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Evaluation of Supply Chain Configurations using Modeling and Simulation

Quantification of Risks in uncertain Environments

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Graz, September 2016

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Abstract

Over the last years Supply Chains (SCs) are subject to major changes. They developed from classical intra-SCs to inter-SCs and further to flexible and more complex SC-networks. Because of globally distributed SC networks, dynamic environments and increasing customer expectations managers are faced with new challenges.

Supply Chain Management (SCM) developed from logistics and is the most recent progress of logistical concepts. While logistics is related to the flow of goods and information, SCM further contains the planning and management of activities along the entire SC. The increasing complexity of SCs results in a new dimension of risks (variable, uncertain, global), that has to be considered and managed. Hence, managers are required to assess these new risks and make decisions in a very complex and dynamic environment. Therefore, methods and tools are needed to support managers in evaluating scenarios and decision making. Modeling and simulation are often used for latter purposes as they are techniques to model and investigate problems. Especially they are used to improve the problem understanding, test and compare different scenarios and make what-if analyses without influencing the real world.

This thesis has been done in cooperation with the business partner Logicdata (LD). It deals with the investigation of possibilities to apply modeling and simulation to evaluate different SC configurations. The focus is on the evaluation of risks along the SC, considering the set up of new SC configurations. The intended configurations include new geographical regions and therefore, special attention has been given to risks related to countries. Appropriate risk indicators have been identified and discussed. Furthermore, a value stream analysis has been carried out to investigate the value and mass streams on both sides: purchasing and sales. Moreover, the existing SC of LD has been studied by means of a questionnaire. The determined information provide a good basis for further simulation work.

Kurzfassung

In den letzten Jahren sind Supply Chains (SCs) großen Veränderungen unterworfen. Aus klassischen intra-SCs entwickelten sich inter-SCs und schließlich flexible und komplexe SC Netzwerke. Aufgrund global verteilter SC Netzwerken, dynamischer Umgebungen und steigender Kundenerwartungen sehen sich Manager mit neuen Herausforderungen konfrontiert.

SCM entwickelte sich aus der Logistik und ist die jüngste Entwicklung im Bereich der Logistikkonzepte. Während sich die Logistik mit dem Waren- und Informationsfluss beschäftigt, beinhaltet SCM die Planung und Steuerung von Aktivitäten entlang der gesamten SC. Die zunehmende Komplexität der SCs führt zu einer neuen Dimension von Risiken (variabel, unsicher, global), die berücksichtigt und gemanagt werden müssen. Das Management ist gefordert, diese neuen Risiken zu bewerten und Entscheidungen in einem sehr komplexen und dynamischen Umfeld zu treffen. Daher werden Methoden und Werkzeuge benötigt, die die Entscheidungsträger bei der Bewertung von Szenarien und im Prozess der Entscheidungsfindung unterstützen. Modellierung und Simulation werden häufig für letztere Problemstellungen verwendet, da sie oft zur Modellierung und Untersuchung von Problemen angewendet werden. Diese Techniken werden verwendet um das Problemverständnis zu erhöhen, verschiedene Szenarien zu testen und zu vergleichen und Wenn-Analysen durchzuführen, jedoch ohne die reale Welt zu beeinflussen.

Diese Arbeit wurde in Zusammenarbeit mit dem Geschäftspartner Logicdata (LD) durchgeführt. Sie untersucht Anwendungsmöglichkeiten der Modellierung und Simulation zur Bewertung von unterschiedlichen SC Konfigurationen. Der Schwerpunkt der Arbeit liegt auf der Risikobewertung entlang der SC, vor allem im Hinblick auf neue SC Konfigurationen und neue geografische Regionen. Deshalb wurde besonderes Augenmerk auf Länderrisiken gelegt. Es wurden entsprechende Risikoindikatoren identifiziert und diskutiert. Darüber hinaus wurde eine Wertstromanalyse durchgeführt, um Wert- und Massenströme sowohl auf der Einkaufs- als auch der Vertriebsseite zu untersuchen. Außerdem wurde die bestehende SC von LD mittels eines Fragebogens untersucht. Die gewonnenen Informationen und Daten bilden eine gute Grundlage zur Umsetzung in einer Computersimulation.

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Abbreviations

In general

AB	Agent-based Simulation
APICS	American Production and Inventory Control Society
BOM	Bill of Material
CLM	Council of Logistics Management
CSCMP	Council of Supply Chain Management Professional
CSR	Corporate Social Responsibility
DES	Discrete-Event Simulation
DL	Deutschlandsberg
DOE	Design of Experiments
e.g.	for example
EMS	Electronic Manufacturing Services
ERM	Entity-Relationship-Model
ERP	Enterprise Resource Planning
ETO	Engineer-to-Order
EUR	Euro
GDP	Gross Domestic Product
GPSS	General Purpose Simulation System
GSCF	Global Supply Chain Forum
HCCM	Hierarchical Control Conceptual Modeling
ID	Identifier
LD	Logicdata
LD DL	Logicdata Deutschlandsberg
LD NA	Logicdata North America
LSCM	Logistics and Supply Chain Management

MRO	Maintenance, Repair and Overhaul
MTO	Make-to-Order
MTS	Make-to-Stock
NA	North America
NDA	Non-disclosure Agreement
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PCBA	PCB assembled
pcs	pieces
R&D	Research & Development
RMP	Risk Management Process
SC	Supply Chain
SCC	Supply-Chain Council
SCM	Supply Chain Management
SCO	Supply Chain Orientation
SCOR	Supply Chain Operations Reference
SCRM	Supply Chain Risk Management
SCRMP	Supply Chain Risk Management Process
SD	System Dynamics
SPI	Social Progress Index
SQL	Standard Query Language
TCO	Total Cost of Ownership
VDI	Verein Deutscher Ingenieure
WIP	Work in Progress
WRI	World Risk Index

Country codes

AT	Austria
AU	Australia
CH	Switzerland
CN	China
CZ	Czech Republic
DE	Germany
DK	Denmark
HK	Hong Kong
HU	Hungary
IT	Italy
KR	South Korea
LT	Lithuania
NL	Netherlands
PL	Poland
SE	Sweden
SK	Slovakia
TW	Taiwan
US	United States of America

1 Introduction

Today supply chains are more and more globally situated and therefore companies are confronted with the arising complexity, and also the associated risks. Managers are required to make decisions in a dynamic and not-clear environment. To set up a new supply chain or to change a supply chain is not a simple and transparent task and therefore possibilities are needed to support the decision making process and to provide a solid basis on which decisions can be taken with confidence.

Based on 'logistics', SCM is quite young, as the term was established in the early 1980s. (Douglas M Lambert and Cooper, 2000) The issue 'logistics' is relatively well known in research and industry and means mainly the transport of goods. The term 'logistics' dates back to early stages and was mentioned in context with military applications. SCM sometime is treated as a synonym for logistics, but this is not accurate. SCM includes more than the transport *of goods, services and information*, it includes also information technology, cash flows and tasks which are related to adjusting and aligning activities between the different SC partners. Thus, various factors influencing the system exist together with many boundary conditions. (Lummus, Krumwiede, and Vokurka, 2001)

Compared to a domestic supply chain, a global supply chain implicates other issues, as for instance currency risks, transport modes and times. A big intention of this thesis was to investigate matters related specially to countries. This means to point out the differences between sourcing in China and Mexico, for example, on a high level. For that reason specially the methods of modeling and simulation were investigated. Primarily the question in which way these methods can provide information in a proper manner and how does a company benefit from using these methods was considered.

Using simulation methods like DES is already common to the electronic and automotive industry, especially to large-size companies. (Semini and Strandhagen, 2006) In opposition to this large-size companies the business partner, with whom this thesis was developed, is a medium-size company, active in the field of micro-controller-based control units and operating elements for ergonomic solutions for the furniture industry. The business partner LD is already acting worldwide with main sales markets in Europe and the United States of America (US). As the company is growing strongly and developing new markets, questions regarding optimizing supply chains and, most notably, regarding setting up new supply chains to improve the distribution in new markets arose. Hence, special attention was given to highlight the chances for medium-sized companies by using these methods.

Understanding the existing system and identifying the influencing key indicators has been focused first. For that reason, a value stream analysis of the purchasing and sales volumes has been done for the overall product portfolio and after that for one reference product. This reference product has only a small share in the product portfolio yet, but the company is pushing it and the sales figures will increase in the next years significantly. The growing sales numbers for this young product raise the question if it is reasonable to look for SC partners in new countries. Therefore, it is an important intention of this thesis to develop a framework for identifying and illustrating risks related to countries. Appropriate indicators are identified to measure the different risks. Possibilities to use simulation for evaluating new SC settings are discussed. Because of that a brief review is given on the simulation paradigms SD, Discrete-Event Simulation (DES), AB and Monte Carlo simulation as well as some prospects for using them.

2 Supply Chain Management (SCM)

Particular attention has been paid to SCM in the last decades. In the early 1980s the term was established first, around ten years later academics started to develop frameworks for it. Not long ago there was no clear distinction between 'logistics' and 'SCM' for most experts in applied sciences and researchers. (Douglas M Lambert and Cooper, 2000) Therefore, this chapter begins by clarifying the terms Supply Chain and SCM in the following section, how they are understood and used in this thesis. Next the framework Supply Chain Operations Reference (SCOR) is introduced. It continues with a brief review of Supply Chain Decision Processes. Finally the issue of risks in the supply chain context is discussed.

Prior to that, the historical development of logistics will be reviewed briefly. As figure 2.1 shows, the development of logistics started with an instrumental approach, meanwhile SCM can be found on the right upper end, which means already phase five in the development process and reaches the highest achievement of objectives. In previous phases the company level was focused, with SCM this changed and the focus shifted to the level of a 'jointly operated network'. For a single enterprise it is not important anymore to be able to handle a whole value chain process by themselves, it is more a question of a fast and successful coordination and cooperation of various companies. Consequently inter-organizational aspects become more crucial. (Beckmann, 2012)

2.1 Definition

As mentioned previously, there was no common definition and understanding of SCM, therefore it is necessary to define the term as used and understood in this thesis. Before that, it is essential to clarify the term 'supply chain' first. John T. Mentzer et al. (2001, p. 3-5) showed that there is a more common understanding in using and defining the term 'supply chain', compared to SCM. A supply chain consists of several parties, who are linked together up- and

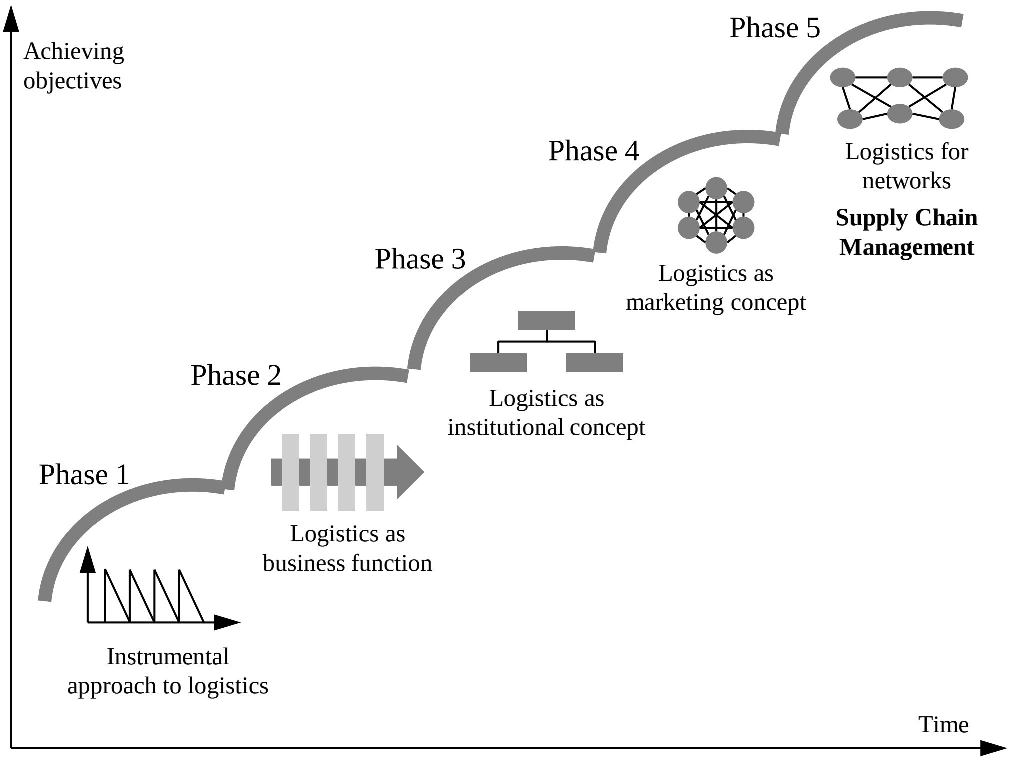

Figure 2.1: Development of logistics, (Beckmann, 2012, p. 5)

downstream in a value chain process in order to create a product. The supply chain reaches from raw material (source) to the end customer (sink).

The Council of Supply Chain Management Professional (CSCMP), former the Council of Logistics Management (CLM), defines supply chain as follows (Vitasek, 2013):

> *1) starting with unprocessed raw materials and ending with the final customer using the finished goods, the supply chain links many companies together. 2) the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers and customers are links in the supply chain.*

In this thesis the definition of John T. Mentzer et al. (2001, p. 4) is used:

> *Supply chain is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.*

John T. Mentzer et al. (2001) distinguishes three levels of complexity of supply chains, as shown in figure 2.2:

- a direct supply chain
- an extended supply chain
- an ultimate supply chain

The 'direct supply chain' can be seen as basic type, where the organization is connected on the one side (downstream) with a supplier and on the other side (upstream) with the customer. The next configuration level 'extended supply chain' considers suppliers and customers not only to tier one, but also to tier two. This means that downstream the supplier's supplier and upstream the customer's customer are included in the *flow of products, services, finances and/or information.* (John T. Mentzer et al., 2001, p. 3-5)
The third level 'ultimate supply chain' is characterized by outsourcing supporting functions of the supply chain, as for example the logistic activities between two entities to a third party logistics supplier. Or for instance, by extending functions not only to the next tier, that is to say engaging a market research firm to gather information of the end customer for an entity at least two tiers down the supply chain. (John T. Mentzer et al., 2001, p. 3-5)

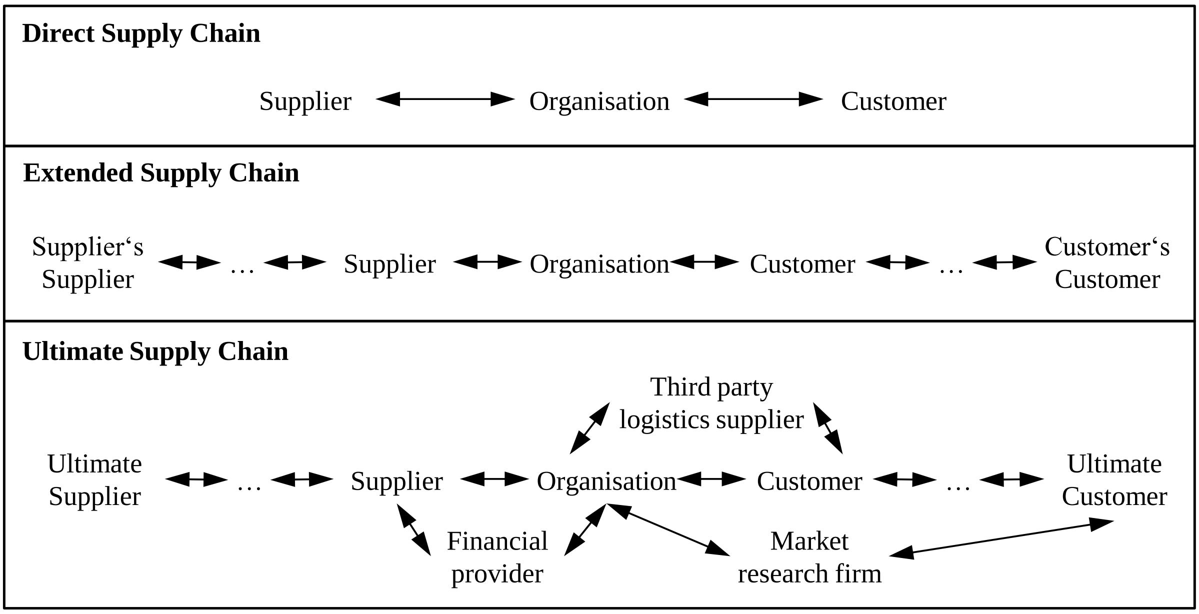

Figure 2.2: Types of channels relationships, (John T. Mentzer et al., 2001, p. 5)

Further more John T. Mentzer et al. (2001) pointed out that a supply chain exists independently of the fact if the company did or did not implement a concept to manage the supply chain - the supply chain simply exists at least as a *phenomenon of business*. A member of a supply chain can also be part of other supply chains, which may often be the case. If the supply chain does not only exist, but the entities obviously put effort in managing it, it leads to the next term, which has to be defined, to 'Supply Chain Management (SCM)'.

In search of a definition of 'SCM' it can be noticed that many authors have used SCM in different ways and consequently there is no common meaning neither in research nor in practice. Besides the age of the discipline has to be mentioned as the term 'SCM' was first used in the early 1980s and so this discipline is pretty young. Moreover the distinction between logistics and SCM makes difficulties, as stated earlier. (John T. Mentzer et al., 2001; Douglas M Lambert and Cooper, 2000; Lummus, Krumwiede, and Vokurka, 2001; Gibson, John T Mentzer, and Cook, 2005)

For instance, the Global Supply Chain Forum (GSCF), a circle of senior executives in industry and researchers, defined SCM as follows:

> *Supply Chain Management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders.* (Douglas M Lambert and Cooper, 2000, p.66)

John T. Mentzer et al. (2001) reviewed the literature and found out that the various definitions of SCM can be grouped into three classes, which are illustrated in figure 2.3: a management philosophy, implementation of a management philosophy and a set of management processes.

'SCM as a Management Philosophy' deals with the SC as a common object and not as separate objects. It intensifies the idea of cooperation between companies, this means it is about a common performance of all supply chain partners influencing each other. All abilities of the own company and between the various partners should be harmonized to optimize the result which ends in maximizing the customer value. In short, 'SCM as a Management Philosophy' forces the entities to put the customer in the center of attention. The authors introduced a new, more precise term for this class - Supply Chain Orientation (SCO). (John T. Mentzer et al., 2001)

> *Supply Chain Orientation is defined as the recognition by an organization of the systemic, strategic implications of the tactical activities involved in managing the various flows in a supply chain.* (John T. Mentzer et al., 2001, p.11)

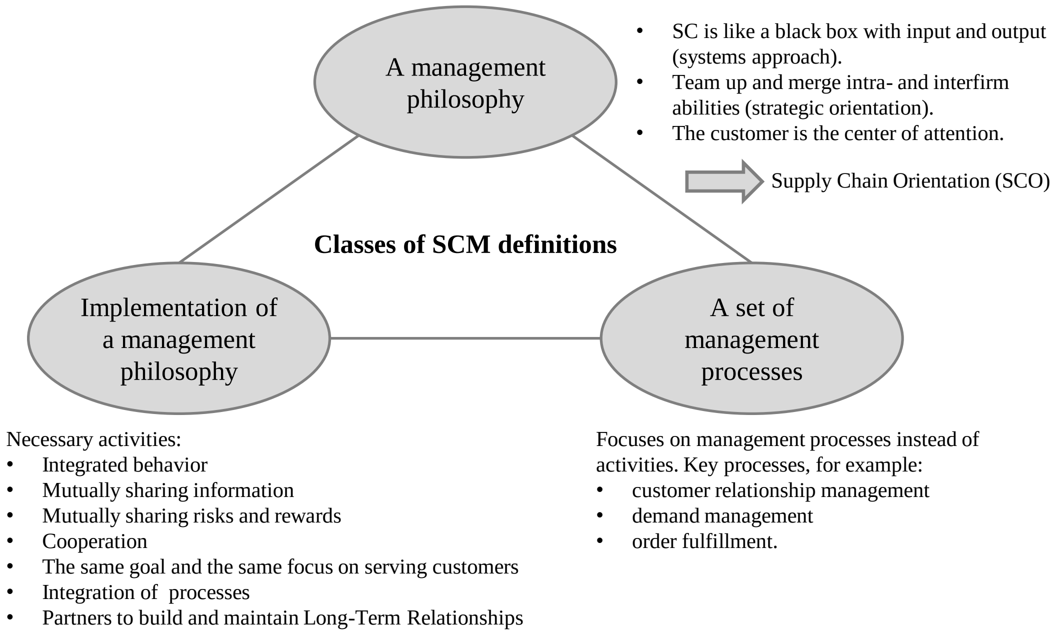

Figure 2.3: Classes of SCM definitions, based on John T. Mentzer et al. (2001)

To have a SCO as a company, it is necessary to look in both directions, up- and downstream, to recognize the effects in only one direction is too weak. The implementation of SCM requires that the involved companies have already a SCO as a precondition. SCM is characterized by working together along the SC and executing the activities mentioned below. (John T. Mentzer et al., 2001) Following John T. Mentzer et al. (2001, p.11) *. . . SCO is a management philosophy, and SCM is the sum total of all the overt management actions undertaken to realize that philosophy.*

'SCM as a Set of Activities to Implement a Management Philosophy' describes guidelines by the management how to put the SCM philosophy into practice. Therefore, the necessary activities can be seen in figure 2.3 and are subsequently briefly described. 'Integrated behavior' means to broaden the company's own behavior and include the SC partners, which comes directly to 'mutually sharing information' between the SC members, for example provide forecasts and inventory levels to improve information flow and predictability. For long-term relationships 'mutually sharing risks and rewards' is essential. 'Cooperation' applies to common activities along the entire SC with the aim of reducing costs and increasing efficiency. 'The same goal and the same focus on serving customers' *is a form of policy integration*. Cultural matching and a common understanding of management approaches are important for a successful integration. 'Integration of processes' along the SC is needed and can be achieved for example by cross-functional teams. (John T. Mentzer et al., 2001)

By contrast 'SCM as a Set of Management Processes' focuses on management processes instead of activities. A process can be seen as a clearly defined set of tasks in a certain sequence with the following attributes: time, place, start point, end point, input, output and an activity plan. (John T. Mentzer et al., 2001)

In figure 2.4 the conceptual model developed by John T. Mentzer et al. (2001) based on their study is illustrated. It shows the relation between the different business functions and their intra- and interfirm coordination. The model can be used as a guideline for practitioners.

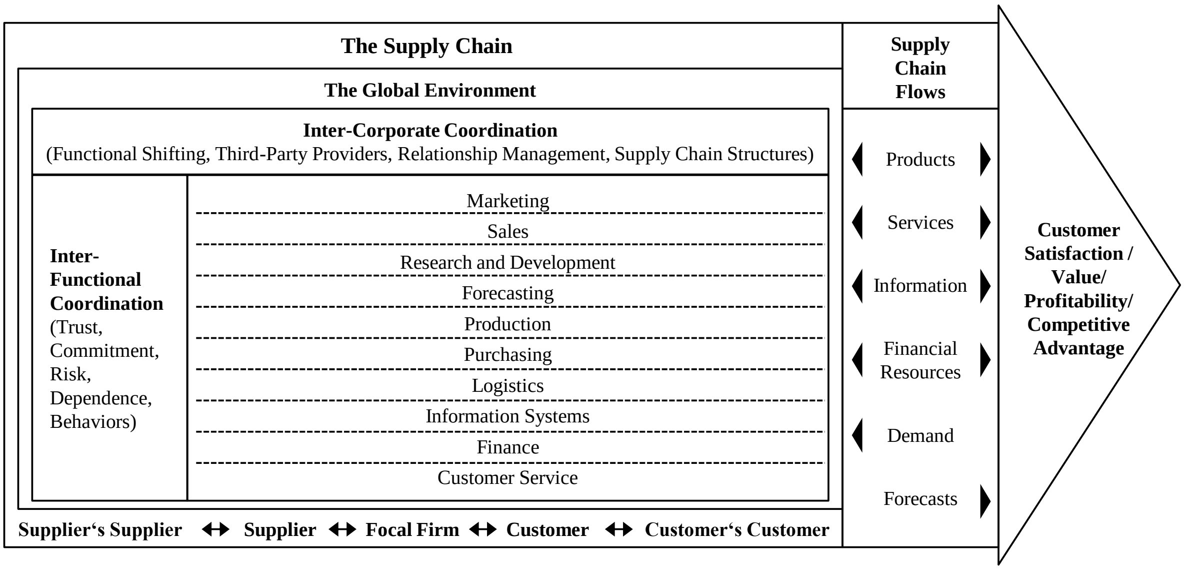

Figure 2.4: A model of SCM (John T. Mentzer et al., 2001, p.19)

Another study by Gibson, John T Mentzer, and Cook (2005) refers to a survey the CSCMP made across its members to find out their view of SCM. One of the major insights was, that more than two-thirds of the respondents are convinced that *SCM involves both strategy and activity*. Another major insight was that collaboration and information technology are the most important activities associated with SCM, beside of marketing, finance, sales and product design.

The present definition of SCM by the CSCMP reads as follows (Vitasek, 2013):

> *Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence,*

management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology.

A shorter and plain definition is made by D. Simchi-Levi, Kaminsky, and E. Simchi-Levi (2003, p. 1) and referred to in this thesis:

Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements.

