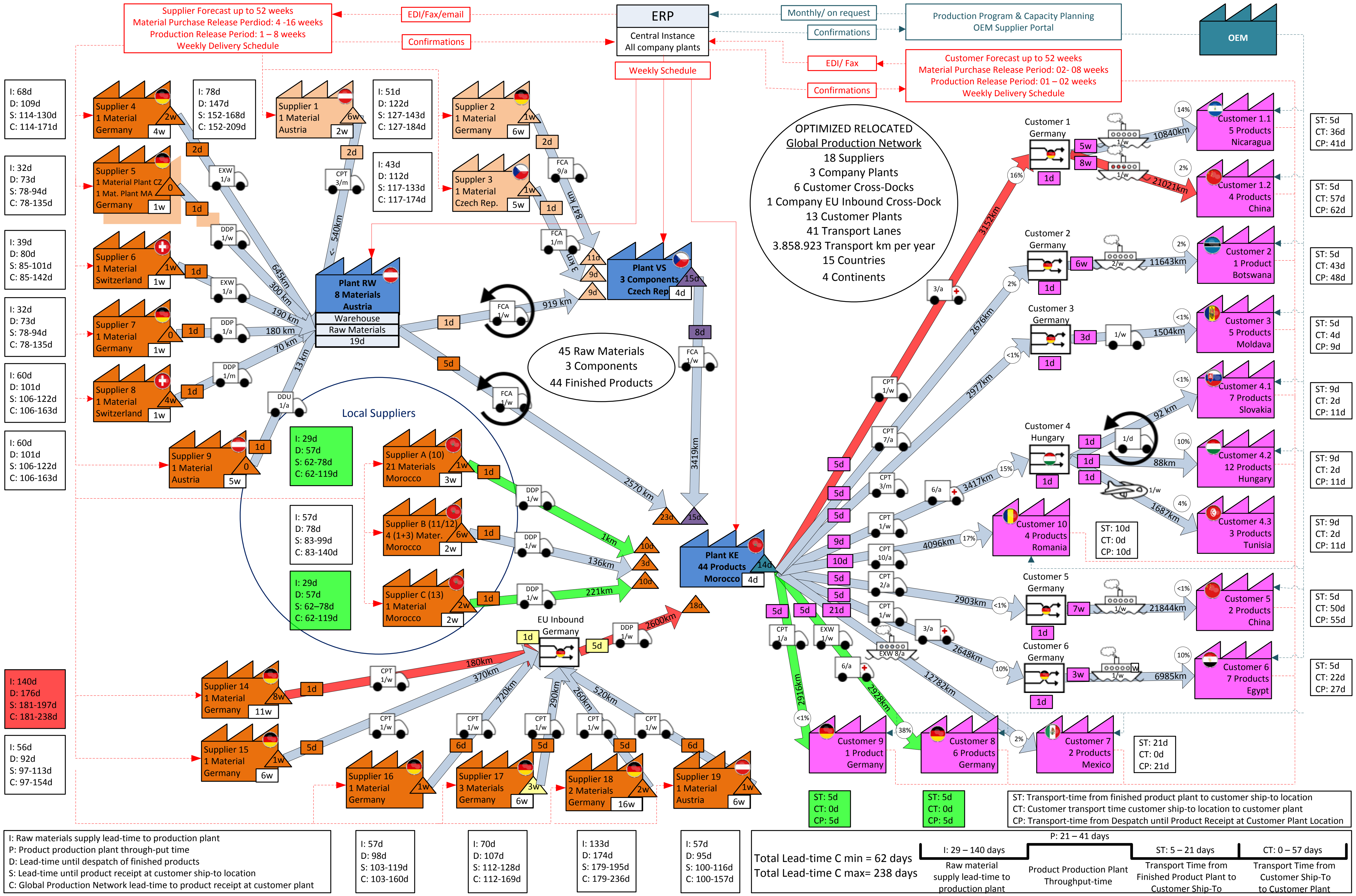
Appendix 12: Visualization and simulation optimized relocated state: inventory costs



Appendix 13: Global Production Relocation Map - current state



Appendix 14: Global Production Relocation Map - relocated state



Appendix 15: Global Production Relocation Map - optimized relocated state