Based on this definition, the SC network is shown in figure 2.5.

Finally, the difference between logistics and SCM has to be clarified. Often the terms of logistics and SCM were used synonymous. Lummus, Krumwiede, and Vokurka (2001) found out in a survey among materials management professionals that *definitions of logistics essentially discuss the physical flow of materials*. The logistical flow is part of the SCM. This viewpoint is shared by the CSCMP, who defines logistic management as:

"Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution-strategic, operational, and tactical. Logistics management is an integrating function which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology.

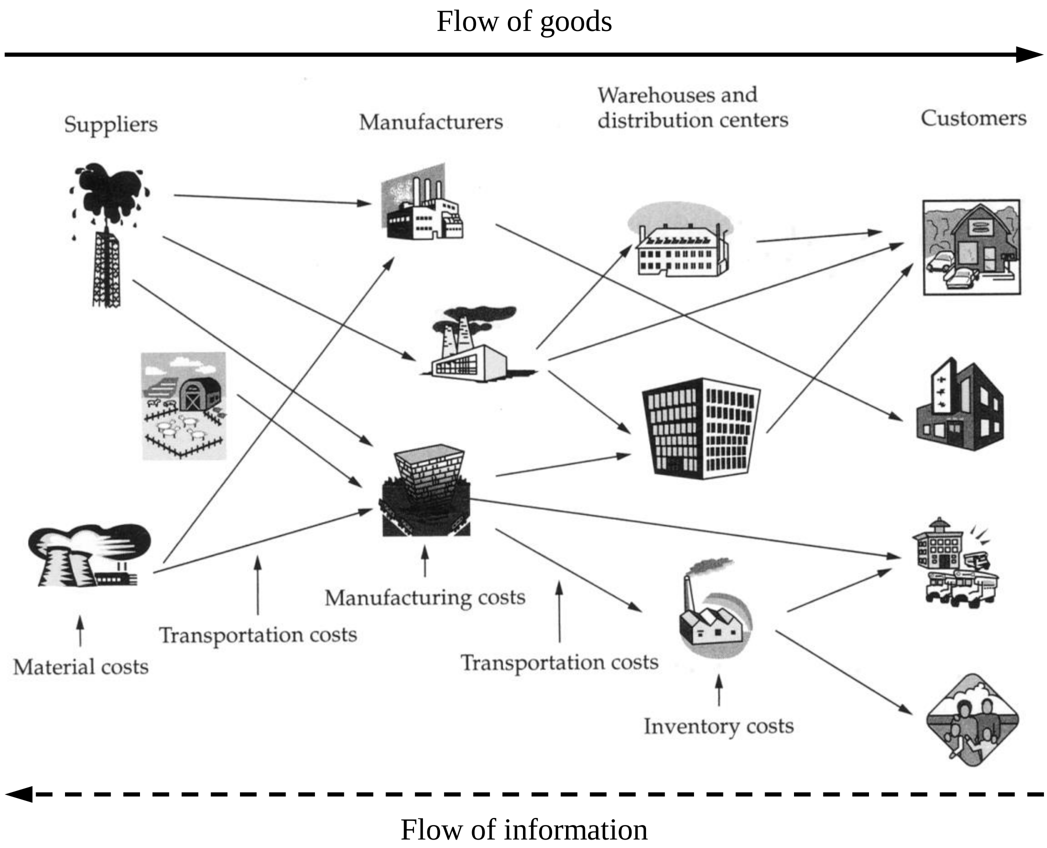

Figure 2.5: Logistics Network, based on D. Simchi-Levi, Kaminsky, and E. Simchi-Levi, 2003

After defining the terms 'SC', 'Supply Chain Management' and 'Logistics' a framework for SCM will be introduced in the next section.

2.2 Operations Reference Model (SCOR)

The Supply Chain Operations Reference, short SCOR, was first released in 1997 by the Supply-Chain Council (SCC), who was founded in 1996 in the USA. SCC was an non-profit initiative set up by Pittiglio Rabin Todd & McGrath (PRTM) and AMR Research. In 2014 SCC merged with American Production and Inventory Control Society (APICS) and is now called APICS SCC. By now, the last and 11th version of SCOR was released in 2012. (Stewart, 1997; APICS Supply Chain Council, 2016)

SCOR is a process reference model, also referred to as a framework to endorse supply-chain activities and processes independently from the certain industry. The intention of SCC to create a framework was to support a common understanding of terms within SCM and enable comparable and evaluable business processes by standardizing. SCOR defines a set of metrics and allows companies to evaluate their current business performance and subsequently to compare it with benchmarks and best-practices. (D. Simchi-Levi, Kaminsky, and E. Simchi-Levi, 2003; Stewart, 1997; Beckmann, 2012; Huan, Sheoran, and Wang, 2004; Douglas M. Lambert, García-Dastugue, and Croxton, 2005)

At first, SCOR described four processes, related to level one, but in the meantime SCOR was further developed and extended to six processes, which are listed in table 4.7. The initial four processes are marked with (*). Figure 2.6 illustrates a SC based on the SCOR model. (Douglas M. Lambert, García-Dastugue, and Croxton, 2005; APICS Supply Chain Council, 2016)

Table 2.1: SCOR Processes, (Douglas M. Lambert, García-Dastugue, and Croxton, 2005; Werner, 2013)

Process	**Description**
Plan (*)	plan demand and supply, evaluate resources and capacities
Source (*)	activities linked to purchasing, to the supplier-side, ensure to meet the required demand
Make (*)	transform raw material and semi-finished products into end-products, value adding activities
Deliver (*)	activities linked to sale, to the customer-side, ensure to meet the required demand
Return	is about returning products to suppliers or get products back from customers
Enable	new process, introduced with version 11, was before a level two process

SCOR consists of four levels, although level four is not directly included in the scope as it is the most detailed level and depends on the specifics of the respective business. It is a hierarchical model, it is top-down and detail increases with the level. An overview of the levels is given in figure 2.7. If a company implements SCOR, it is important to implement all four levels. Then it allows an easy configuration of the internal and external SC and improves the entire SC performance. The individual processes can be supported by software products, which refer to the standardized SCOR processes. (Stewart, 1997; Douglas M. Lambert, García-Dastugue, and Croxton, 2005)

As mentioned before there are metrics defined in SCOR to ease companies to compare their SC performance, respectively their figures with benchmarks and best-in-class data. More than 250

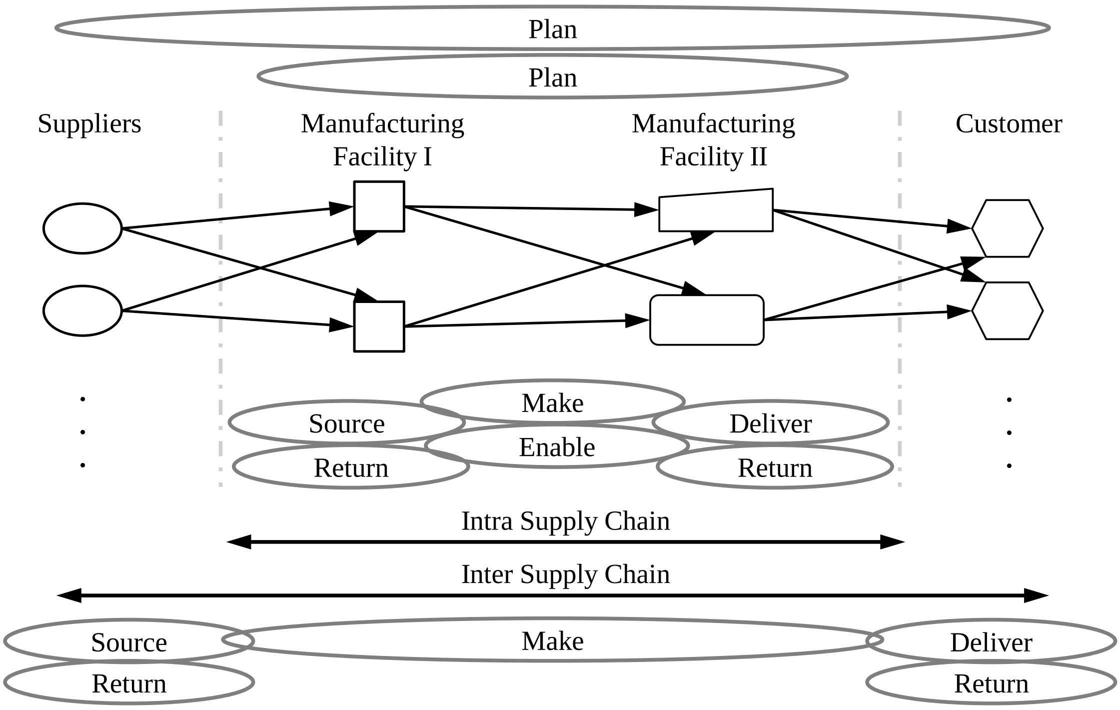

Figure 2.6: SCOR model-based SC, based on (Huan, Sheoran, and Wang, 2004)

metrics are defined for level one to level three, which are classified in five performance attributes: Reliability, Responsiveness, Agility, Costs and Asset Management Efficiency. Reliability is about the stability of processes, Responsiveness refers to speed, Agility means the capability to cope with changes caused by external factors, Costs correspond more or less to production costs and Asset Management Efficiency is about handling of assets. The metrics of level one are shown in table 2.2. (APICS Supply Chain Council, 2016)

Top-down from level one in the SCOR-model is level two. There the key processes of level one are split up into 30 process categories, which describe the key processes in more detail. These process categories form a kind of SCOR-Toolbox, where you can find on the horizontal axis the processes Plan, Source, Make, Deliver and Return and on the vertical axis the process types Planning, Execution and Infrastructure. The toolbox serves as a configuration toolbox and is illustrated in figure 2.8. (Werner, 2013; Beckmann, 2012)

Although, SCOR has strength and weaknesses, as most theoretical frameworks. An advantage is the common language and the cross-industry standardization. Furthermore, a plus for companies is that it is a possibility to reflect on their own existing processes, find out quick

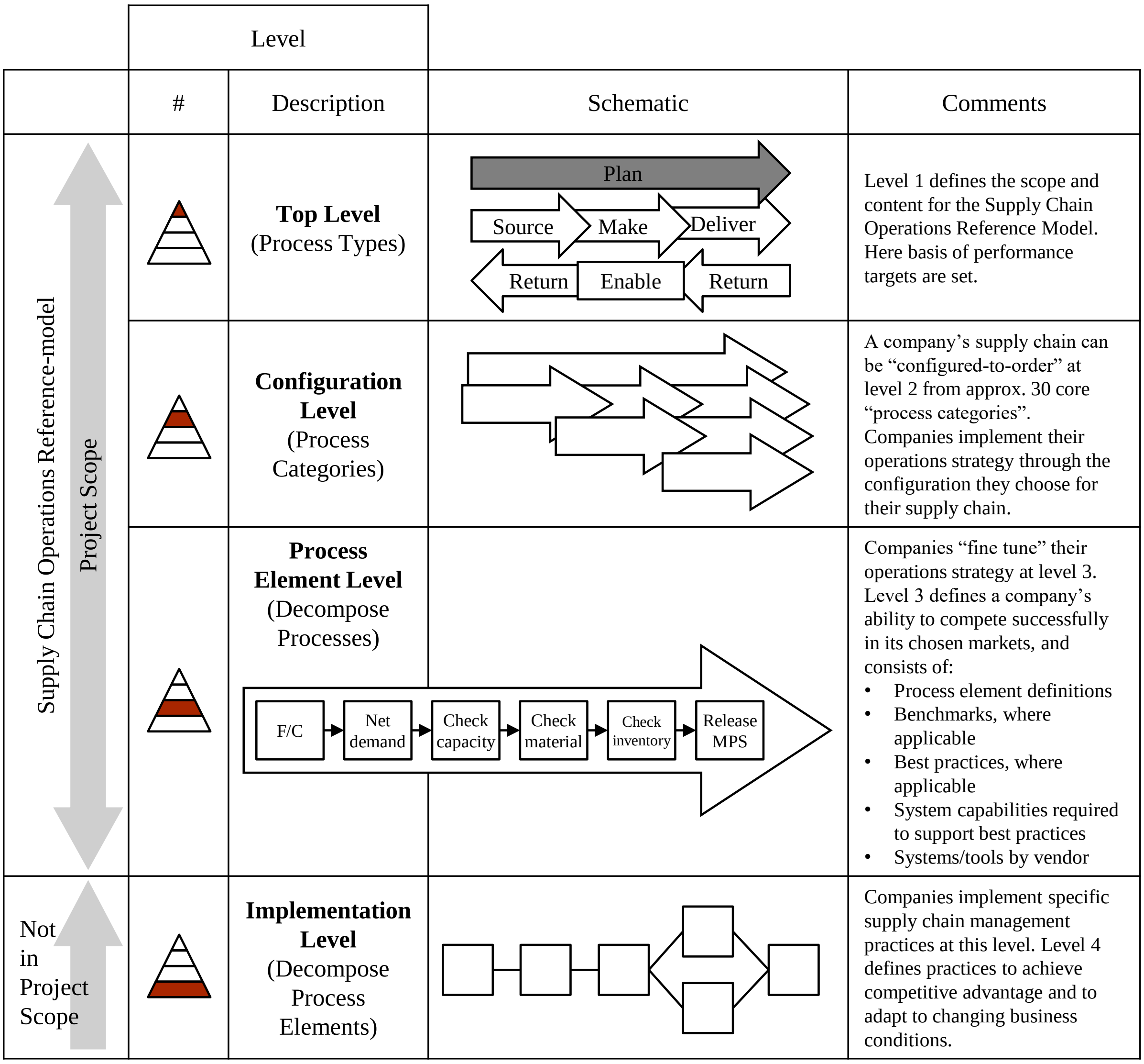

Figure 2.7: SCOR model structure, definition of levels, Stewart (1997), updated

pay-back chances and to learn from best-in-class examples. The focus on activities in the areas source, make and deliver can ease the implementation. A drawback of the SCOR-model is the high level of abstraction. Moreover, as cost reduction is one of the main issues, it can result in missing other opportunities, like for example a redesign of the product. Loosing independence and Know-how due to close ties with partners can also be a disadvantage. (Werner, 2013; Douglas M. Lambert, García-Dastugue, and Croxton, 2005)

Table 2.2: SCOR level 1 metrics, (D. Simchi-Levi, Kaminsky, and E. Simchi-Levi, 2003; APICS Supply Chain Council, 2016)

	Attribute	Metrics	Measure
external	Reliability	Perfect Order Fulfillment	Percentage
	Responsiveness	Order Fulfillment Cycle Time	Days
	Supply Chain Agility	Upside Supply Chain Flexibility Upside Supply Chain Adaptability Downside Supply Chain Adaptability Supply Chain Value at risk	Days
internal	Supply Chain Costs	Total cost-to-serve	
	Asset Management	Cash-to-Cash Cycle Time Return on Supply Chain Fixed Assets Return on Working Capital	Days Turns

All activities and processes within a SC require various decisions, which have different decision horizons and arise in different phases. Therefore, more insight in the Decision Making Processes in Supply Chain Management (SCM) is given in the following section.

2.3 Decision Processes

Where should the production facility be located? Which supplier should be chosen? Which sourcing strategy should be chosen? Does the forecast have an impact to the current scheduling? These and a lot of other questions are issues of SC management and demand answers, respectively decisions. Regarding the decision horizon, questions can be assigned to different levels: from a strategic to a operational and a tactical level. These levels differ mainly regarding the time frame, this means how often decisions are made and which time horizon they affect, but also regarding the domains they have an impact on. Decisions within a time frame of two to five years belong to the strategic level, they are long term decisions and often have an influence on the whole company. Whereas decisions of the tactical level shift within a time frame of one month to a year and are medium term decisions. The operational level is characterized by day-to-day activities and refers to short term decisions. In figure 2.9 different SC processes are shown in two dimensions: decision horizon and time. Further more the mentioned decision processes are associated with SCOR, level one processes: Source, Make, Deliver. (Thierry, Bel, and Thomas, 2010; Tako and Stewart Robinson, 2012)

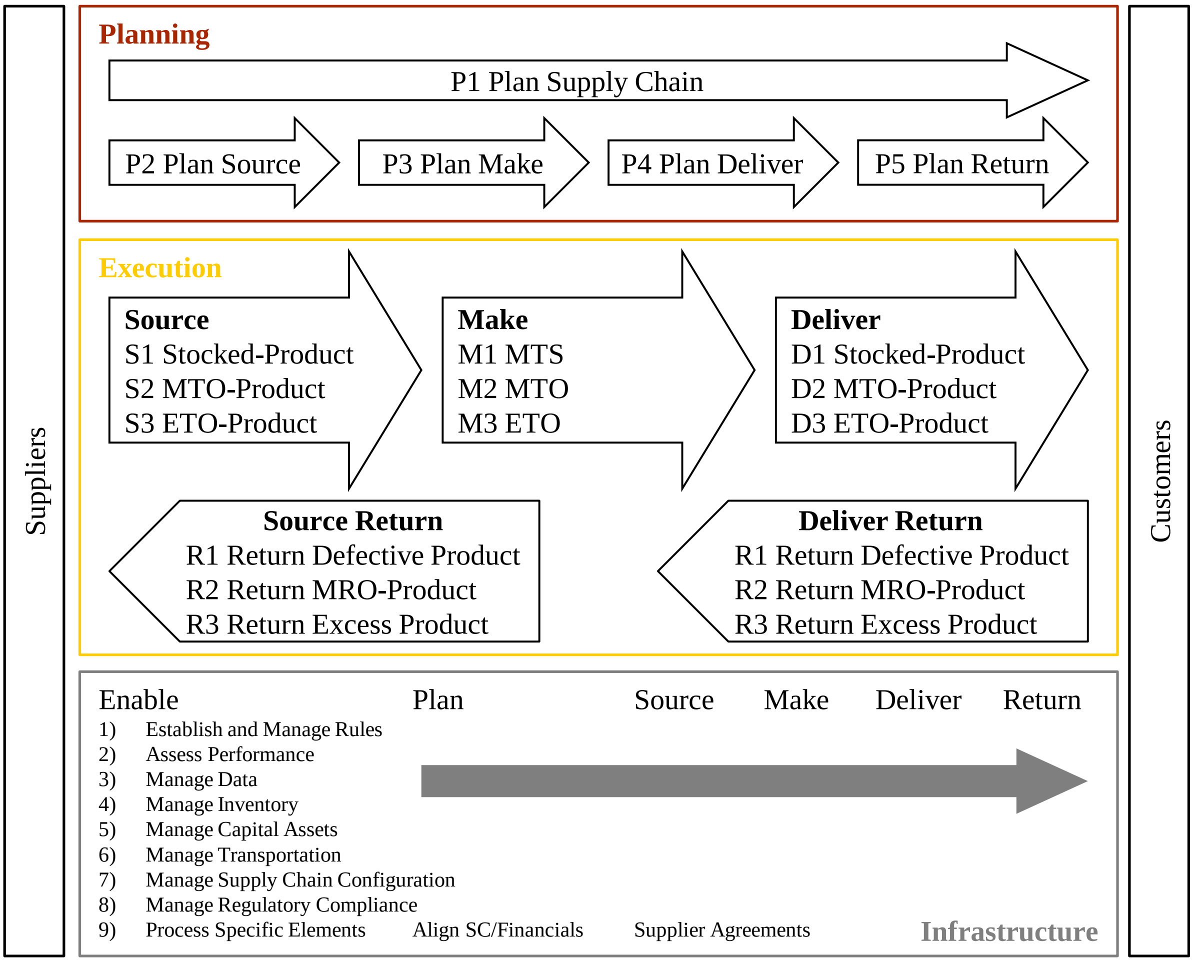

Figure 2.8: SCOR configuration toolbox (based on Werner, 2013; Beckmann, 2012)

In a recent study Tako and Stewart Robinson (2012) reviewed articles to find out more, among others, about LSCM issues and their levels. It has to be mentioned that their research study was limited to simulation studies, especially DES and SD, and their usage for LSCM issues. Nevertheless the proposed ranking of LSCM issues to the levels, which can be seen from figure 2.10, allows good insights. Following Tako and Stewart Robinson (2012) it is not always possible to assign the different LSCM issues to the above mentioned levels exactly. Boundaries are not clearly demarcated, they are blurred.

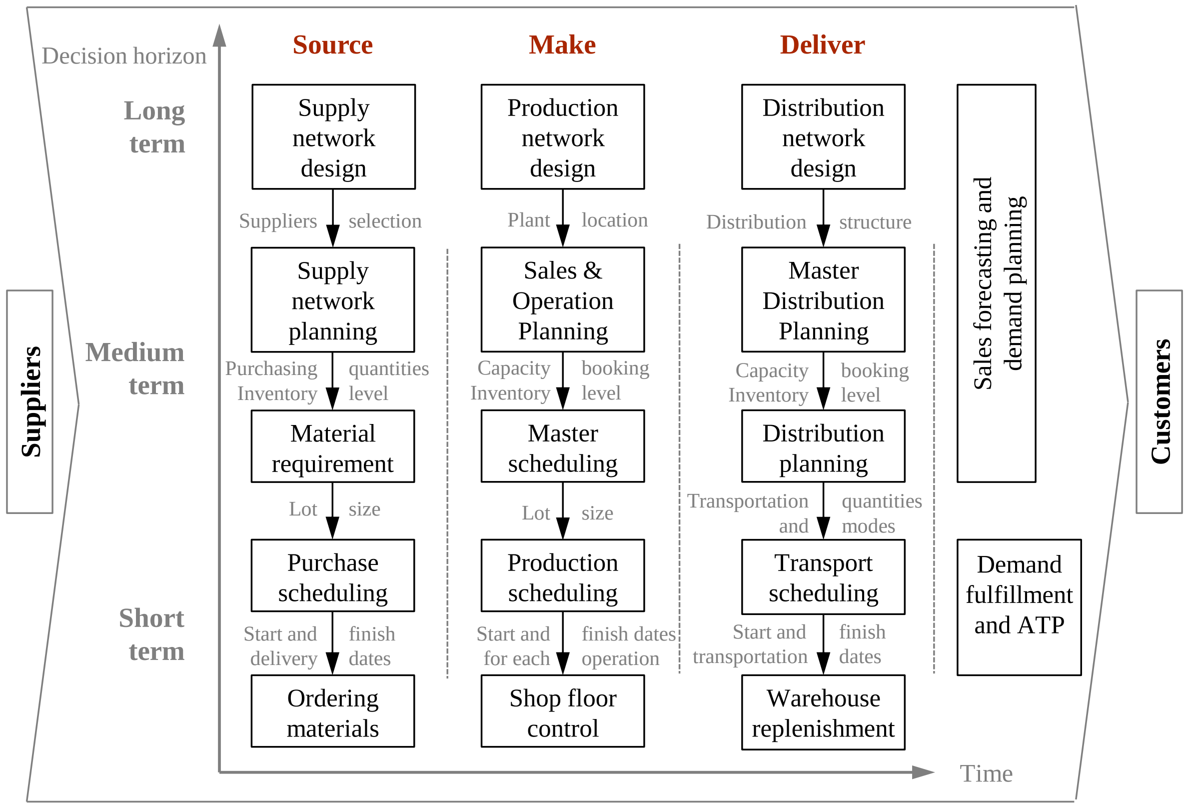

Figure 2.9: Different SC decision processes (adapted from Thierry, Bel, and Thomas, 2010, p. 2)

Decisions are always associated with a certain degree of uncertainty and also with risks. Identifying, measuring and evaluating risks are important tasks that give further insights and allow the management to make their decision based on facts and their judgment. It is not about risk avoidance, rather it is about risk awareness. The underlying risks in context with SC are explained in the following section.

2.4 Risks

Production has changed in the last decades and is becoming more and more complex. That means, in former times production flow was simple, from the raw material via the manufacturer to the end customer. Today companies are faced with global competition and price pressure. Further, rapid developments in the area of information technologies, for example using Enterprise Resource Planning (ERP) systems, have changed access and availability of data. The simple production flow changed to more complex, longer and global SCs with a

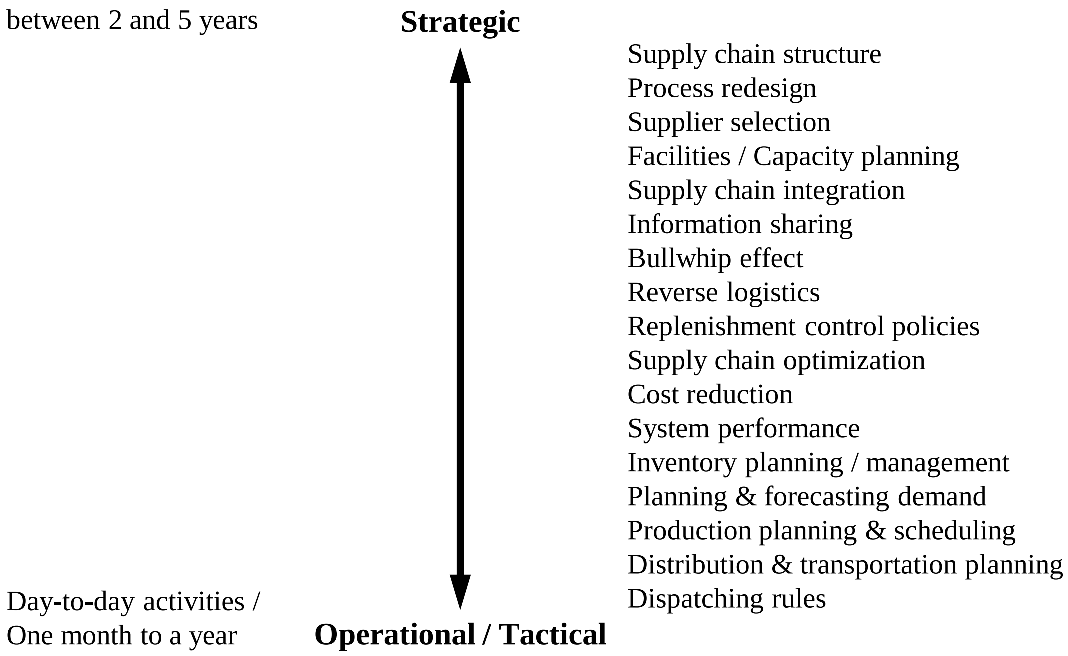

Figure 2.10: Ordering of LSCM issues (Tako and Stewart Robinson, 2012, p. 805)

higher number of participants, influenced by two major trends: globalization and consolidation of firms, which results in a higher unpredictability for the market players. Hence risks have also changed and new ones have to be added. Risks can be directly connected with the end product, as for instance the product recall of Mars in 55 countries due to plastic found in the chocolate bars, or by interruptions somewhere in the SC, for instance due to hurricanes, epidemics, terrorist attacks or other events. One popular case is the one of a company called Ericsson. They had a single-source strategy for the chips, they used in their products. A fire accident at the suppliers stopped the supply and caused an estimated loss of USD 400 million. Therefore risk and risk management is an important issue regarding SCs. (Tang and Nurmaya Musa, 2011; Manuj and John T. Mentzer, 2008b; Harland, Brenchley, and Walker, 2003; BBC News, 2016)

The increasing importance of Supply Chain Risk Management (SCRM) is also reflected by the number of articles published in the literature. Since 2004 the publications on risk issues highly increased and this shows the growing attention of both, academics and experts in applied sciences. (Tang and Nurmaya Musa, 2011)

2.4.1 Definition

Manuj and John T. Mentzer (2008a) demonstrated that risk is understood in different ways in the literature, depending on the domain. Finance defines risk in another way than marketing or psychology. But also the kind of industry influences the view of risk. Despite this variety they found out that there are three elements, all these approaches share:

- potential losses
- likelihood of those losses
- significance of the consequences of the losses

The term 'Risk' is defined by Harland, Brenchley, and Walker (2003, p.52) widely as

> *... as a chance of danger, damage, loss injury or any other undesired consequences.*

The literature review in the study of Manuj and John T. Mentzer (2008b) demonstrated that there is no suitable definition of risk in context with global SCs. There is a degree of uncertainty around the terminology risk and associated terms like vulnerabilities. Therefore, they developed a definition with focus on global SCs, which reads as follows:

> *. . . the distribution of performance outcomes of interest expressed in terms of losses, probability, speed of event, speed of losses, the time for detection of the events, and frequency.*

What both definitions have in common are the potential losses, what Manuj and John T. Mentzer (2008b) added is the issue 'speed' in many contexts, which is an important point for global acting SCs.

After this short review on definitions of risk the question arises after the classification and kinds of risks, which will be discussed in the next section.

2.4.2 Types

Which types of risks can arise in a global SC? How can risks be classified? These questions and more come up when dealing with the issue risk. Therefore, some classifications need to be given.

In general, risks can be of quantitative or qualitative nature. Quantitative risks are measurable for example by stock levels, delivery times, delivery reliability. Qualitative risks are not measurable in this way and refer for example to reliability, to know-how and so on. (Manuj and John T. Mentzer, 2008a)

For the classification of risk along the entire SC, the following proposal can be found in the literature:

- supply risks
- operational risks
- demand risks
- security risks

This four types of risks are directly connected to the SC and influence the way from the supplier's supplier to the end customer, in other words they influence supply and demand, as illustrated in figure 2.11. These risks can be completed by macroeconomic risks, policy risks, competitive risks and resource risks.(Manuj and John T. Mentzer, 2008a; Manuj and John T. Mentzer, 2008b)

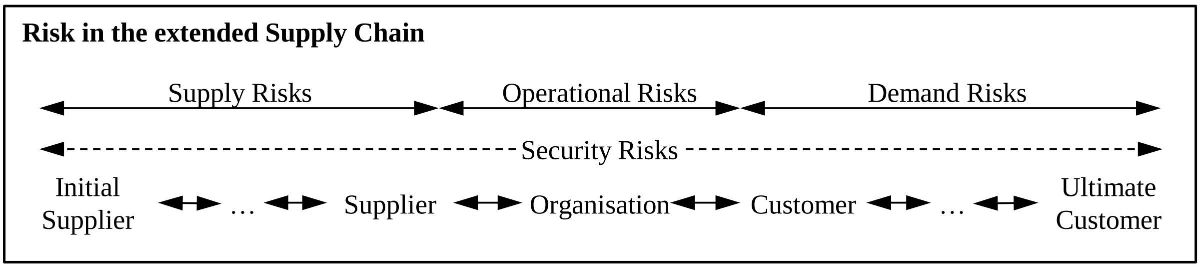

Figure 2.11: Risk in the extended SC (Manuj and John T. Mentzer, 2008a, p. 138)

In figure 2.12 the correlation between different risk types 'supply risks', 'operational risks', 'demand risks' and 'other risks' is illustrated. There are also individual risk sources given as examples for the different types. 'Supply risks' are the probability of interruptions in the inbound supply and they impair the organization to fulfill the need of the customers. They can lead to higher costs, delivery delays, supply shortages. 'Operational risks' refer to the capabilities of the organization itself. Breakdown in production or quality problems for example influence the capabilities. Upstream in the SC the 'demand risks' and be found, which describe the probability of interruptions in the outbound supply. These risks influence customer's willingness to place orders with the organization. 'Security risks' are more or less beyond the organizations control and can be divided into 'information security risk' (e.g. hacker attacks), 'infrastructure security risk' (e.g. freight breaches) and 'human security risks' (e.g. crime). (Manuj and John T. Mentzer, 2008a; Manuj and John T. Mentzer, 2008b)

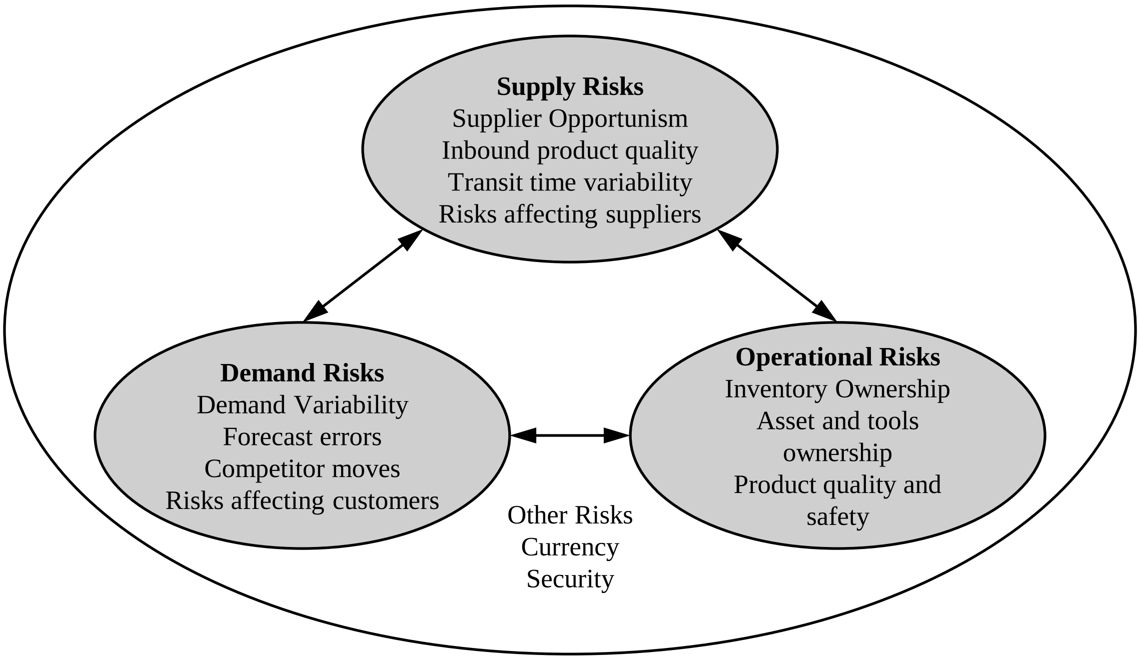

Figure 2.12: Risks in global SCs (Manuj and John T. Mentzer, 2008b, p. 201)

Another categorization of risks is presented in table 2.3 by Tummala and Schoenherr (2011). The risk categories are more detailed, than the above mentioned, but basically the categories are part of them. Inventory risks and supply (procurement) risks can be assigned to supply risks. Manufacturing (process) breakdown risks and physical plant (capacity) risks can be summed up as operational risks. Disruption risks, systems risks and sovereign risks can be grouped by security risks, as well as delay risks and transportation risks. There are also risk triggers or risk sources listed to the different risk categories.

Table 2.3: SC risk categories and their triggers, (Tummala and Schoenherr, 2011, p. 475)

Risk category	**Risk triggers**
Demand risks	Order fulfillment errors Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage
Delay risks	Excessive handling due to border crossings or change in transportation mode Port capacity and congestion Custom clearances at ports

(*table continues*)

Table 2.3: SC risk categories and their triggers (continued)

Risk category	**Risk triggers**
	Transportation breakdowns
Disruption risks	Natural disasters Terrorism and wars Labor disputes Single source of supply Capacity and responsiveness of alternate suppliers
Inventory risks	Costs of holding inventories Demand and supply uncertainty Rate of product obsolescence Supplier fulfillment
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards) Lower process yields Higher product cost Design changes
Physical plant (capacity) risks	Lack of capacity flexibility Cost of capacity
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance Supplier fulfillment errors Selection of wrong partners High capacity utilization supply source Inflexibility of supply source Poor quality or process yield at supply source Supplier bankruptcy Rate of exchange Percentage of a key component or raw material procured from a single source
System risks	Information infrastructure breakdowns Lack of effective system integration or extensive system networking Lack of compatibility in IT platforms among SC partners
Sovereign risks	Regional instability Communication difficulties Government regulations Loss of control Intellectual property breaches
Transportation risks	Paperwork and scheduling Port strikes Delay at ports due to port capacity Late deliveries Higher costs of transportation Depends on transportation mode

In conclusion, it can be noted that there are many risks triggers respectively risk sources and they can be grouped in some main categories, which can be assigned to the SC structure: supply risks, operational risks, demand risks, security risks.

2.4.3 Assessment

The assessment of risks is an important step in risk management and it means to find out the probabilities of the various risks and also the weight of the consequences, if a risk occurs. The probability depends on the one hand on how exposed the incident is, in other words how dangerous an event can be in terms of risks. And on the other hand it depends on the chance that the trigger will be activated. An activation can be triggered by individuals or by organizations, but also by things beyond control. The second part is also a question of the power of the company, in what extent the company is able to influence their environment. The weight of the consequences can be roughly calculated if there exist directives or laws and therefore, the consequences resulting from non-compliance are relatively well known. But there are also consequences depending on other facts, as for example the publicity of a company. Hence, it is a difference if a big group like for instance Volkswagen Group is in focus or a small unknown company. It is important to have in mind not only quantitative measurable consequences or losses, but also other intangible values like reputation and image. It has to be mentioned that the influence of media and social media should be taken into account. A demonstrative example of different aspects of risk based on a taxi company is shown in table 2.4. (Harland, Brenchley, and Walker, 2003; Tummala and Schoenherr, 2011)

Table 2.4: Illustrative example of different aspects of risk (Brenchley, 2000)

Benefit	Exposure	Event (enforcement)	Consequence	Business impairment	Magnitude of loss
Example 1 - driver					
Income for taxi firm and driver	Parking illegally	Parking ticket	Fine	Increase costs	Can range from minor to major
		Vehicle towed	Fine and time to collect vehicle	Increase costs and time	
	Speeding	Caught by police or camera	Fine	Increase costs	
	Running a red light		Points (possible loss of license	Possibly cease trading	
	Drink driving	Caught by police and breathalyzed	Fine	Increase costs	
	Faulty products fitted to vehicle	Fails MOT	Driving ban Vehicle off road while remedial action taken	Cease trading Temporarily cease trading	
Example 2 - customer					
CEO can work in transit and low stress	Company uses taxi to get CEO to important meeting	Taxi involved in crash	CEO misses meeting	Business lost	Can range from minor to major

Beside of that, it is significant to know the risk probability distribution, this means to answer the question if is it a uniform distribution, a normal distribution or a exponential distribution for example. To find out the nature of the distribution historical data or other available objective information can be used. In case no data are available, the estimation of the distributions needs to be based on judgment and subjective experiences. This can be supported by using techniques such as Delphi method, expert groups or Monte-Carlo-Simulation. (Manuj and John T. Mentzer, 2008a; Tummala and Schoenherr, 2011)

Manuj and John T. Mentzer (2008a) argues that there are three groups of risk assessment tools and frameworks: decision analysis, case study and perception based. An example for decision analysis is the approach for sourcing decisions by Treleven and Bergman Schweikhart (1988), who suggest to decrease either *... the probability of risk components (P) or the impact for each of the risk components (I)*:

$$I_T = P_{ds} \cdot I_{ds} + P_{pe} \cdot I_{pe} + P_{is} \cdot I_{is} + P_{ta} \cdot I_{ta} + P_q \cdot I_q$$

where:

I_T	. . . the total impact of the sourcing strategy
P	. . . probability
I	. . . impact
ds	. . . disruption of supply risk
pe	. . . price escalation risk
is	. . . inventory and scheduling risk
ta	. . . technology access risk
q	. . . quality risk

The business case framework from Hauer (2003) gives an example for case studies and recommends using a two-dimensional risk map: risks and business processes. As a model for perception based the framework by Norrman and Lindroth (2004) should be mentioned. It is a cube and therefore uses three dimensions. The first dimension is the unit of analysis, from single logistics to supply network. The second dimension is the risk and business continuity management process, from low level analysis to high level analysis. And on the third dimension is the risk type, uncertainty and progresses, from operational to strategic.

As it can be seen probabilities and weight of consequences are the main issues of risk assessment. Hence, it is very important to focus not only on measurable and objective assets, but also on 'soft'-facts. According to Manuj and John T. Mentzer (2008a) *. . . the heart of risk assessment is asking the right questions.*

2.5 Risk Management Process

The SCRMP is a conceptual framework suggested by Tummala and Schoenherr (2011), who adapted the Risk Management Process (RMP) to the SC. The framework consists of three phases, from risk identification in phase one to risk control & monitoring in phase three. Further influencing variables are internal and external drivers, risk categories, data management systems, supplier/logistics evaluation criteria and supplier/logistics performance measures. The individual phases and variables and their relations are shown in figure 2.13.

Phase one of the SCRMP contains 'risk identification', 'risk measurement' and 'risk assessment', and these steps should be realized in the mentioned sequence. The task of 'risk identification' is to find out all risk factors influencing the SC and get a complete 'picture' of them. At this step it is important to learn about the inter-dependencies between the individual risks and to recognize the variety. It is helpful to have a closer look on resources (humans, machines, capital) and on impacts endangering these resources. In the next step 'risk measurement' the consequences of the identified risks and their order of magnitude are set. Consequences are of different nature, for example time (e.g. delays), money (e.g. exceeded costs), performance (e.g. poor quality). A widely known classification of consequences is made by Crockford (1986) and is shown in table 2.5. Trivial consequences or losses are not a problem a all for the company, they are part of daily business and the company can cope with them. Small losses cause little problems, but the company can cope with them. A medium loss does make problems, but not to an extent that the company is really threatened. Whereas large losses are a serious problem and can be a threat for the company, even they occur very rarely. (Tummala and Schoenherr, 2011)

Table 2.5: Risk classification - consequences (Crockford, 1986)

Consequence	**Frequency**	**Severity**	**Predictability**
trivial	very high	very low	very high
small	high	low	reasonable, with infrequent occurrence
medium	low	medium	reasonable, with frequent occurrence
large	very low	high	minimal

The last and third step of phase on is 'risk assessment'. This kind of task has been already described before in section 2.4.3 on page 22. Phase two of the SCRMP contains two steps: 'risk evaluation' and 'risk mitigation & contingency plans'.

The first step 'risk evaluation' consists of two sub-steps: 'risk ranking' and 'risk acceptance'. 'risk ranking' is defined as:

$$Risk\ Exposure\ Value\ of\ Risk\ Factor = Risk\ Consequence\ Index \times Risk\ Probability\ Index$$

For 'risk acceptance' the authors suggest a classification in unacceptable, tolerable and acceptable. The task of the second step of phase two 'risk mitigation & contingency plans' is to prepare 'risk response action plans'. Risk planning as part of it makes assumptions about cost for implementing such action plans and evaluates them to find the best solution. (Tummala and Schoenherr, 2011)

Phase three contains 'risk control & monitoring' and is the control instrument of the SCRMP. It considers target-actual comparisons, monitoring of disturbances and developing of further improvements.
Finally, it has to be noted that this SCRMP does not result in decisions, rather the framework supports decision making by providing a structured and most complete basis. (Tummala and Schoenherr, 2011)

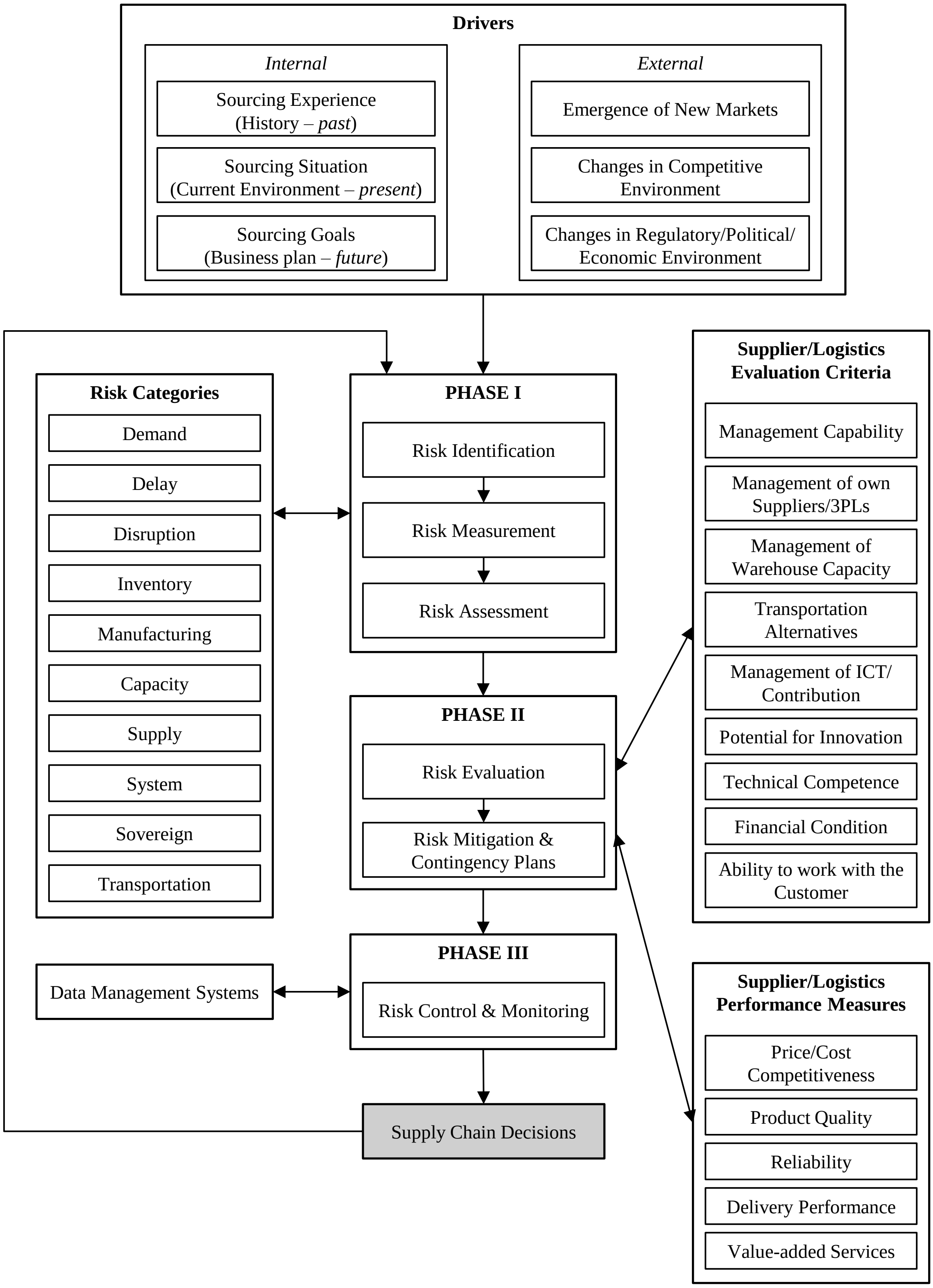

Figure 2.13: Supply Chain Risk Management Process (SCRMP) (Tummala and Schoenherr, 2011, p. 477)

3 Modeling and Simulation

New aspects or questions within a certain environment arise and they make it necessary to investigate the concerned system to find answers. The system refers to real world problems, which can be a process or activities of interest. For example, the waiting periods of an emergency room should be analyzed to find out if enough medical staff is available. Then this part of the hospital can be defined as a system. If the utilization of operating rooms is part of the investigation, then the system includes other parts of the hospital. Therefore, a system consists of various entities, for example humans, rooms, machines or resources. To study a system in a scientific way, it is often necessary to make assumptions and to simplify the real world. Hence, a model has to be built. (Law, 2015)

To understand a system, gain insights and discern relationships, there are different ways to study it, which are shown in figure 3.1. There are distinct kinds of models and simulation can be seen as a part of 'mathematical models'. Simulation can be a helpful and powerful tool, e.g. for designing and analyzing manufacturing systems, re-engineering of business processes and analyzing SCs. (Law, 2015)

Birta and Arbez (2013, p.v̇ii) describe modeling and simulation as follows:

> *Modelling and simulation is a tool that provides support both for the* ***planning, design and evaluation of dynamic systems*** *as well as the* ***evaluation of strategies for system transformation and change.***

In the next sections, the tool or technique of 'modeling and simulation' is described in more detail, starting with modeling, which serves as a basis for simulation. Subsequently, simulation is discussed as well as some paradigms: System Dynamics (SD), Discrete-Event Simulation (DES), Agent-based Simulation (AB) and Monte-Carlo simulation.

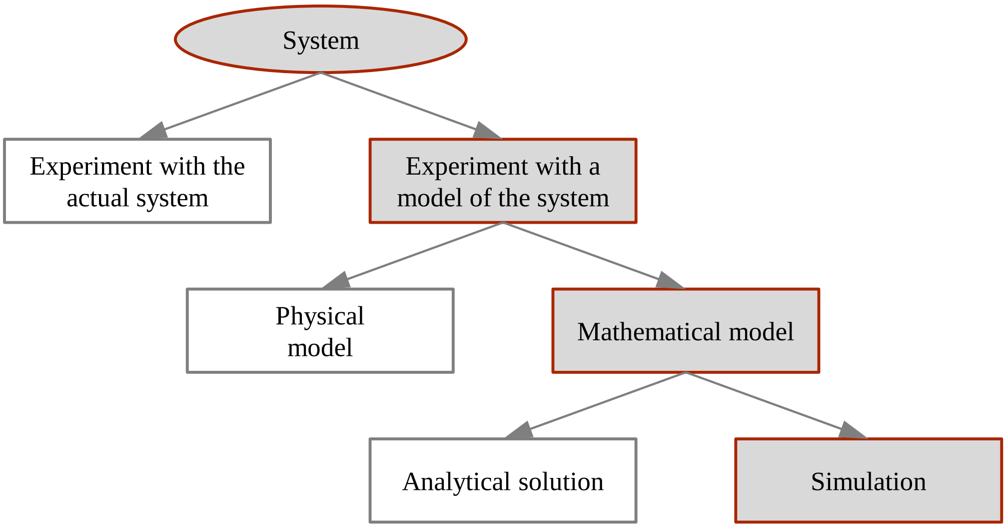

Figure 3.1: Ways to study a system, (Law, 2015, p. 4)

3.1 Modeling

Problems in the real world often cannot be solved by experimenting with it. Therefore, a model is needed. An illustrative example for a model, in that case a physical model, is a flight simulator, which is disconnected from a real airplane. To find out why the landing maneuver on the Hudson river proved successful, it would not be recommendable to try it a second time. It is much more reasonable to try this maneuver on a simulator. But also in other cases it would not be possible to make tests in the real world, as for example to set up an investigatory production site to find out whether it would work due to capacity, as this would incur significant costs. In such cases, using a model is a helpful tool. This means to create a model which represents the real word, but is much simpler. Accordingly, assumptions have to be made and it is focused only on the factors influencing the system. In figure 3.2 the way from the real world to the model (in different stages and complexities) back to a new real world is shown.

3.1.1 Life Cycle

Balci (1990) emphasizes the role of the life cycle of a simulation study to be successful, which is shown in figure 3.3, as well as the role of verification and validation. The presented life cycle contains 10 phases, 10 processes and 13 credibility assessment stages. It has to be pointed out that the processes are normally handled in sequence, but due to a detected failure, it can be

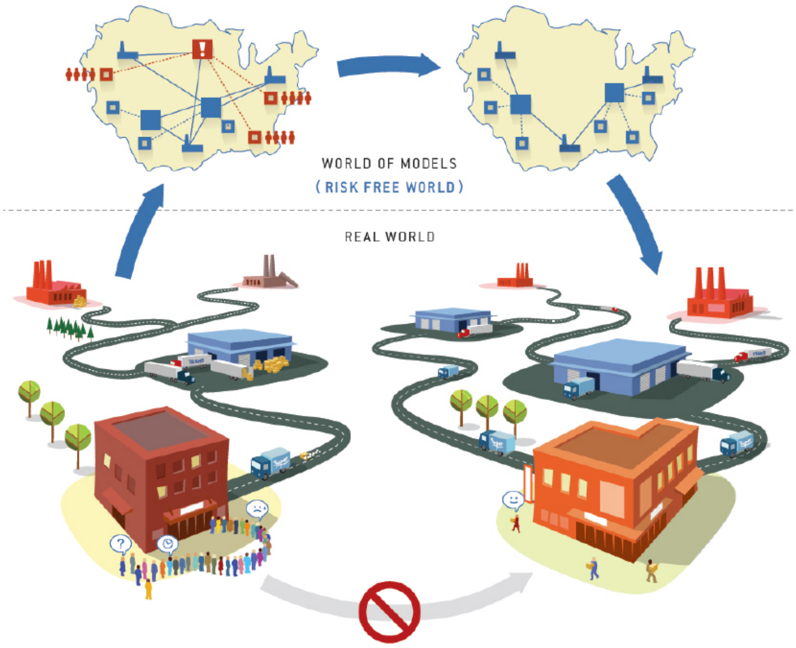

Figure 3.2: Modeling (Borshchev, n.d., p.25)

necessary to go back to a former process and therefore the life cycle is *iterative in nature*. The life cycle starts with an arising problem and the first process named 'problem formulation', which is transferring the problem into a formulated problem, clearly understandable for all involved parties and well-defined. Next, the process 'investigation of solution techniques' follows to find out the best suitable technique for the problem, also in terms of costs and time. After selecting the technique, the next step is 'system investigation'. Following Shannon (1975), there are six major system characteristics: change, environment, counter-intuitive behavior, drift to low performance, inter-dependency and organization. According to Balci (1990), these characteristics should be investigated with the formulated objectives in mind. When knowing the system characteristics and having a practicable system complexity, the process of 'model formulation' can be started to get a conceptual model which mainly serves the modeler. 'Model representation' then means to build a model which can be used to communicate with the involved parties. Graphs or flow charts can therefore be a useful form. Only now the communicative model is translated into a programmed model by using a programming language in the process of 'programming'. Next, the 'design of experiments' as a planning process considering the objectives and also costs has to be done. During the process of 'experimentation', the simulation model is used to get results for the specified objectives, for example forecasting, optimization or comparison of different operating policies. The gained results can be presented to the decision makers. It has to be noted that simulation models are descriptive and thus the results need to be analyzed and interpreted. Furthermore, the gained results can be new input for another simulation run, to adjust the model or for an alternative scenario. The cycle is accompanied by two important processes: verification and validation. In brief, verification is about *building the simulation model right* and validation about *building the right simulation model*. (Balci, 1990)

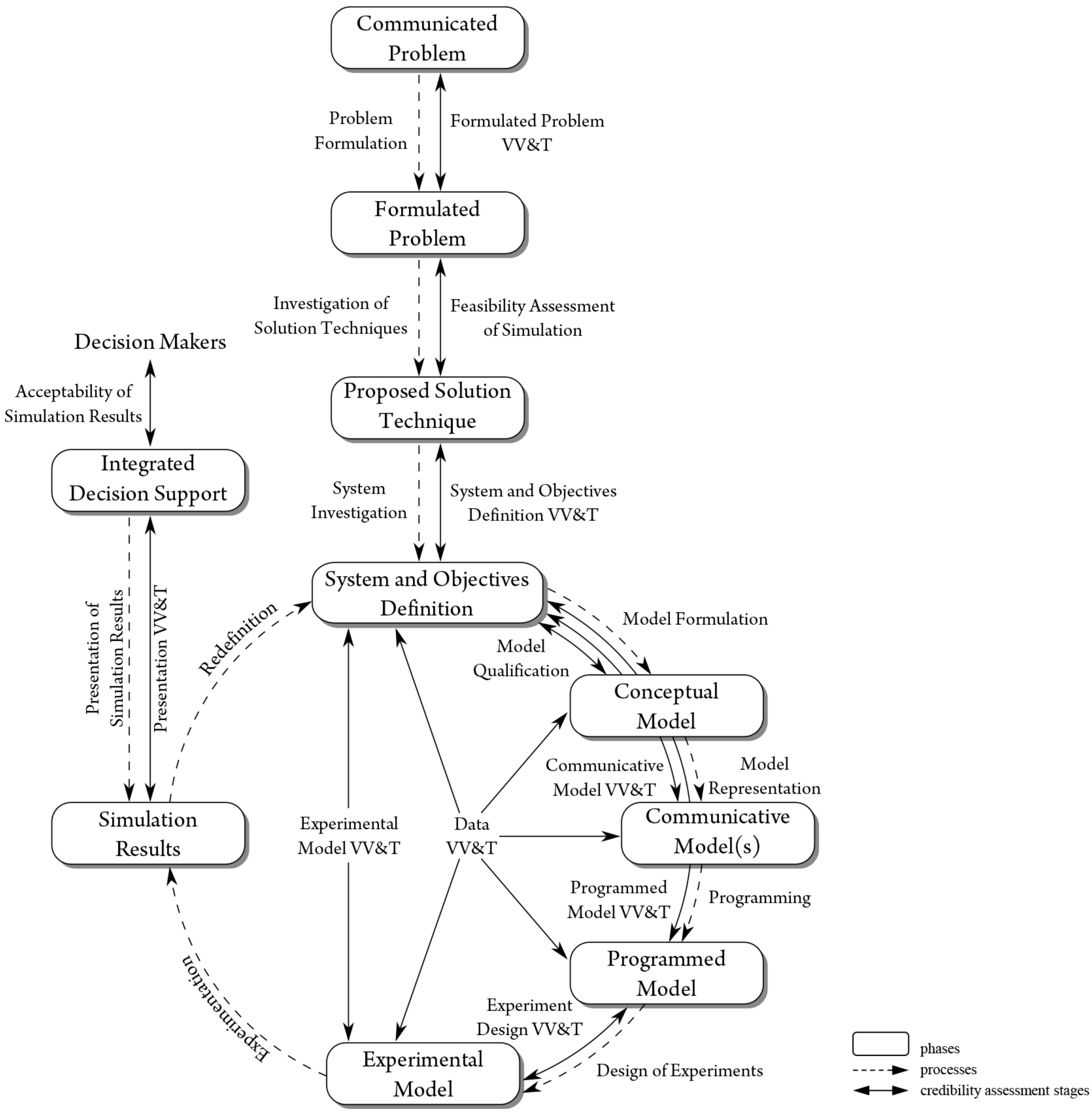

Figure 3.3: Life Cycle (Balci, 1994, p.216)

In the next section, the process of conceptual modeling, containing the processes from problem formulation to model formulation, as a part of the life cycle and the conceptual model will be discussed in more detail, as this can be seen as a key process.

3.1.2 Conceptual Model

The procedure from the real system to a conceptual model, which can be translated into a computer model is a significant one, as the real world needs to be modeled in a sufficient way, but as simple as possible. Therefore, it has to be inquired what has to be included in the model. The real world needs to be abstracted on a certain level which is called conceptual modeling. The result of this is the conceputal model, and this is defined by Stewart Robinson (2008a) as follows:

> *The conceptual model is **a non-software specific description** of the computer simulation model (that will be, is or has been developed), describing the **objectives, inputs, outputs, content, assumptions** and **simplifications** of the model.*

As can be seen from figure 3.4, assumptions are needed to get the system description and furthermore simplifications to get the conceptual model. Assumptions have to be made, if too little data are available, knowledge is limited or there is a lack of time. Simplifications are made in order to get a simple model, this means for example to limit the input factors to the important ones for the problem. Another important point is that the conceptual model is not a computer model, it is the basis for programming a computer model. As S. Robinson (2011) points out, it is a major issue to understand the difference in nature between system description and the conceptual model because of the distinctive domains. The problem domain represents the real world and the arising problem. Compared to the life cycle of Balci (1990), the problem domain refers to the phases from 'communicated problem' to 'system and objective definition'. By contrast, the model domain represents the abstracted world and the model's level of detail. To model the system description would lead to enormously big and complex models and would be a major failure. The model should be as simple as possible, but sufficiently accurate to meet the targets. (S. Robinson, 2011)

Not only S. Robinson (2011), but several authors have argued that the complexity of the model is a key issue for a successful project. (Balci, 1990; Zeigler, Praehofer, and Kim, 2000; Furian et al., 2015) Zeigler, Praehofer, and Kim (2000) state that *successful modeling can be seen as valid simplification*. Over-complex systems are sometimes hard to understand by humans

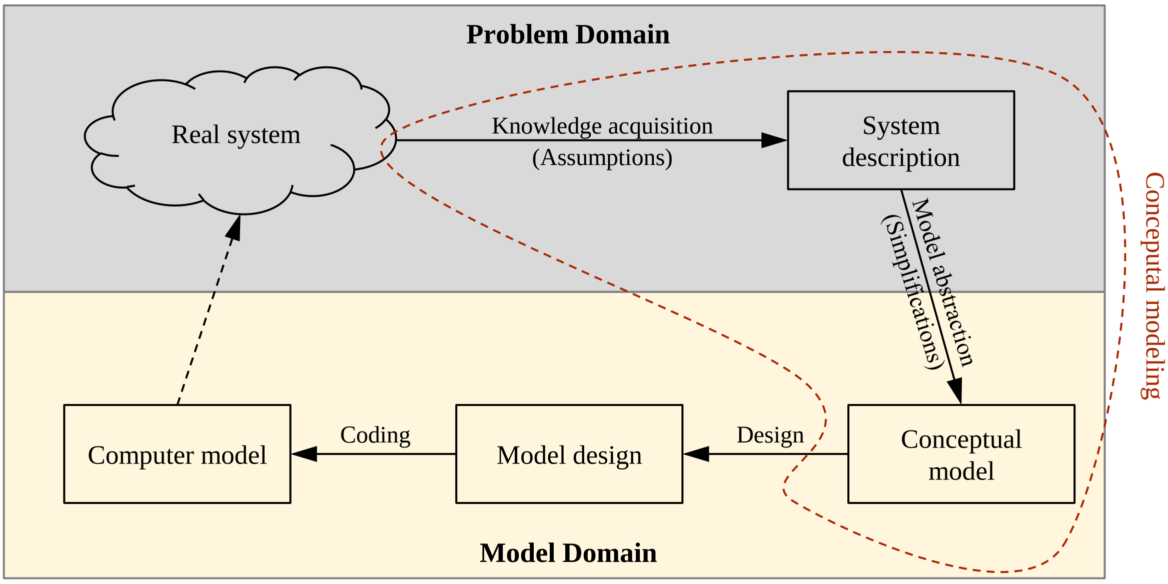

Figure 3.4: Artefacts of conceptual modeling (S. Robinson, 2011, p.1427)

respectively they are not inuitively understandable and need some resources. For simulators in terms of computers, this means that they need a lot of memory capacity. Even if information technology provides faster and faster and more capable computers, there are still limitations. Therefore the challenge is to simplify the model as far as possible without it losing its validity. Zeigler, Praehofer, and Kim (2000) explain a pair of models in this context: base and lumped models. The lumped model is more abstracted than the base model and is valid within a particular experimental frame, while the base model is more proficient and therefore needs more resources, but is also valid within a wider frame of interest. The essential point is, that for the respective frame of interest, the lumped model is valid and therefore adequate. There is no need for a more proficient model.

A framework for conceptual modeling is the Hierarchical Control Conceptual Modeling (HCCM) framework, suggested by Furian et al. (2015). It can be seen from the figure 3.5 that after understanding the problem situation the next step is 'identification of modeling and general objectives', which is a precondition for building the conceptual model. The modeling objectives refer to the specific purpose for which the simulation study is done, in other words to the company's aim. The general objectives define the specification of the simulation tool, for example run-time or flexibility to changes. Phase three contains 'defining input factors' and 'defining output responses'. Following Furian et al. (2015) and S. Robinson (2011) input factors are experimental factors, which are normally altered with the various experiments and simulation runs with the aim to meet the modeling objectives. Outputs are the results of the experiments and they notify about having met the modeling objectives or not. Outputs can be illustrated as graphs or tables. The next phase 'model content' consists of model structure, model individual behavior and model control. According to Furian et al. (2015) the model structure is determined by the included entities, which can either be active or passive. Active entities are characterized by their individual behavior and are humans, resources and other entities varying their role. As opposed to this, passive entities do not have an individual behavior, for example a loading ramp. To investigate the individual behavior of the various entities and to decide to include or exclude the different attributes is task of the next step, 'model individual behavior'. 'Model control' contains the control structure, in case of HCCM a hierarchical structure with advanced control mechanisms for DES.

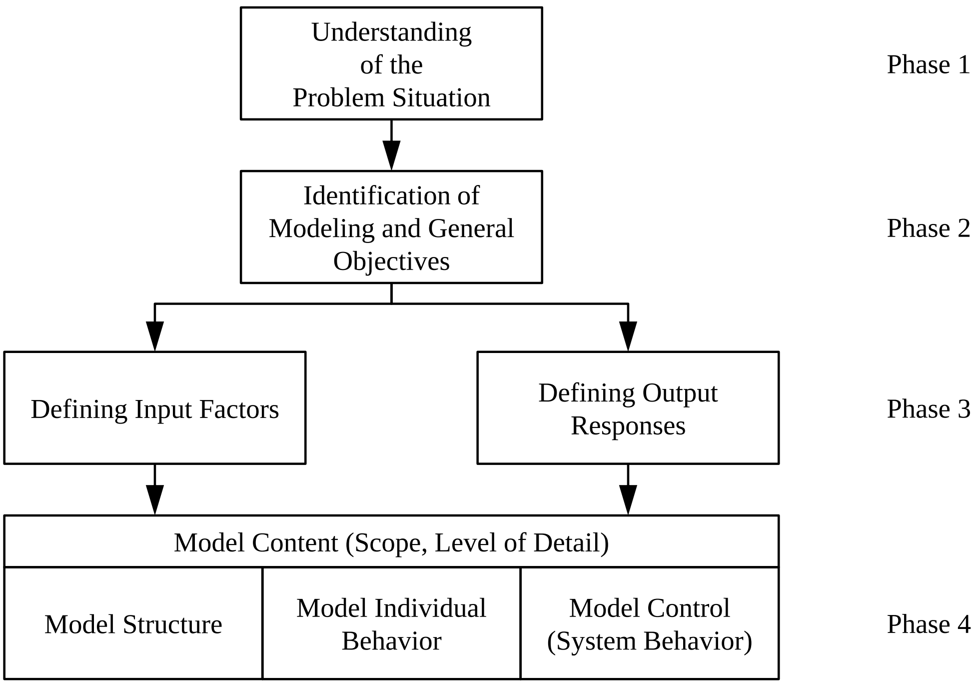

Figure 3.5: Structure of the HCCM framework (Furian et al., 2015, p.89)

Drawing on earlier work by Stewart Robinson (2008a) *there are four main requirements for conceptual models: validity, credibility, utility and feasibility*, shown in figure 3.6. 'Validity' can be understood as the question if the model is right, respectively adequately precise for the specific purpose from the perspective of the modeler. 'Credibility' is basically the same as 'validity', but from the client's point of view. Because it is important that both, the modeler and the client, are convinced that the model is accurate and understandable 'validity' and 'credibility' are two requirements. Certainly, there can be differences between the perspectives. If the modeler decides that the model is valid, it does not necessarily mean that it is credible and transparent for the client. Sometimes details are added to the model, not because they are needed, but because they increase credibility. Concurrently, it has to be paid attention to the complexity, this means not to add so much details to the model that it becomes over complex at the end. The third requirement 'utility' is about the usability of the model, for example in terms of flexibility, visualization, run-time, and not about accuracy. A model fulfills 'utility' when both parties approve of the model. The last requirement 'feasibility' refers to the realization of the conceptual model. Both parties are convinced that the conceptual model can be transferred into a computer model within the given boundary conditions of time, resources and available data. (Stewart Robinson, 2008a)

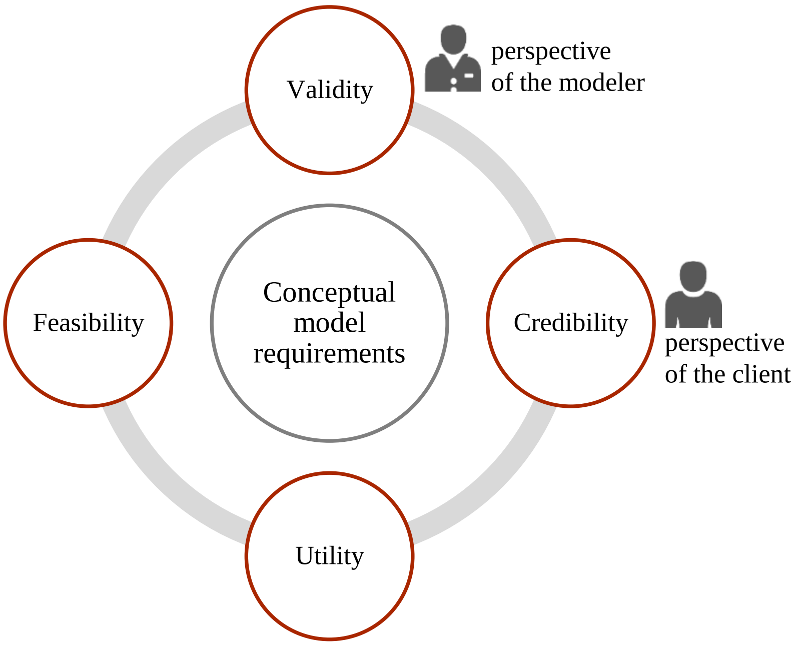

Figure 3.6: Conceptual model requirements (Stewart Robinson, 2008a, p.19)

Finally, the key activities of conceptual modeling should be underlined. Following Stewart Robinson (2008b) the five key activities are:

- understanding the problem situation
- determining the modeling and general project objectives
- identifying the model outputs (responses)

- identifying the model inputs (experimental factors)
- determining the model content (scope and level of detail), identifying any assumptions and simplifications

It is very significant that all involved parties get a common understanding of the problem situation, as this can certainly deviate because of the different points of views based on the role. Clearly defined objectives (meaning what should be achieved) are essential, for example an increase in performance or a reduction in purchasing costs for a certain product by 5 %. The model outputs should meet the client's requirments of the model as well as its reporting (for example charts, time-series, tables). On the input side, the data are altered with the individual experiments with the aim to reach the goal respectively the modeling objectives, as already mentioned before. Data are of quantitative or qualitative nature. The model content can be defined in a top-down approach: first define the edges, then find out the components and lastly, evaluate them and decide which are included and which excluded, always with the requirements described above in mind. The number of attributes for each component is defined by the level of detail, which is based on the assessment of the involved parties, on experience, on available data or on prototyping. Table 3.1 shows some examples for the level of detail, but is not exhaustive. (Stewart Robinson, 2008b)

Beside of the process of conceptual modeling the question, which modeling techniques exist, arises, and should be used for the specific purpose. In the next section a brief overview is given on this issue.

3.1.3 Modeling Techniques

Different types of models require different kinds of modeling techniques. Therefore, it is useful to have a look on the type of the problem first. According to Balci (2012) there are three different types of problem, which are shown in figure 3.7. Depending on the given factors, the questions vary and hence, the models are different. Explanation models explain a system by known input, system and output. Forecasting models relate to the problem type 'Analysis', Design models to 'Synthesis' and Optimization Models to 'Instrumentation'.

As Balci and Ormsby (2000) have noted, there are two kinds of categories of models: prescriptive (normative) models and descriptive models. 'Prescriptive/Normative' Models evaluate a system behavior and consequently classify the solution as "good" or "bad". For example, Operations Research models like Linear Programming, Integer Programming or Mixed Integer

Table 3.1: Template for level of detail by component type (Stewart Robinson, 2008b, p.299)

Component	Detail	Description
Entities	Quantity	Batching of arrivals and limits to number of entities Grouping so an entity represents more than one item Quantity produced
	Arrival pattern	How entities enter the model
	Attributes	Specific information required for each entity, for example type or size
	Routing	Route through model dependent on entity type/attributes, for example job shop routing
	Other	For example, display style
Activities	Quantity	Number of the activity
	Nature (X in Y out)	For example, representing assembly of entities
	Cycle time	
	Breakdown/repair	Nature and timing of breakdowns
	Set-up/changeover	Nature and timing of set-ups
	Resources	Resources required for the activity
	Shifts	Model working and break periods
	Routing	How entities are routed in and out of the activity
	Other	For example, scheduling
Queues	Quantity	Number of queue
	Capacity	Space available for entities
	Dwell time	Time entities must spend in the queue
	Queue discipline	Sequence of entities into and out of the queue
	Breakdown/repair	Nature and timing of breakdowns
	Routing	How entities are routed in and out of the queue
	Other	For example, type of conveyor
Resources	Quantity	Number of the resource
	Where required	At which activities the resource is required
	Shifts	Working and break periods
	Other	For example, skill levels, interruption to tasks

Programming rank among this category of models. However, 'descriptive models' evaluate a system behavior without this judgment of "good" or "bad". The solution of such a model needs to be analyzed and interpreted. Simulation models defines as descriptive models.

Simulation is one modeling technique, analytic methods are another. Queuing theory, graph theory, Markov process and stochastic processes belong to analytic methods. Simulation includes Monte-Carlo Simulation, System Dynamics (SD), Discrete-Event Simulation (DES) and Agent-based Simulation (AB). These simulation techniques are further discussed in the next sections.

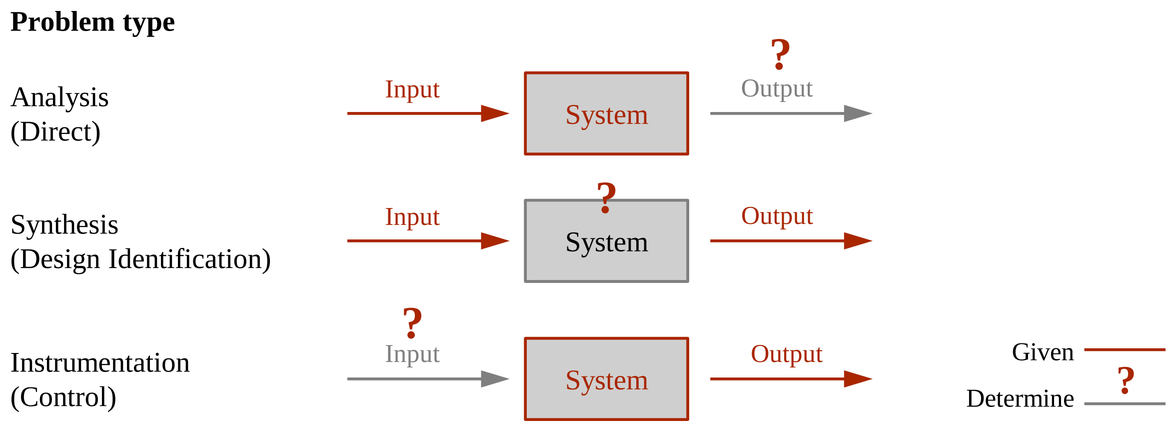

Figure 3.7: Types of problem, based on Balci (2012, p.6)

3.2 Simulation

Simulation is a modeling technique, which is used to model systems of interest that are usually too complex to be studied by analytic solutions. With analytic methods exact solutions can be gained. With simulations estimated solutions are obtained, as the model is assessed numerically. The system and its behavior is imitated by using a computer. It can be compared with a airplane model in a wind tunnel, which is also a simulation, but with a physical model. By changing the experimental factors different scenarios or what-if analyzes can be simulated and because of computer power and speed a number of years can be simulated within a very short time. Simulation is a widespread technique and since there are software packages of high quality that ease the translation of the simulation model into a computer model, it has even become more common. But it has to be mentioned, that simulation is not just making a program code. The simulation methodology is not a question of soft- and hardware used. (Law, 2015; Hillier and Lieberman, 2005) Simulation can be a useful tool for a great variety of fields, as for example 'Designing and operating transportation systems such as airports, freeways, ports and subways', 'Evaluating designs for service organizations such as call centers, hospitals' or 'Analyzing supply chains', which is focused in this thesis. (Law, 2015) Also the Verein Deutscher Ingenieure (VDI) has recognized the role of simulation in logistics and published the first guideline VDI 3633 in 1993, which summarizes important terminology in the field of simulation. (Eley, 2012) Kleijnen (2005) emphasizes the role of simulation in SC context:

> *. . . simulation is important because it may support the quantification of the benefits resulting from supply chain management.*

Figure 3.8 shows the framework developed by Heath, Hill, and Ciarallo (2009) for the different roles simulation can have: Generator, Mediator and Predictor. The role of simulation is related to the level of knowledge of the system. When the system is like a black box, meaning the knowledge of the system is little, then the simulation has the role of a 'generator'. Hypotheses and theories can test if the system conducts itself as expected. If more information about the system is disclosed, theories can be tested and improved and gained insights can be processed into the system, the simulation role is called 'mediator'. Testing conceptual models if they represent their systems well, are also mediator simulations. The last role 'predictor' describes a simulation for very well-known systems. Systems' behaviors can be predicted with high accuracy. It has to be mentioned that the roles are not sharply separated, they are blurred. (Heath, Hill, and Ciarallo, 2009)

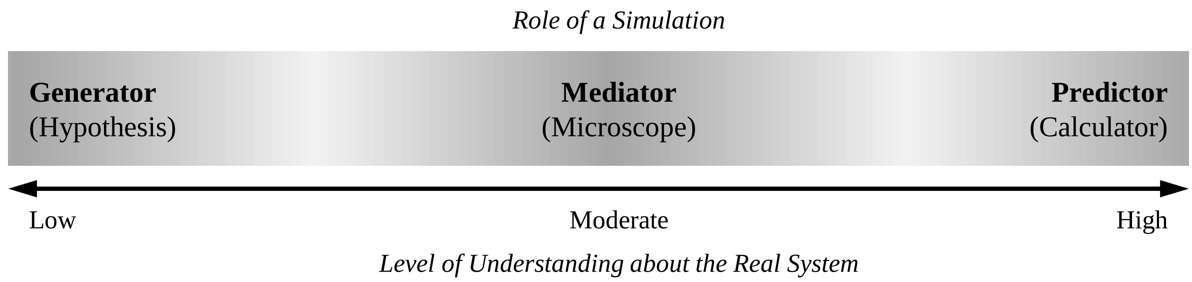

Figure 3.8: Purpose of the simulation (Heath, Hill, and Ciarallo, 2009, p.7)

With respect to the various problems and questions arising, the range for applications within simulation modeling is manifold. Figure 3.9 illustrates applications with regard to the decision level, abstraction level and level of detail. On the base. 'physical models' can be found that are exactly defined by size, velocity, and so on. On the top, individual objects are not of interest anymore, but aggregates and feedback loops are, for example. In between, individual objects are aggregated on different levels, for example not the individual passenger of an incoming flight is addressed, but the aggregated passenger flow. To the various problems and levels, different simulation paradigms can be assigned, shown in figure 3.10. The paradigms System Dynamics (SD), Discrete-Event Simulation (DES) and Agent-based Simulation (AB) and Monte-Carlo Simulation are described in more detail in the following section. (Borshchev and Filippov, 2004)

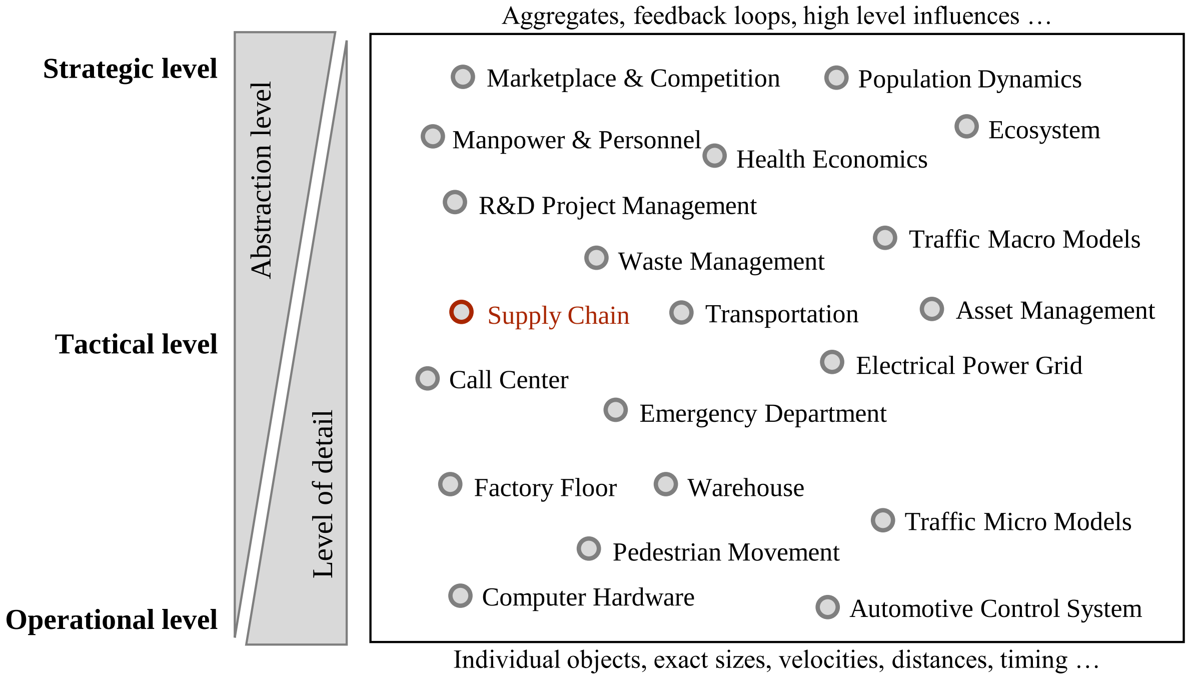

Figure 3.9: Applications of Simulation Modeling on Abstraction Level Scale, adapted from Borshchev and Filippov (2004)

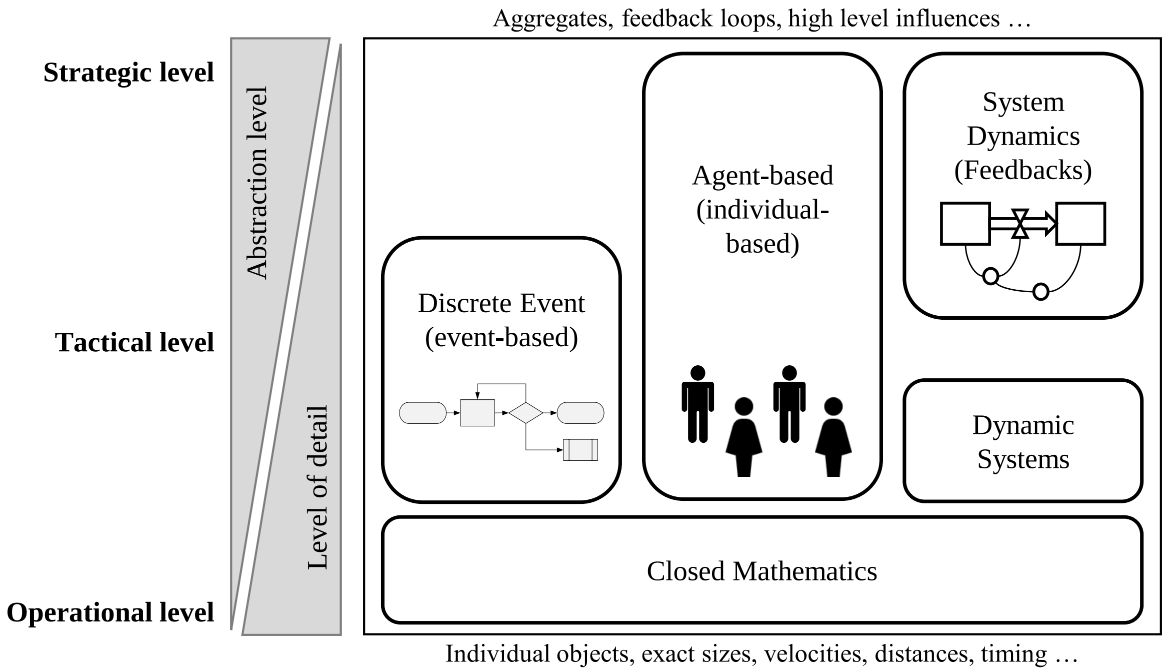

Figure 3.10: Paradigms in Simulation Modeling on Abstraction Level Scale, adapted from Borshchev and Filippov (2004)

3.3 Paradigms

The system of interest can be observed from different levels and point of views, with respect to the modeling objectives. In figure 3.11 different simulation paradigms and their characteristics are illustrated. The paradigms differ by abstraction level (system-level or individual-centric), by continuous or discrete state changes, by aggregation level. Certainly a combination of the different paradigms is also possible, called multi-method simulation approach. From a historic point of view, the paradigms SD and DES are known since the middle of the last century and therefore more popular and common in research and industry. However, AB is the youngest paradigm and was mainly used for academic purposes for a long time. In the last years, AB has also become more generally used in industry due to the increasing requirements as for example complexity of systems, global business optimization. (Borshchev and Filippov, 2004)

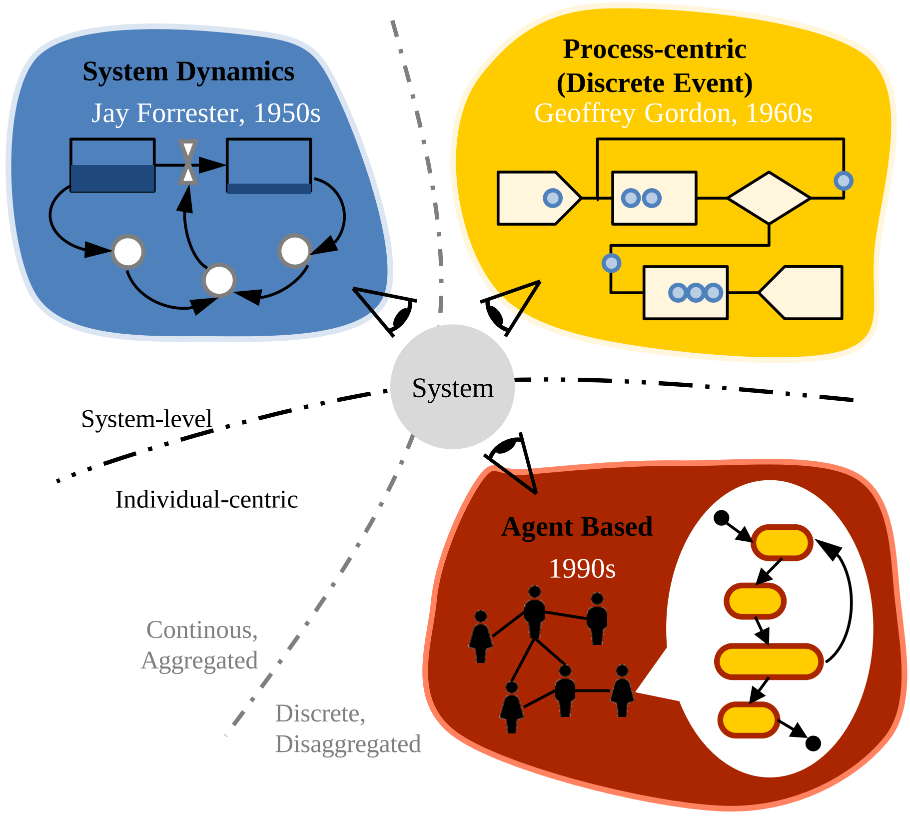

Figure 3.11: Simulation paradigms (AnyLogic, 2016)

3.3.1 System Dynamics

System Dynamics (SD) was developed in the late 1950s by Jay Forrester with the intention to model business and social systems. The application varies from modeling of SCs to the entire world. The focus of SD is on high-level strategic issues and policies. State changes of the represented dynamic processes are continuously over time. SD models consist of stocks and flows. Stocks are the variables of the system, that usually represent average values. They describe the system's state. Flows describe the behavior of stocks over time, which are mathematically formulated as differential equations. The approach of stocks and flows is based on a hydraulic metaphor. It can be compared with a bathtub (stock), which has a water supply (inflow) and a waste pipe (outflow). The differential equation for the change in stock (water reservoir) is: (Tako and Stewart Robinson, 2012; Borshchev and Filippov, 2004; North and Macal, 2007; Sterman, 2000)

$$\frac{\mathrm{d}Stock(t)}{\mathrm{d}t} = Inflow(t) - Outflow(t)$$

SD models are deterministic models and do not consider unpredictability or randomness. As the focus is on the understanding of the whole system's behavior, considering unpredictability and randomness does not make a big difference and is therefore disregarded. Moreover, SD is a top-down modeling approach. A common example for using SD is the 'Beer Distribution Game' demonstrated by John Sterman and shown in figure 3.12. (Tako and Stewart Robinson, 2012; Borshchev and Filippov, 2004; North and Macal, 2007)

3.3.2 Discrete Event

The origin of Discrete-Event Simulation (DES) was in the 1960s made by Geoffrey Gordon developing his ideas of General Purpose Simulation System (GPSS). Since then DES is a widely used tool in research and industry, mainly at tactical level. DES is often used for the simulation of queuing systems from, waiting lines in daily life such as the queues in the supermarket, to applications in business and industry for example production lines. As the name assumes, changes respectively events are only at discrete points of time. At this points in time an event occurs possibly causing a status change. As an example the mean waiting time at the cash desk of a supermarket is investigated. The arrival of a customer at the cash desk is an event and causes a status change: either the status of the cashier changes from idle to busy or the queue increases by one. The departure of a customer is an event too. DES models are a network of

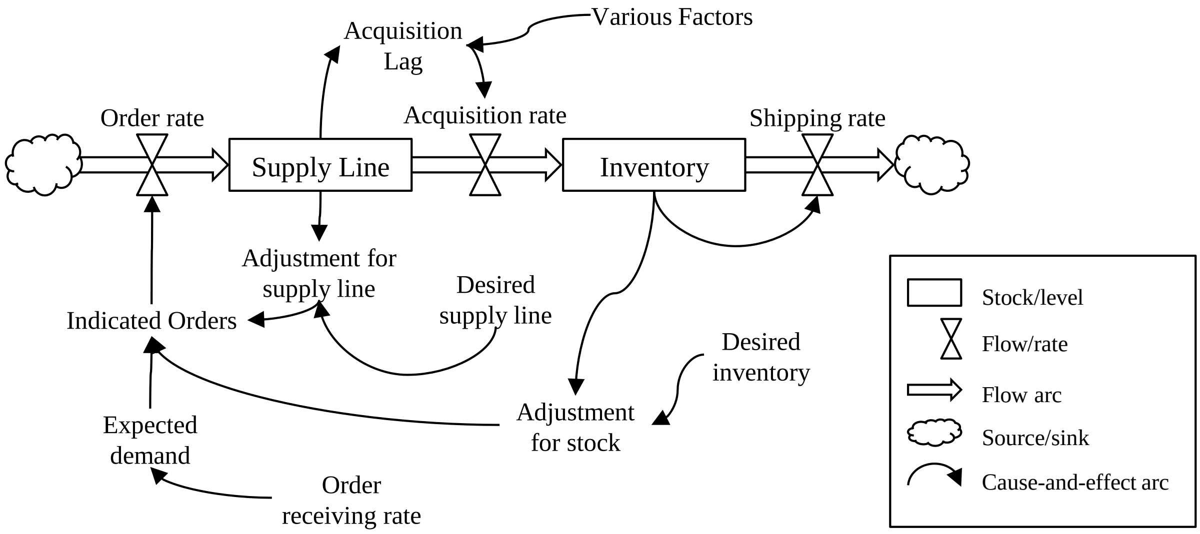

Figure 3.12: Beer game, retailer agent, SD causal loop diagram, adapted from North and Macal (2007, p.68)

queues (key element) and activities. Entities (objects, people, tasks) are not aggregated, but rather represented individually and provided with attributes determining what occurs because of simulation. DES are stochastic models and consider unpredictability and randomness, which seems to be obvious when considering that DES has its roots in Monte Carlo simulation. Besides, it is a top-down modeling approach. DES is often used for queuing problems and when processes and relations can be seen as static that means they do not change with time. An example for using DES is the everyday schedule of a distributor, shown in figure 3.13. (Tako and Stewart Robinson, 2012; Borshchev and Filippov, 2004; North and Macal, 2007; Law, 2015)

3.3.3 Agent-Based

Agent-based Simulation (AB) is the most recent technique with increasing interest since the beginning of the new millennium. As opposed to the before mentioned simulation techniques, the focus of AB lies on the agents, an individual having its own autonomous behavior and making its own decisions. Agents are also able to learn and adopt their behavior. Therefore, it is used to simulate humans respectively when the interaction of individuals is of interest. Examples are consumer market, spread of epidemics, but also SCs. The global system behavior is not determined, it results from the agents' interactions (directly and indirectly). (Borshchev and Filippov, 2004; North and Macal, 2007; Law, 2015)

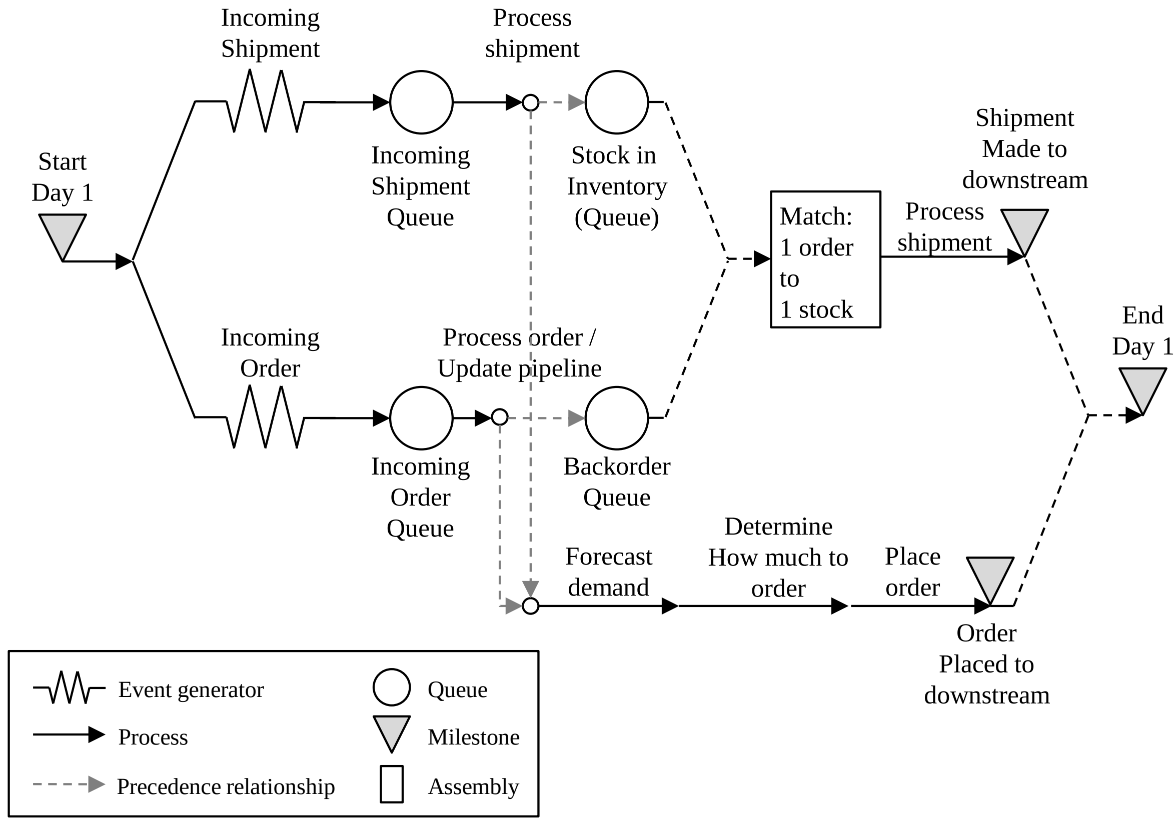

Figure 3.13: DES model for the SC distributor (North and Macal, 2007, p.73)

AB are highly stochastic models. Furthermore, it is a bottom-up approach. In figure 3.14, the world of a SC agent on the right side, as well as its representation on the left side, are illustrated. (Borshchev and Filippov, 2004; North and Macal, 2007; Law, 2015)

3.3.4 Monte Carlo

Monte Carlo simulation was developed around the middle of the last century, is a well known and popular method and refers to the field of operations research. Monte Carlo simulation is used in various business systems, for example SCs, when a system has uncertainties and randomness. Monte Carlo simulation gains insights into the performance of the system by considering randomly varying input factors and into the probability distribution of output variables by executing a large number of experiments. Therefore, the probability distributions of the factors causing uncertainty need to be determined. State variables mainly change at discrete time intervals, but continuous changes can also be treated by Monte Carlo simulations.

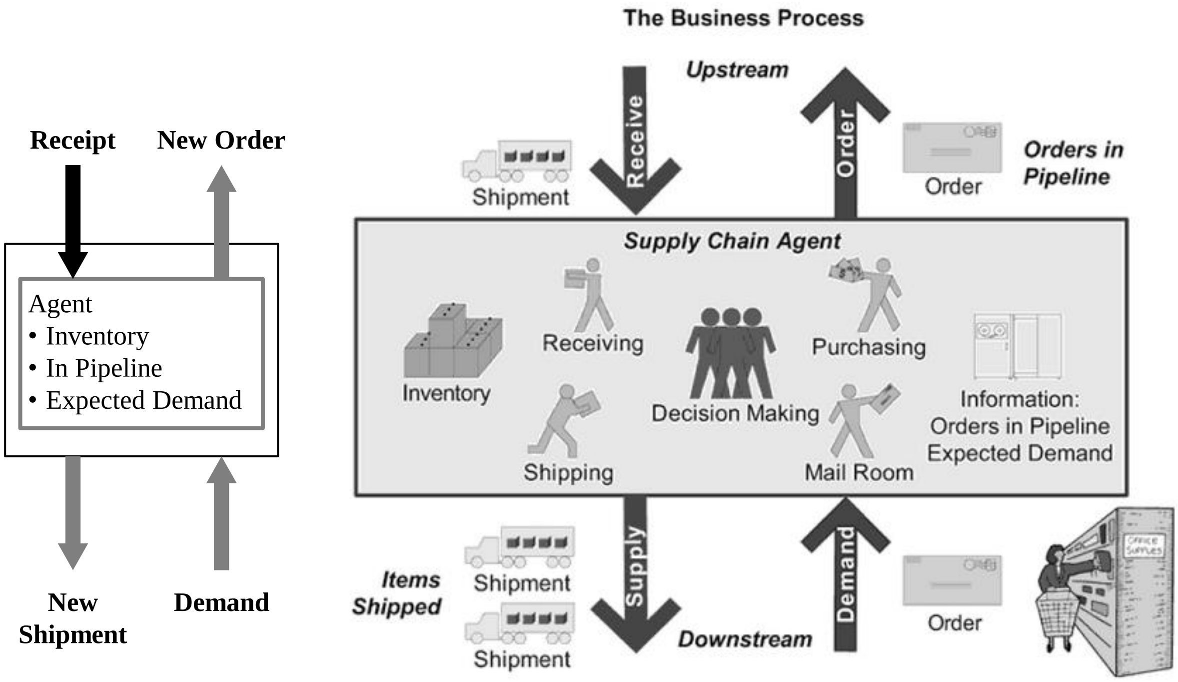

Figure 3.14: SC agent - representation and world, based on North and Macal (2007, p.89f)

Statistical analysis is needed to evaluate the results. Monte Carlo simulation does not optimize systems' behaviors. (North and Macal, 2007; Shapiro, 2007; Law, 2015)

Finally, the first three, above mentioned, paradigms are summarized in table 3.2.

Table 3.2: Comparison SD - DES - AB, adapted from Gunal (2012, p.23)

SD	DES	AB
Group focus (Cohort)	Individual focus (Entity)	Individual focus (Agent)
Rates are defined	Processors defined	No processors defined
Rules are defined in differential equations	Rules are defined in processors	Rules are defined in Agents (autonomy)
Queues exist explicitly but as levels	Queues exist explicitly	Queues exist implicitly
Rates derive the simulation	Event derive the simulation	Local environment and agents drive the simulation
Mostly deterministic	Mostly stochastic	Mostly deterministic
Stepped time intervals	Discrete time intervals	Stepped time intervals
Top-down	Top-down	Bottom-up

3.4 Applications in Supply Chain Management

As Terzi and Cavalieri (2004) have pointed out, simulation can be a very powerful tool to support decision makers in a multi-decisional environment like SCs. Simulations are often used to provide what-if-analyses and to assess benefits in terms of numbers respectively quantitatively, which are key properties of simulations. Different decision scenarios can be tested, reproduced and compared to each other in order to find out the most optimal and robust strategy.

Semini and Strandhagen (2006) identify some reasons for using simulation as a decision support tool within manufacturing logistics. First, a simulation model can help to grasp a better understanding of the real system and its behavior. Second, the process of building a simulation model provides new insights into the system and its relations assisted by a systematic approach. Third, it eases communication with other parties and can be a good starting point for discussions. Lastly, it allows to run different scenarios, analyze and evaluate the results by what-if analyses without affecting the real system.

An example of applicaton is the research of Nguyen and Takakuwa (2008), who study the use of simulation to evaluate different manufacturing line designs in Japanese automobile manufacturing plants. The design and redesign of manufacturing lines is mainly based on the experience of engineers. The authors show the possibilities of simulation in this context and its advantages. They apply the simulation approach to set up a new cellular welding manufacturing line. Three types of manufacturing lines are investigated: a manual production line, an automated line and a hybrid line. With regard to utilization, line productivity and manufacturing costs they discovered that the hybrid manufacturing line achieves the best results and will be realized. Furthermore, the simulation study has reduced project time and costs in terms of investment.

In a literature review, Semini and Strandhagen (2006) investigate the areas of applications of simulation within a SC context, limited to discrete manufacturing companies and the usage of DES. Discrete manufacturing companies produce individual parts such as cars, semiconductors, in contrast to continuous production, for instance oil or electricity. The review shows that simulation is often used to design production systems. Another application is the evaluation of production policies including lot sizes and Work in Progress (WIP) levels. Furthermore, simulation is used in the fields of: short-term planning and scheduling, inventory policies, physical plant location, distribution system design and materials program (assemble-to-order strategy). Another observation of the literature review was that the leading industries in using simulations are the semiconductor and the automotive industry, and mainly large companies.

Pfeiffer, Anwander, and Hellingrath (2013) investigate the issue SC flexibility and developed an approach to evaluate it by using DES. Flexibility is closely related to costs, more flexibility often means increasing costs. But flexibility is an important issue in volatile markets and variations in demand are a significant point why flexibility in SC is needed. Therefore, a trade-off between flexibility and costs has to be found. The study focused on volume flexibility. The authors applied their approach to an SC in the table-top product manufacturing industry. For instance, table coverings, cups & glasses and candles are part of the product portfolio. There are also seasonal products. The study is limited to two flexibility measures: safety stock levels and production lot sizes. There are three major constraints to the SC volume flexibility: low safety stocks and therefore low tied up capital versus high flexibility, flexible production by using small lot sizes but high safety stocks for raw material and higher set-up costs, variable lead times for the raw material between 4 and 16 weeks due to production processes. For measuring the performance, three indicators were used: delivery reliability, deviation in demand that the SC is able to cope with and the operational costs. The results show that the simulation-based approach allows to find the optimal combination of flexibility measures and as a consequence, it can support managers in decision making.

A study made by Deleris and Erhun (2005) investigates the application of simulation to SCRM. In a use case for a high-tech company in the Silicon Valley, they develop a tool to evaluate unpredictability in SC networks. The initial question of the management concerns strategic SC issues: selection of partners and geographical locations. The authors' approach uses a flow model to determine the network in terms of possible network paths and mass flow combined with a Monte Carlo simulation. The network vulnerability is quantified by 'loss of product volume', which is converted into a financial loss. The task of the Monte Carlo simulation is to determine the probability density function of the measures. For the use case, the following risks are chosen: strikes, shortage of components, political instability, natural disasters (hurricanes). The simulation provides information about losses for each product family, which are aggregated to quarterly losses and their probability density function. The flow model has some limitations: the network is assumed to be static and the generated mass flow was roughly estimated. To cope with this limitations the flow model could be replaced by DES.

In a recent study, Chen et al. (2013) analyzed the usage of AB in the context of SCRM, as AB is an appropriate tool to simulate complex systems. Therefore, traditionally mathematical models often in combination with Monte Carlo simulation or Design of Experiments (DOE) are used. Because of the increasing complexity of SCs, Chen et al. (2013) argue that AB has a lot of potential in solving such complex and adaptive systems. The literature review shows that by now there is in comparison only a little number of studies within this context. The authors pointed out different applications: risk identification and assessment, risk response, risk monitoring and evaluation, SC planning on different levels, SC robustness and flexibility. For example, one study has *developed simulation models based on several networks to evaluate stochastic demand and supply disruptions*. Another one has developed a model to optimize inventory using the *transshipment policy for multi-location inventory system with several retailers who share a common supplier*. A further example treats a model that ensures the product availability to the customer considering disruption risks and uncertainty.

It can be summarized that there are many possibilities to apply simulation to SCRM issues. In the case study, which is described in the next chapter, a possible application of these techniques within this context is discussed.

4 Case Study

In the following sections, an overview of the initial situation is given. The business partner, with whom the case study was developed, is introduced as well as the products investigated. The SC is described and the important characteristics are highlighted in particular. Furthermore, an analysis of an existing SC is done using a questionnaire and a value stream analysis. The value stream investigation provides useful information on purchase and sales volumes and mass flows. Next, arising risks along the SC are investigated, discussed and evaluated. To be able to compare and assess these risks in a simulation study, it is necessary to find quantitative values to measure them. Therefore, appropriate indicators are analyzed. Finally, a simple prototype for risk information related to countries is illustrated.

4.1 Initial Situation

The initial point for this case study was the question of the business partner LD, who is introduced in the following section, how the company can use modeling and simulation as a tool for evaluating SC configurations, especially new set ups. The innovative and strongly growing middle-size company is facing new challenges. Therefore, SCM and Risk Management issues become more, and more important and appropriate tools to support these processes are needed. In the following sections the initial situation is described in more detail.

4.1.1 Company and Products

This case study was developed together with the business partner LD. LD was founded as a sole proprietorship in 1994 by Walter Koch in Aichegg, Styria, Austria. Three years later the company was transformed into a limited liability company. In 2001, the first assembly line in Hungary was opened. The first subsidiary was founded in 2011 in the USA, one year later the subsidiary in Maribor, Slovenia was established. In recent years, the company has grown extensively. The headquarter in Deutschlandsberg has just been extended, the number of employees is constantly rising. Today LD is a medium-sized company with around 226 employees at four locations: Deutschlandsberg (Austria, Headquarter), Maribor (Slovenia), Grand Rapids (USA) and Hong Kong (China). A more detailed illustration is provided in figure 4.1. (Logicdata, 2016)

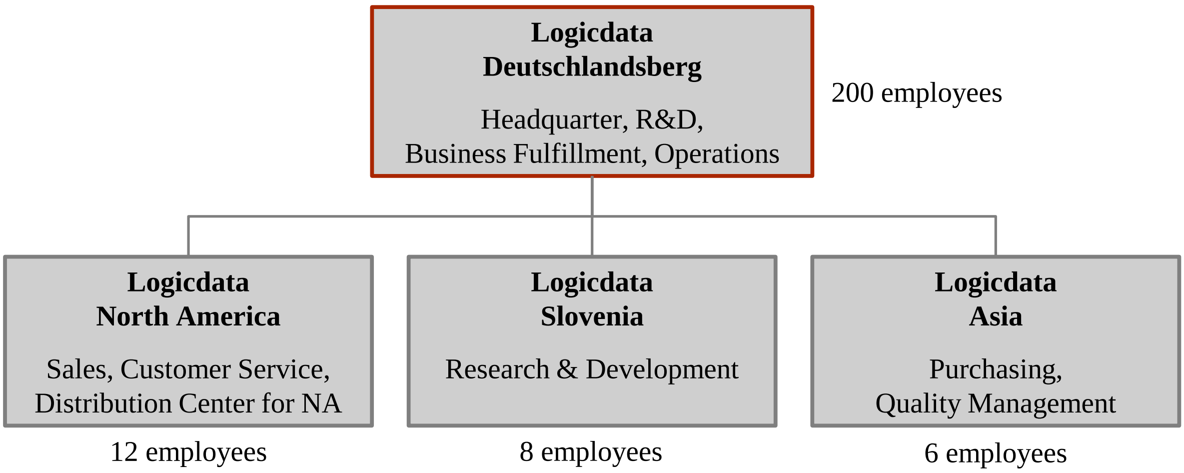

Figure 4.1: LD Group

The company is active in the field of micro-controller-based control units and operating elements for ergonomic solutions serving the furniture industry. The business unit 'Logic **Office**' is engaged in drives and controls for height-adjustable office furniture and the business unit 'Logic **home**' in drives and controls for adjustable beds, motion furniture and recliners. An overview of business units and products is given in table 4.1.

Table 4.1: Business Units

Product Group	**Business Unit**	
	home	**Office**
Control Units	x	x
Handsets	x	x
Accessories	x	x
Power Supplies	x	
Drives		x

Logicdata's Customers are primarily furniture manufacturers and suppliers of drive systems for the furniture industry. With reference to the supply pyramid (see figure 4.2) LD is a system supplier (1st-Tier-Supplier) as well as a module supplier (2nd-Tier-Supplier), depending on the investigated products.

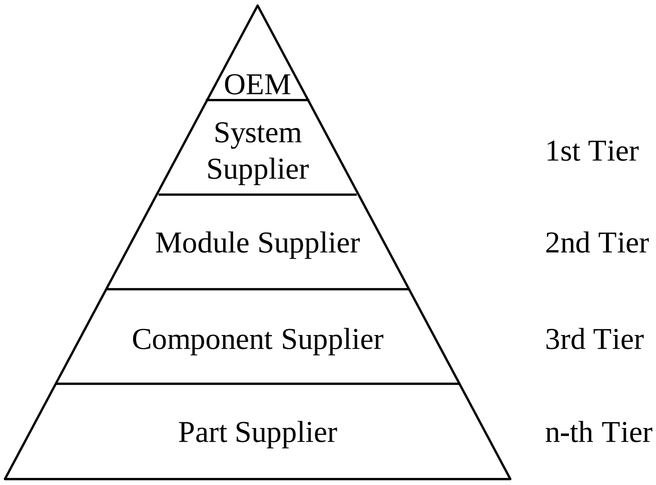

Figure 4.2: Supply Pyramid, based on Beckmann, 2012, p. 42

The main sales volume for the business unit 'Office' is currently situated in Germany, Scandinavia and the United States of America, while the business unit 'Home' is based in the United States of America. The company is expanding into new geographical markets hence, first customers could be acquired in China and Australia. In 2015 LD sold one million control units and 150.000 drives, leading to a revenue of EUR 65 millions. In 2016 LD could increase sales to 1.3 million control units, to 400.000 drives and to a revenue of EUR 70 millions. (Logicdata, 2016)

In contrast to the previously mentioned sales markets, the procurement markets are in Austria, Germany, Hungary, Czech Republic and China. It can be seen that there is also some logistic effort necessary to serve the customers in North America, as there is no production site nearby. The production process has some particular properties which leads to a specific SC setting that is described in the following section.

In figure 4.3 the product portfolio of LD can be seen as well as some product examples for each segment. LD started in the field of control units and developed the first user-programmable control box in 1999. Therefore, the main sales volume is made by the segment 'control units' thus far. LD intends to extend their portfolio and therefore, grow in the segment 'drives'. It is planned to sell 800.000 drives in 2017 and 1.2 million drives in 2018. As there is a major focus on this product segment by LD, it is of special interest in this thesis.

Figure 4.3: LD Product Portfolio (Logicdata, 2016)

The present case study is focused on the business unit 'Office' and the product group 'Drives'. Currently, there are three different models on the market:

- SLIMdrive-500: Inline actuator for single-stage legs
- SLIMdrive-660S: Inline actuator for dual-stage legs
- LOGICdrive-660: The first intelligent inline drive system, which integrates the control box into the drive itself.

4.1.2 Characteristics of the Supply Chain Setting

Firstly, it is necessary to look at the main characteristics of LDs SC setting. The most noticeable attribute is that LD has no production, this means manufacturing and assembling are entirely outsourced to suppliers. At this point, it is useful to look at the different process steps, which are illustrated in figure 4.4.

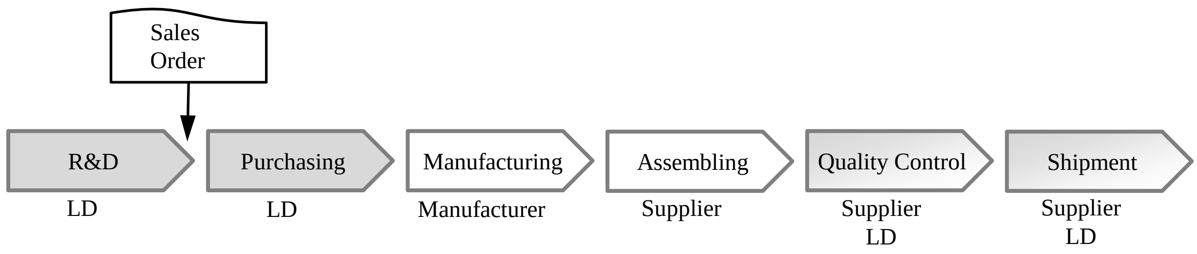

Figure 4.4: Process steps

Research and development is done by LD, mainly at the headquarter. When the product is ready to be manufactured, all parts (for example electronic and mechanical components) will be purchased from suppliers and delivered to the LD headquarter Deutschlandsberg. There, goods are received and distributed to the external assembling companies. In some cases the purchased parts are sent directly to the assembling company by the part supplier, mainly in established long-term partnerships between the parties. LD does an incoming control of the parts and makes randomly quality checks to ensure the quality level and to avoid that defective parts are delivered to the assembling company respectively manufacturer. Quality control for the assembled product is split up between LD and the manufacturer: The quality processes and the equipment for quality control are developed and provided by LD. Executing the quality control is the manufacturer's task. For the shipment to the customer afterwards there are different possibilities: Either the parts are sent to LD in order to be selected and distributed from there, or the parts are sent directly to the customer. The various routes of the parts (in different production stages) can be seen in figure 4.5. The black arrows show a standard connection between the SC partners. The different part suppliers (PS^n) deliver their parts to Logicdata Deutschlandsberg (LD DL) ($LD_{EU}{}^1$). Subsequently, the parts are delivered to the manufacturer (M^n) and then back to LD DL. From there the products are sent to the customers in Europe ($C_{EU}{}^n$) and to Logicdata North America (LD NA) ($LD_{US}{}^1$). The grey arrows are alternative routes.

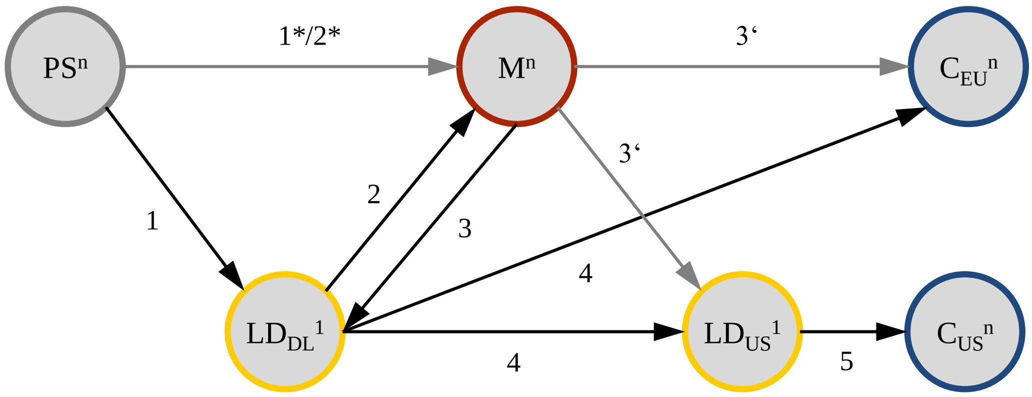

Figure 4.5: Supply Chain

Figure 4.5 illustrates the different roles of LD within the SC well. The headquarter plays an essential role in distribution, as it collects most of the purchased parts in Deutschlandsberg and distributes them to the individual SC member. When the products are assembled, they are picked up by a logistic partner and brought back to Deutschlandsberg. The logistic partners usually do regularly round trips. There, the products are packed and sent to the customers. LD US also figures as a distribution center, although it is smaller than Deutschlandsberg, because only customers in the United States of America are supplied by it. The company monitors all delivery times and has to consider all lead times, which can be up to approximately 30 weeks. They also take account for lead times of 'tier minus two' suppliers, although their own SC only reaches to tier one. For instance, purchasing of electronic parts is such a case. The electronic components like resistors, semiconductors, etc. are bought from a distributor in Austria, who purchases them somewhere in Asia. Some of them are on stock at the distributor, but others have to be shipped from Asia to Europe. Therefore, it is necessary to keep the long lead time of this parts, mainly due to shipping, in mind. Another case could be that LD specifies a certain part that has to be used, but the part is a component of an assembly, which is purchased en bloc. Therefore, the assembly is treated by LD like a single part, but needs more attention regarding lead time under some circumstances . An example for this case is explained in more detail in section 4.1.3.

To sum up, Logicdata's SC reaches to tier one, manufacturing and assembling are outsourced, despite monitoring of delivery times is done for all parts. LD has an important role to control processes along the SC. The next section provides a detailed explanation of a certain product's SC.

4.1.3 Analysis of an existing Supply Chain

For a more detailed insight into an existing SC the product SLIMdrive-660S was chosen, which is shown in figure 4.6. The SLIMdrive-660S exists of three assemblies:

- Gear Motor
- Spindle System
- Electronics.

Figure 4.6: SLIMdrive-660S (Logicdata, 2016)

The SLIMdrive-660S consists of 11 parts and 3 modules. The module 'Spindle System' consists of 26 parts, the module 'Electronics' of 10 parts. Figure 4.7 illustrates a simplified structure of the product.

The parts for the module 'Electronics' are mainly electronic components, like resistors and semiconductors. All parts are purchased by LD, whereby most components are bought from a distributor due to the fact that the purchase volume is not large enough to buy from suppliers, for example in Japan, directly. All components are delivered to LD, packed and sent to a company in Hungary, that assembles the Printed Circuit Board (PCB). As the design of the PCB is a key competence of LD, the Business Partner decided to make this production step in Europe, for reasons of secrecy and the assumed higher risk of intellectual property breaches in countries outside of Europe.

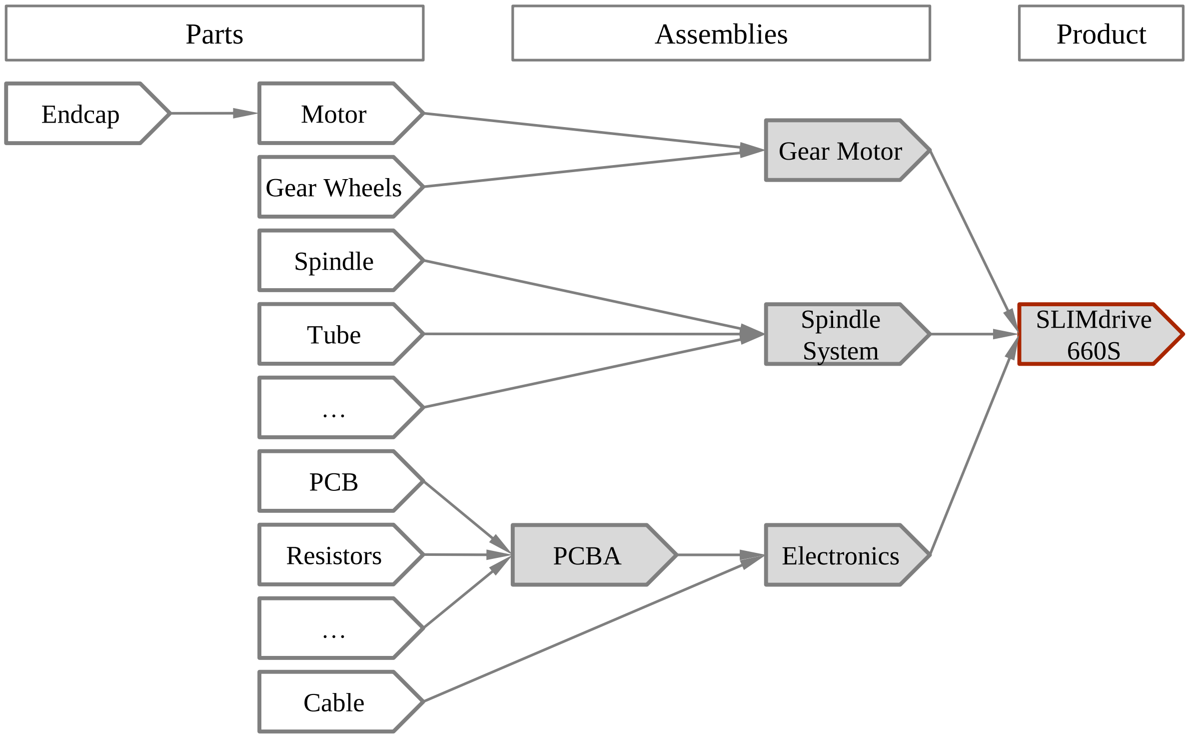

Figure 4.7: SLIMdrive 660S

To illustrate the goods and information flow, the part 'Motor' of the module 'Gear Motor' is chosen as an example, because it is a critical part, mainly due to long lead times, but also due to high quality requirements. As it can be seen from figure 4.8 the motor is purchased from a Chinese supplier. From Logicdata's point of view, the motor is treated as a single part, even if it consists of many parts and is, in fact, an assembly. However, LD influences the Chinese supplier in choosing his suppliers. This means for a certain part, the so called 'Endcap', LD specifies a German supplier due to very high quality requirements, which can only be fulfilled by this specific supplier. For logistics and lead times this implies that the endcap is delivered to the Chinese supplier, where it is assembled with the other parts and finally shipped to LD in Europe. In terms of delivery times, this means approximately 10 weeks for the delivery of the endcaps from Germany to China and approximately another 10 weeks for the delivery of the module 'Motor' from China to Austria as the parts are shipped. As a result, this means a lead time of approximately 20 weeks without the time needed to produce the motor.

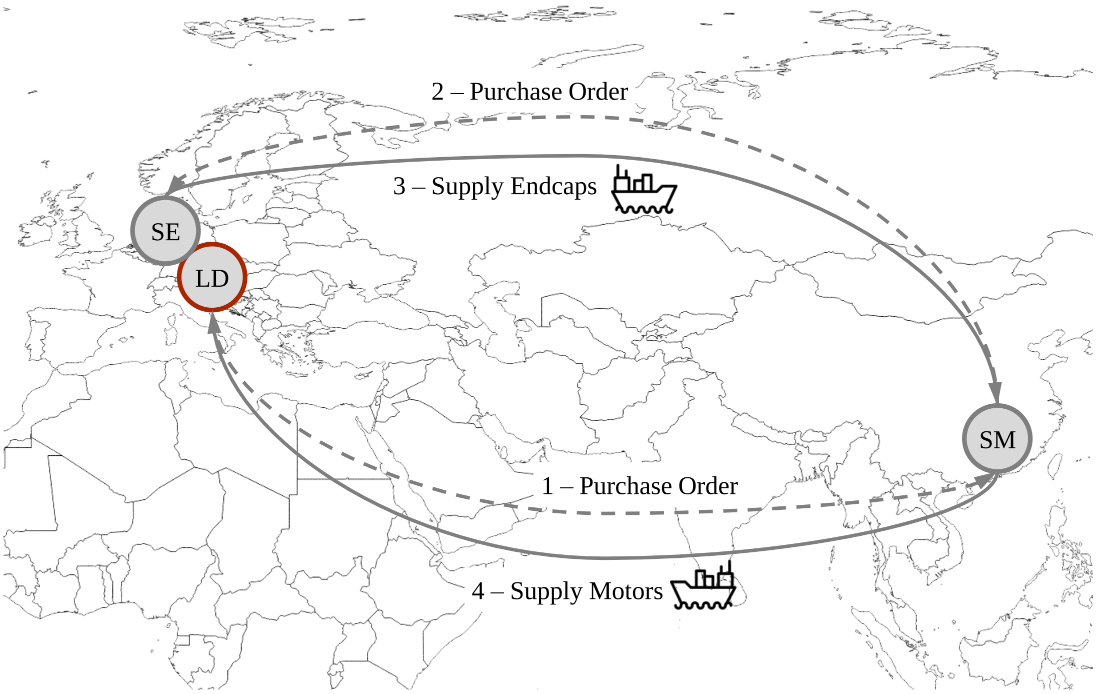

Figure 4.8: Module Motor - Information and goods flow

Compared to the lead time of some parts of the SLIMdrive-660S, LD customers demand shorter delivery times, for example two to four weeks. Short delivery times on customer side have a big impact on the supplier side, respectively purchasing. As a result, demand forecasts as well as appropriate purchasing strategies are of high importance.

This leads to one major intention of this thesis, namely the capability of modeling and simulation tools to evaluate various SC configurations. Before thinking of different configurations, it is necessary to understand the existing system in more detail, also in terms of numbers. Therefore, a questionnaire was made and a value stream analysis of the company as well as for the specified product is done in section 4.1.4.

The questionnaire was based on a form of McKinsey&Company, n.d. and consists of six topics (see figure 4.9), which are queried in 113 questions. For the answers a five-part range was chosen: Not at all, To a limited extend, To a moderate extent, To a great extend and To a very great extend. It was answered by two respondents: Respondent A represents the department 'Supply Chain Management' and respondent B the department 'Strategic Purchasing'. The full questionnaire and the individual answers can be found in the Appendix.

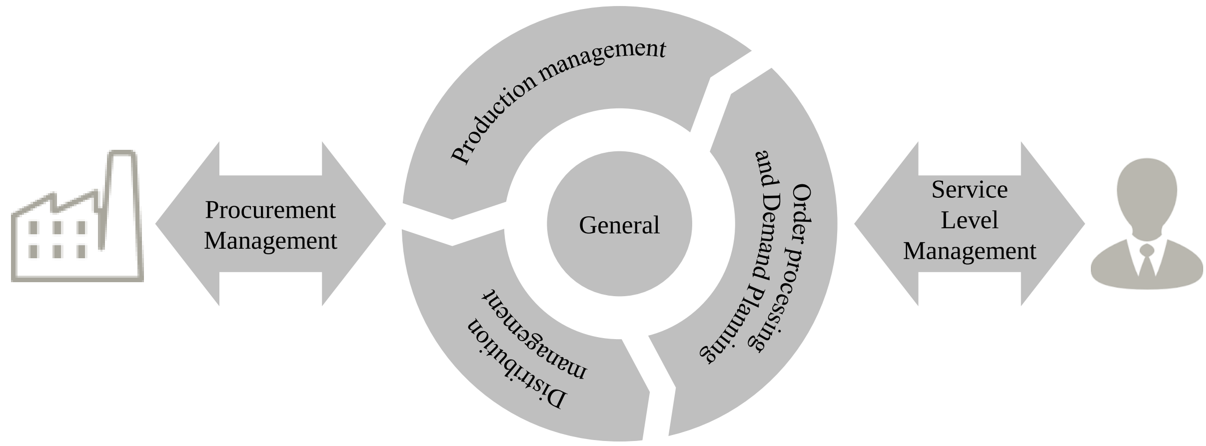

Figure 4.9: Questionnaire - Topics

In a first analysis the response frequencies were investigated and illustrated in figure 4.10. Respondent A chose answer 'to a moderate extent' most often, followed by 'not at all'. It should be noted that respondent A chose seven times two adjacent answers and one time no answer. The possibility 'To a very great extent' was not picked at all. Respondent B on the other hand selected the various options more equally distributed with a little preference for 'To a very great extent'. Considering the total frequency, which means the sum of respondent A and respondent B, it can be noted that the answer in the middle, 'To a moderate extent', was chosen most often, followed by 'Not at all' and 'To a limited extend'. The remaining two answers 'To a great extent' and 'To a very great extent' are equally distributed.

In a next step the averages of the answers of respondent A and B were calculated. After that the averages per group were determined. In figure 4.11 the response values of both respondents and the averages are shown.
In the field of 'Customer and Service Level Segmentation' LD has a moderate position. Customer segmentation and the mapping to service levels were not, or were hardly, used. Already more attention is paid to things, which influence prices directly like express or standard delivery. With 'Service level measurement' LD is already more familiar and is evaluated good. The group 'Service Level Management' appears good. It seems that 'Principles of Order Processing' are already used in daily business, because this subgroup is evaluated as very good. Also 'Demand Planning' is well implemented. Only the regularity of logistics planning can be improved and the usage of statistical methods for planning models could be an idea for future thoughts. 'Order Generation and Processing' outlines good too. Here mainly the support by IT-systems and automation is not that much as it could be, but it is constantly enhanced and extended. At

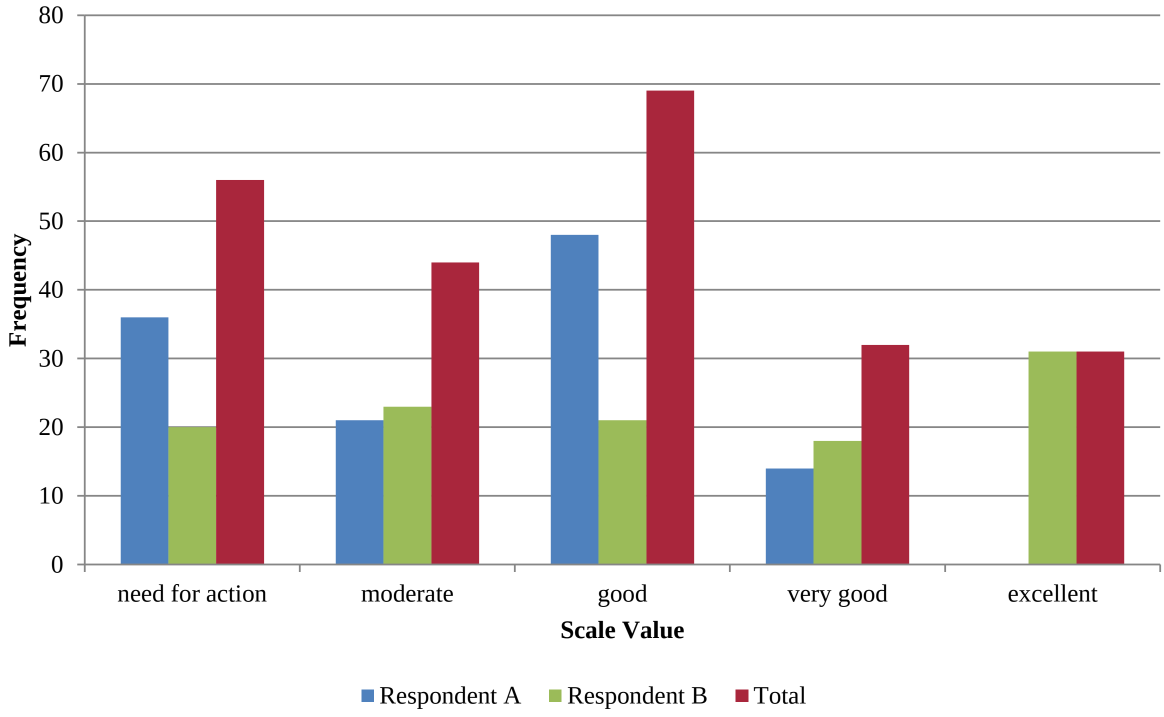

Figure 4.10: Response frequencies

this point it should be stated that LD started two years ago with the implementation of the ERP-system Microsoft Dynamics AX. Since the last year the system of LD US has also changed to the new system of LD Deutschlandsberg and the data have been transferred.
'Production Planning' got also a good mark and the weak point is either the IT-system support. 'Capacity Management' shows up good basically. The delivery date can not be confirmed on the day of order receipt, but normally within three days, which seems sufficient. Emergency plans for suddenly production losses do not really exist. In the past, there were problems with suppliers suddenly canceling capacities, but fortunately no production losses due to force majeure. For the first case strategies exist, but are not formalized, the second case should be kept in mind. All in all 'Production Management' is fine.
'Supplier Management' is already very good established in the company. Further improvements can be made in the regularity of supplier evaluations and in the optimization of the SC process by using concepts like just-in-time delivery for example.
Whereas 'Inbound Logistics' is only moderate positioned. On closer examination weak points are electronic interfaces and IT-systems. 'Procurement Management' can be described as good. 'Distribution Network' is evaluated as good, 'Warehouse Management' as moderate. Automation by electronic devices like using transponders and barcodes is not widely used yet and

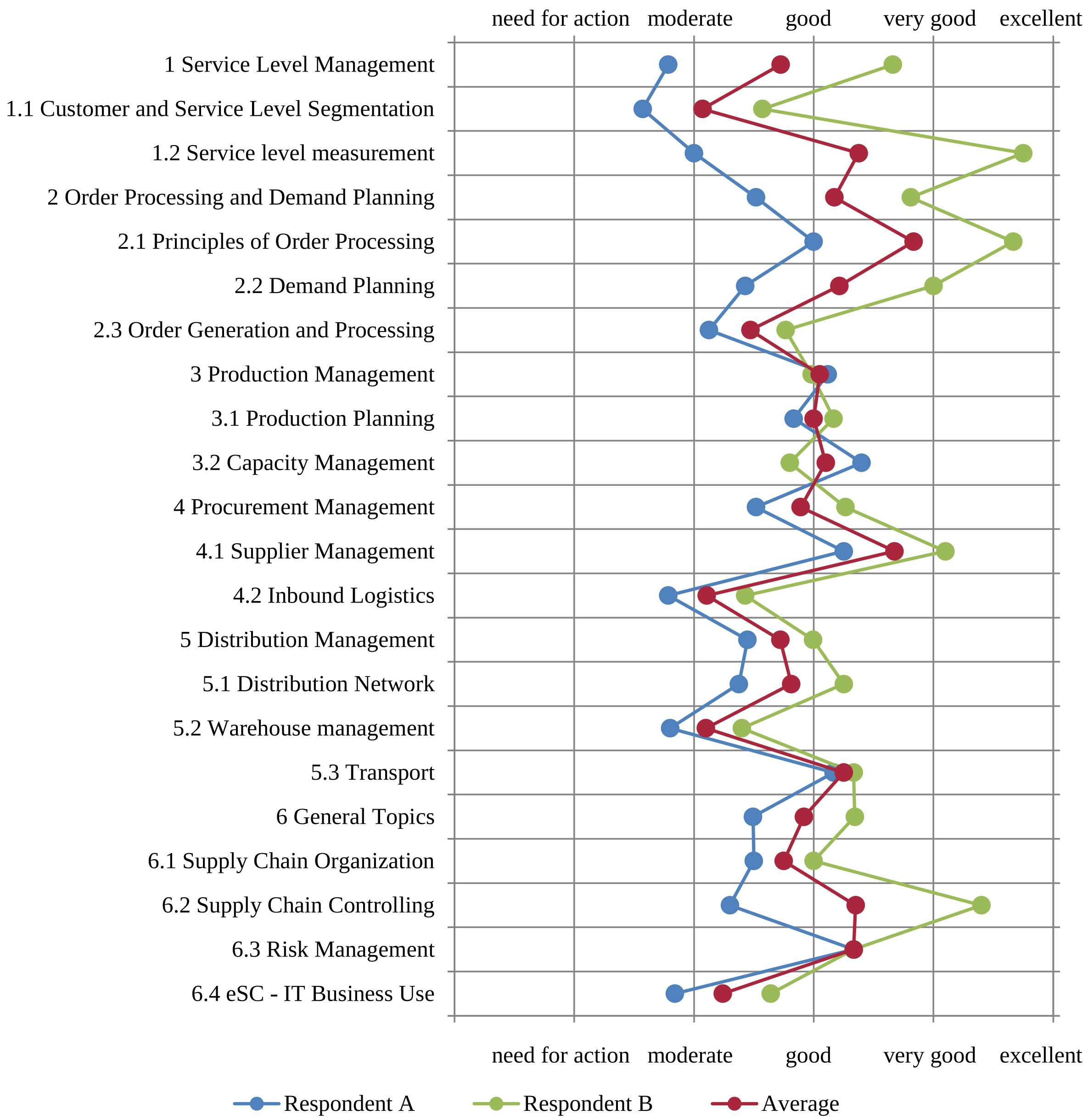

Figure 4.11: Averages of responses per group

offers potential for improvement. 'Transport' is rated good, the utilization could be increased. 'Supply Chain Organization' seems to be good, the responsibility for overall SC objectives needs to be positioned at the senior management. 'Supply Chain Controlling' and 'Risk Management' appear good as well. The last group 'eSC - IT Business Use' is evaluated moderate, which is not surprising, as in former issues the lack of IT-system support and automation facilitated by electronically devices were weak points.

Finally the differences in the evaluation of respondent A and B are investigated. In 29 questions respondent A and B agree, in 39 questions there is a difference of one point. That means that in 60 % of the questions respondent A and B (almost) agree. In 25 % of the questions the difference between the answers is more than one point, but equal or less than two points. In the other 15 % the difference is more than two points. In 7 questions the difference is four points, which means an opposite point of view of the respondents and these questions are examined more closely. The relevant questions are listed in table 4.2.

Table 4.2: Questionnaire - Opposite viewpoints

Supply Chain Analytics					
Please mark the most suitable answer with "x".	Not at all	To a limited extend	To a moderate extent	To a great extend	To a very great extend
	1	2	3	4	5
1.2 Service level measurement					
Do you consider the costs associated with the service level requirements, when you evaluate the profitability of customers or products?	A B				B
2.1 Principles of Order Processing					
Does your planning process assign resources and capacities correctly and as far as possible automatically to the current demand?	A		A B		B
2.3 Order Generation and Processing					
Are stability and reliability of your delivery times measured and depending on the result corrective actions taken?	A			A	B
6.2 Supply Chain Controlling					
Do you measure the overall performance of your supply chain after every significant step from the starting point of the supply chain to the end customer?	A				B
6.4 eSC - IT Business Use					
Does your planning process assign resources and capacities correctly and as far as possible automatically to the current demand?	A		B	A	B
Are the numbers of unintended "0"-stock levels tracked and are the causes investigated?	A			A	B

These opposite view points are discussed with both respondents. The review of the answers has led to changes in the answers, which are shown in blue color. As a result there is an agreement concerning the question in group 1.2, as there are different costs for various service levels, but the profitability of the customer or product is not evaluated in this way. Additional to the question in group 2.1 respondent A remarked, that the order processing does not happen automatically. The property 'automatically' was obviously higher rated by respondent A than by B and results in this opposite point of view. After discussing this opposite view point with respondent B, the answer was corrected to 'to a moderate extent', because the resources and capacities are assigned, but not automatically. Respondent A reviewed his answer for group 2.3 to 'to a great extend'. Delivery times are monitored by the lead buyers and in weekly status meetings possibly arising problems are discussed and necessary actions defined. To the question in group 6.2 respondent A noted that not all employees were familiar with these measures, but this has been changed now. Respondent B stated that the performance is measured by CLIP and RLIP rate, for example. In weekly meetings the important measures are presented on a one pager. Regarding the questions in group 6.4 respondent A revised his answers to 'to a moderate extent'. It bears mentioning that no aggregated average value was evaluated 'need for action'. Furthermore, it has to be noted that the company has already started some improvement processes, especially regarding the IT infrastructure.

4.1.4 Value Stream Analysis

Purchasing parts and products are sourced from and delivered to different countries, main sales markets are obviously not main purchasing markets. For a more in-depth understanding a value stream analysis of the sales values as well as of the purchasing volumes was done. Data from the years 2014, 2015 and 2016 were used. It has to be mentioned that the data of 2016 refer not to a full year, but to a half year (January to June). The business year from LD ends with February, albeit the analyses were carried out according to the calender year. First the sales values were analyzed, followed by the purchasing numbers.

Turnover

For the value stream analysis the turnover prognosis was provided by LD. In 2014 data were available only from October to December, which was too less, so therefore this analysis was reduced to the years 2015 and 2016. Based on the customer the country was added to the raw-data and the products were categorized for reasons of simplifications. From the overall prognosis all datasets referring to samples, item numbers beginning with '300. . . . ', transport or insurance cost were excluded.

About the shares of the business units 'Home' and 'Office' it can be stated, that approximately one out of four is related to 'Home' and the other three out of four to 'Office'. It is remarkably that the total share of 'Home' is made in the United States of America, as can be seen in figure 4.12.

Figure 4.12: Turnover 2015 - Home and Office

Following the categories added to the items, the categories were aggregated in 'main categories': Accessories, ACS, Cables, Drives, Handsets and Control units. The exact classification can be found in the Appendix. An interesting aspect is, that about 68 % of the sold products in 2015 were control units. The share of drives was only approximately seven percent. The partitions of the overall categories can be seen in figure 4.13.

In figure 4.14 the turnover in 2015 and the first half year 2016 is shown for the 'Top-Ten customer countries'. It can be noted that in 2015 85 % of the total sales volume was gained

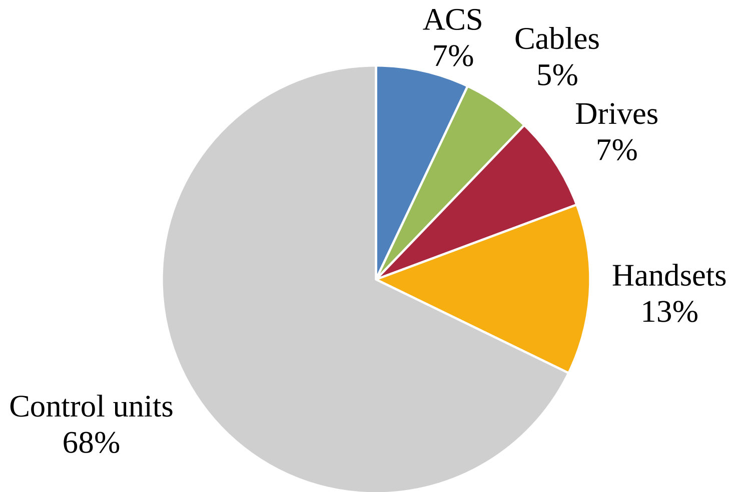

Figure 4.13: Turnover 2015

in only three of 25 countries: United States of America, Germany and Sweden. Further ten percent are split between China and Lithuania. The sales volume of 18 countries is less than one percent. The situation in 2016 is very similar to 2015, currently it seems that Poland and Netherlands increased their sales volumes in 2016.

Table 4.3: Turnover

Turnover				
	EUR		%	
Country	01-12 2015	01-06 2016	01-12 2015	01-06 2016
United States of America	19.871.886	10.623.747	37.9	29.4
Germany	18.476.999	13.357.674	34.6	37.0
Sweden	6.205.355	4.241.520	11.6	11.8
China	2.462.716	1.534.231	4.6	4.3
Lithuania	2.456.161	953.992	4.6	2.6
Netherlands	1.139.969	1.957.980	2.1	5.4
Australia	895.948	636.911	1.7	1.8
Switzerland	696.392	349.037	1.3	9.7
Poland	353.299	1.604.829	6.6	4.4
Denmark	143.894	58.914	2.7	1.6

Considering the turnover of the drives it can be noted that nearly all sold drives belong to the series 'SLIMdrive660'. This model is the predecessor product of 'SLIMdrive-660S'. For this reason the model 'SLIMdrive-660' is included in the reports to get significant values for market

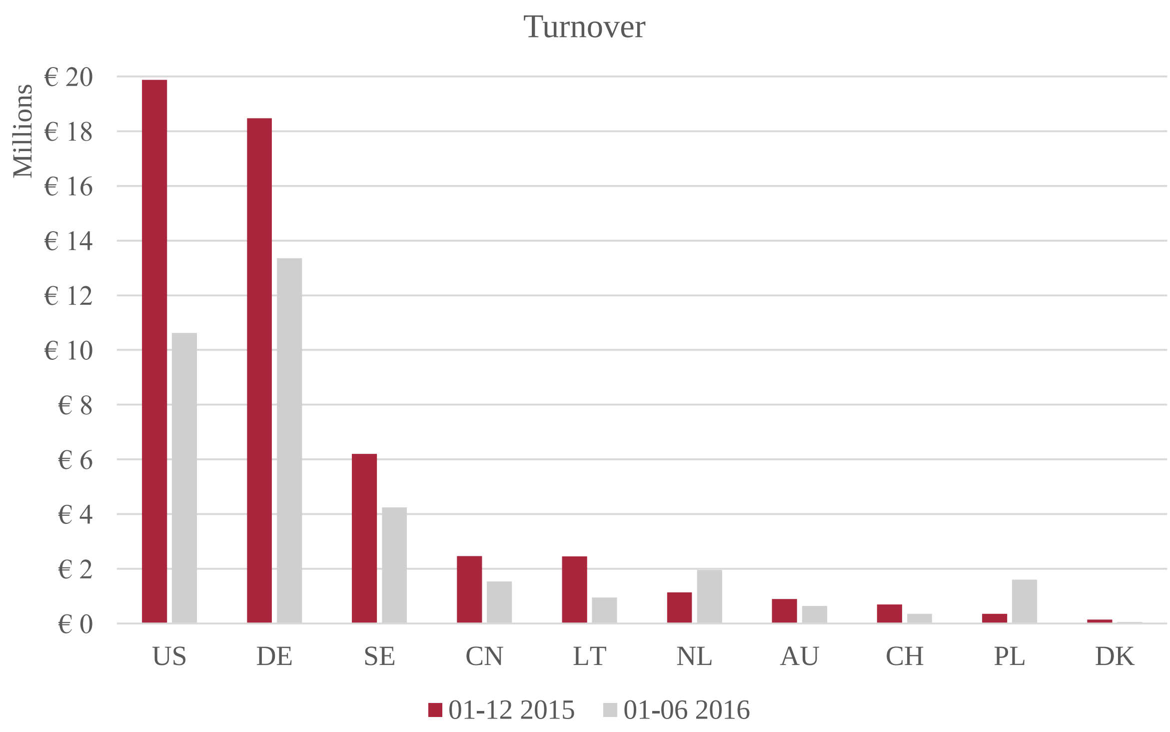

Figure 4.14: Turnover 2015 and 2016, Top-ten countries

volumes. The main markets are Germany and Sweden. Poland has an increasing market share in 2016, interestingly only the new model is sold. The market in the United States of America for drives is on the rise with around 12.000 pieces. In summary it can be stated that all current relevant sales markets for drives are located in Europe. The United States of America seems to be no big market in this segment by now, in contrast to the share of all products. There the United States of America had a share of around one out of four in 2015 based on sold pieces respectively around 40 % based on the amount in EUR.

Purchasing Volume

For the analysis of the values streams on the supplier side the Purchasing Volumes of the last years were provided by LD. For the evaluation the years 2014, 2015 and 2016 were used, but it has to be mentioned, that the data for the year 2016 were only available until calender week 25, which is nearly half a year. All orders with status 'canceled' were excluded, as well as orders with supplier 'LD' and 'LD Asia'. Per year approximately 330 million parts are purchased.

As a first step the total purchasing volume per country was analyzed. The provided data were

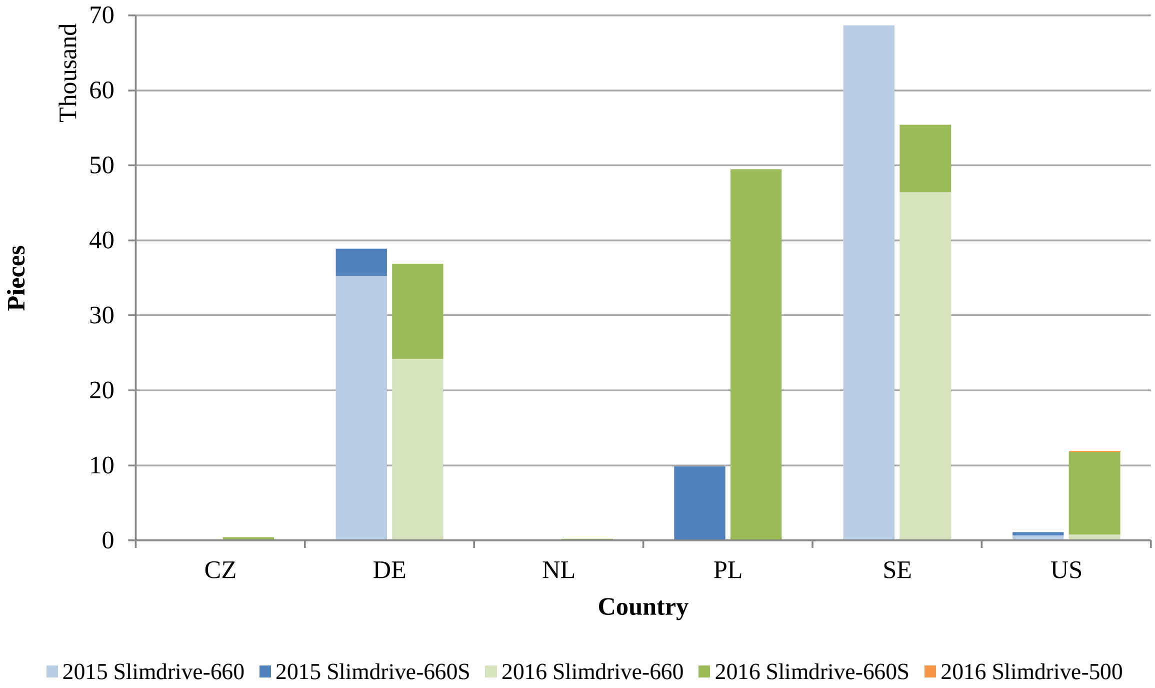

Figure 4.15: Turnover SLIMdrive-660 and 660S

complemented with the countries, which were based on the individual suppliers. The top-ten purchasing countries based on the volumes in Euro in 2015 are shown in figure 4.16. A very interesting fact, resulting from this analysis is that around the half is purchased in Austria. With regard to the quantities, even around 80 % were purchased in Austria. The reason for this high volumes is that all the electronic components like resistors, semiconductors, etc. were purchased at a distributor in Austria, who sources the parts in Asia for his side. The next countries in the ranking are Hong Kong and China, both with around 14 % volume in Euro. The next players with a volume of around five percent in Euro are Hungary, Germany and Slovakia.

In figure 4.17 the purchasing volumes per category and per country are illustrated. In Asia predominantly electronic components and cables are bought. It can be identified that Electronic Manufacturing Services (EMS) are completely situated in Europe, respectively in Slovakia and Hungary.

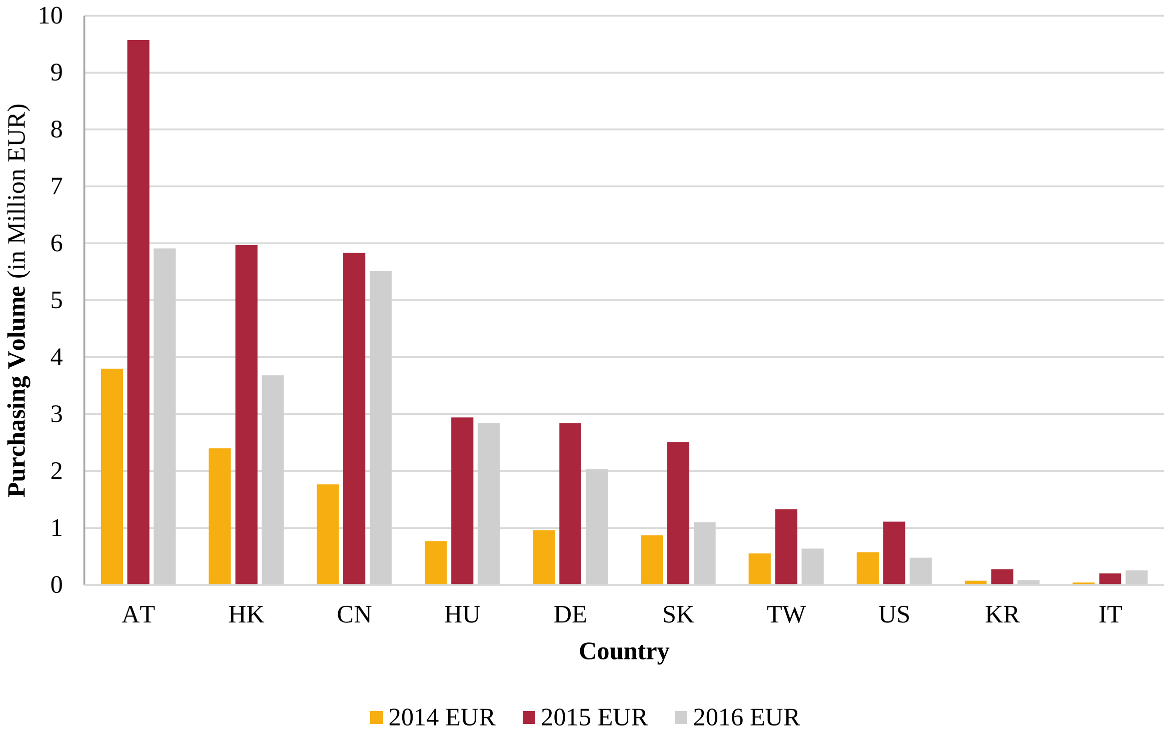

Figure 4.16: Purchasing volumes of the top-ten countries

Figure 4.17: Purchasing volumes by category

Next an investigation on price per piece was done. Therefore the data from 2015 were adduced

Table 4.4: Purchasing Volume

Turnover						
	EUR			%		
Country	01-12 2014	01-12 2015	01-06 2016	01-12 2014	01-12 2015	01-06 2016
Austria	3.798.538	9.574.711	5.909.250	32.1	29.2	26.0
Hong Kong	2.397.942	5.970.196	3.679.892	20.3	18.2	16.2
China	1.763.848	5.828.618	5.508.958	14.9	17.8	24.2
Hungary	767.726	2.938.223	2.839.547	6.5	9.0	12.5
Germany	959.493	2.838.583	2.028.989	8.1	8.7	8.9
Slovakia	868.614	2.510.572	1.096.746	7.3	7.7	4.8
Taiwan	550.736	1.325.870	636.498	4.7	4.0	2.8
United States of America	569.731	1.111.135	474.822	4.8	3.4	2.1
South Korea	74.478	276.522	84.759	0.6	0.8	0.4
Italy	41.524	200.823	250.874	0.4	0.6	1.1

and adjusted: orders with status 'canceled' were removed as well as orders with negative purchasing quantities, that represent credit notes and orders with supplier 'LD', as these are orders from LD US, which are handled by LD Deutschlandsberg and therefore the orders for the raw-material, semi-finished products and so on are included in the remaining data sets. The histogram in figure 4.18 shows, that nearly 50 % of the purchased parts have a price per piece below EUR 0.10 and 80 % of the parts are below EUR 2.00.

Then the question regarding purchasing quantities arose. The analysis was based on the same data as for the price per piece. Barely 25 % of the purchasing quantities are below 1000 pieces and around 60 % below 10.000 pieces, as can be seen in the histogram in figure 4.19. The next 20 % are between 10.000 and 30.000 pieces, approximately five percent of the orders have a purchasing quantity of more than 100.000 pieces.

It can be assumed that there exists a correlation between purchasing quantities and price per piece. For this reason the purchasing quantities are represented on the y-axis in the diagram in figure 4.20, and the price per piece is represented on the x-axis, both in a logarithmic scale. The diagram shows that the majority of the orders are up to a purchasing volume of 200.000 pieces and up to a value of EUR 1 per piece. Parts with a price per piece of EUR 0.001 have purchase quantities starting at around 10.000 pieces and higher. For parts with a price per piece of EUR 10.00 a purchase quantity of 10.000 is near the maximum. It seems that a trend can be recognized: with increasing price per piece the purchase quantities decrease.

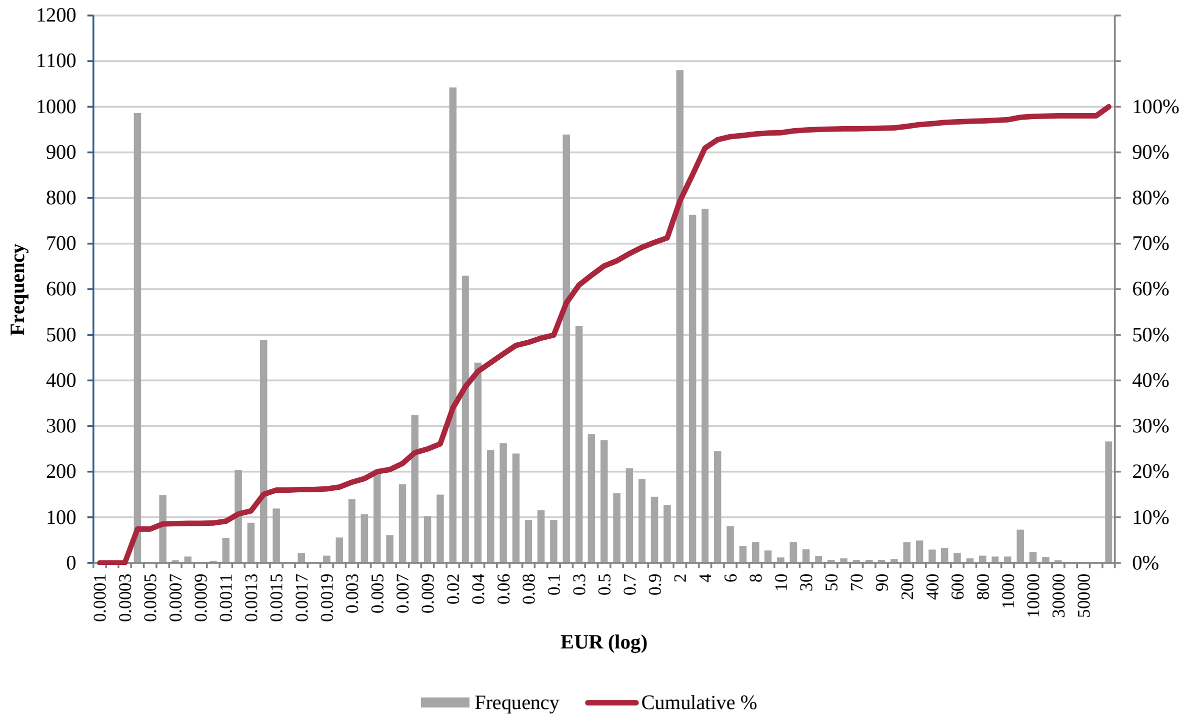

Figure 4.18: Histogram - Price per pieces

The findings can be summarized as follows: the majority of the purchased parts has a value below EUR 2.00 and a volume below 30.000 pieces. Parts with a higher price per piece have minor purchasing quantities.

Finally the purchasing value streams of the defined product 'SLIMdrive-660S' were investigated. In 2015 13.939 pieces were sold and in in the first half-year 2016 82.759 pieces. The value streams have been evaluated based on the Bill of Material (BOM) of the product, which includes also the manufacturing costs. For pricing the various parts, the mean values of the purchasing prices of the years 2014 (if available), 2015 and 2016 were used. In case the part is used in more products, a price for the year 2014 is available. For new products prices are only available as of 2015, since the product has been sold in 2015 the first time. The quantities needed for the sold pieces were multiplied by the calculated mean values. The results can be seen in table 4.5.

It can be noted that 59 % of the purchasing volume in EUR is situated in Europe and 41 % in Asia, as can be seen from the pie chart in figure 4.21. However when one considers the purchasing quantities even 70 % are purchased in Europe and 30 % in Asia (see figure 4.22). The proportion accounted for Hungary consists only of manufacturing costs, as the manufacturing of the 'SLIMdrive660S' is only done in Hungary by two suppliers.

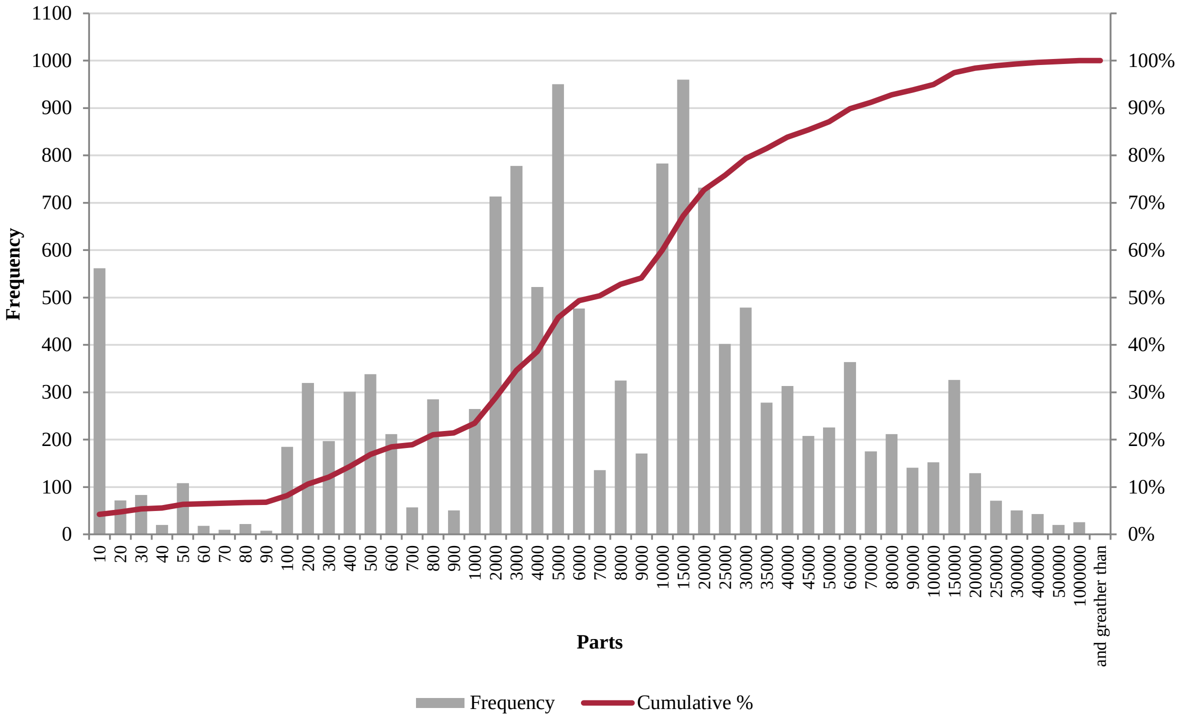

Figure 4.19: Histogram - Purchasing Quantities

The most expensive part of the 'SLIMdrive-660s' is the motor with a price per piece of EUR 4.79, made in China, followed by the manufacturing costs of EUR 2.41 (Hungary) and the steelspindle with EUR 2.33, made in Germany.

If the purchasing volume in EUR refers to the purchasing quantity, the countries get a new ranking, which is shown in table 4.6.

In figure 4.23 the value streams for the chosen product SLIMdrive-660S are illustrated. The blue arrows show the turnover values and the red arrows the purchasing volumes. The shown data belong to the year 2016. The values for the turnover prognosis consider the model SLIMdrive-660S and the preceding model SLIMdrive-660. The purchasing volumes are calculated by multiplying the prices per piece with the needed quantities according to the BOM.

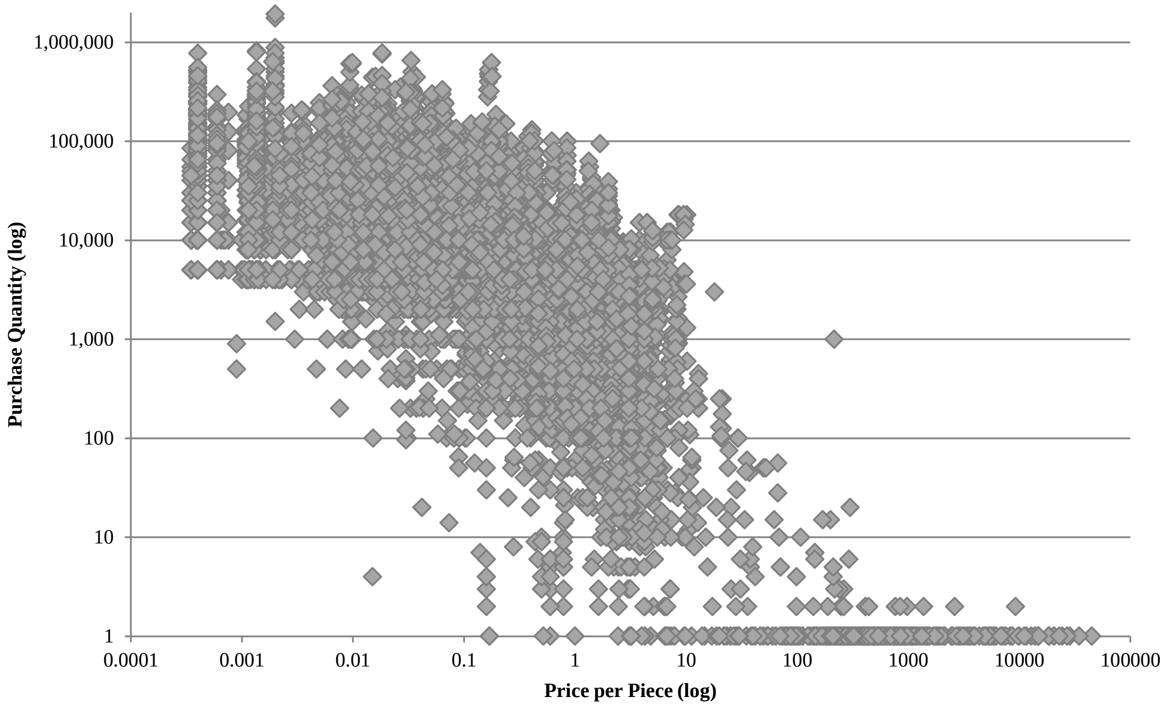

Figure 4.20: Purchasing Quantities and Price per Piece in EUR

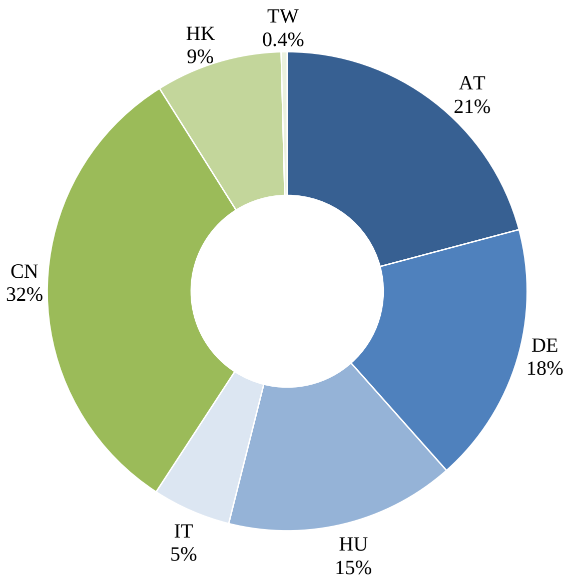

Figure 4.21: SLIMdrive660S - Purchasing Volumes 2016 in EUR

On balance, the overall impression is that in general the majority of the parts is purchased in Europe, which is similar to the purchasing for the 'SLIMdrive-660S'. High lot sizes are

Table 4.5: SLIMdrive-660S - Purchasing Volume

Purchasing Volume				
	EUR		Number of Pieces	
Country	01-12 2015	01-06 2016	01-12 2015	01-06 2016
Austria	51.453	269.579	362.595	1.949.908
Germany	73.214	227.388	181.207	974.467
Hungary	42.441	200.006	27.878	149.918
Italy	13.097	68.214	13.939	74.959
Sum Europe	180.205	765.187	585.619	3.149.252
China	81.280	411.913	209.085	1.124.385
Hong Kong	21.993	110.214	27.878	149.918
Taiwan	995	5.213	13.939	74.959
Sum Asia	104.269	527.340	250.902	1.349.262
Total Sum	284.473	1.292.527	836.521	4.498.514

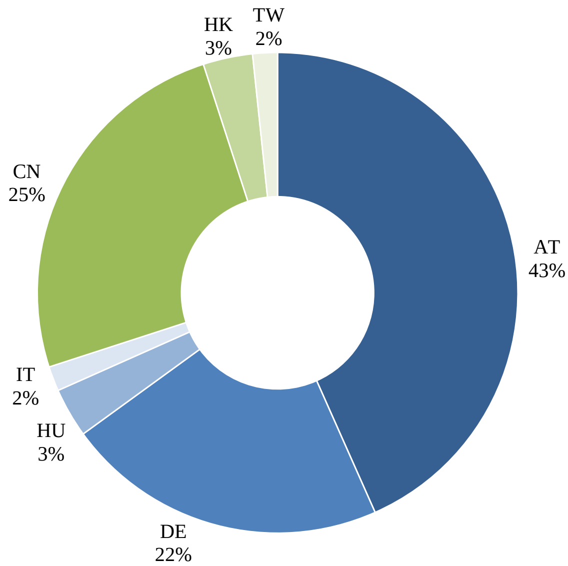

Figure 4.22: SLIMdrive660S - Purchasing Quantities 2016

purchased, which means several thousand pieces per order, but for products with a very low price per piece. As mentioned before in general the majority of the parts have a price per piece below EUR 2.00.

Compared to all products drives have currently a market share of only seven percent. The emphasis is on control units, with which the company started once. This also explains the high purchasing volumes on electronic parts.

Table 4.6: SLIMdrive-660S - Country Ranking

Country	EUR/pcs
Hungary	1.43
Italy	0.92
Hong Kong	0.76
China	0.38
Germany	0.32
Austria	0.14
Taiwan	0.07

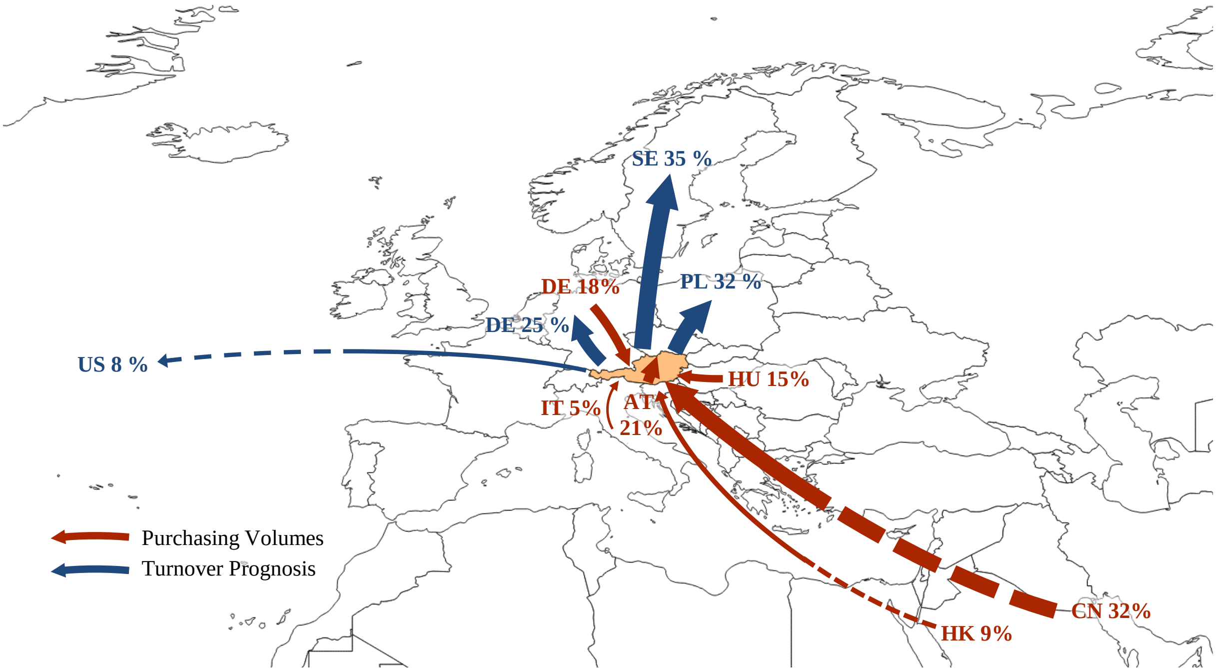

Figure 4.23: SLIMdrive-660S - Map Value Streams (2016, EUR)

4.2 Conceptual Model

In section 3.1.2 the purpose of conceptual modeling and the conceptual model was discussed. In the section before, the 'world' of LD was introduced and insights were gained. Hence, conceptual model has to be created to represent the current system.

4.2.1 Objectives

As a most significantly objective the issue of monitoring influences related to countries extracted from discussions with the business partner. Subsequently the model shall provide insights and information to support decisions when discussing new set-ups of SC or modifying existing SCs in order to optimize them. Another important objective is to demonstrate the applicability of modeling and simulation to the current problem formulation and provide a guideline, as LD has currently less experience with both techniques. Because of the expected growth of product segments, which have less than ten percent volume thus far, new challenges have to be met. Furthermore, the investigated product is an electro-mechanical system, which has other requirements compared to the main sales product by now, which is an electronic system solely.

4.2.2 System Description

When investigating the system, it seems that there are many different issues influencing the supply chain. Especially impacts belonging to the countries arose as an important factor for LD. Therefore, in this thesis it has been looked more closely at the dimension 'country' and the connection to related topics.
Subsequently three dimensions could be identified: 'Country', 'Company' and 'Route/Link'. In figure 4.24 these dimensions and some of their attributes are illustrated. The term 'dimension' is for this purpose defined and understood in this thesis as umbrella term for different entities and their related risks and opportunities. The dimension 'Country' describes all inputs, outputs and influences directly related to country level, for instance political issues, governmental regulations, currency or trade restrictions. These dimensions are assigned to levels, which are understood in this thesis as a kind of a view flight level, in other words a high level refers to a macro level. 'Country' is positioned on the highest level. The next dimension 'Company' is situated on a more detailed level than 'Country' and involves all matters associated with the individual supplier, for example quality, technical performance, know-how, financial situation, flexibility or capacity. The third dimension 'Route/Link' can not be assigned to one of these two levels, as it depends on the kind of usage. 'Route/Link' covers issues that belong to the connection between two entities. Depending on the type of entity, the dimension is located on the different levels or between them, this means 'Route/Link' can connect two or more suppliers, two or more countries, but also suppliers and countries, as illustrated in figure 4.25.

It expresses all topics concerning the linkage, as for example the distance between the entities, transport mode, border crossings.

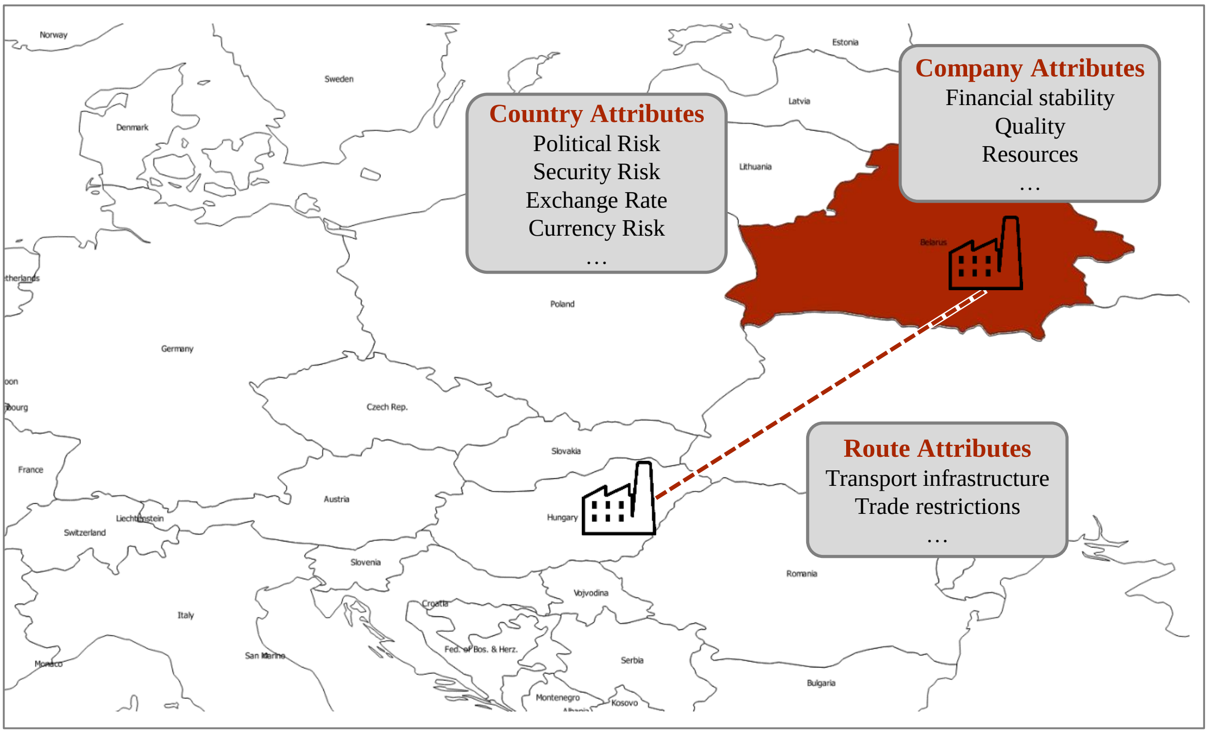

Figure 4.24: Dimensions

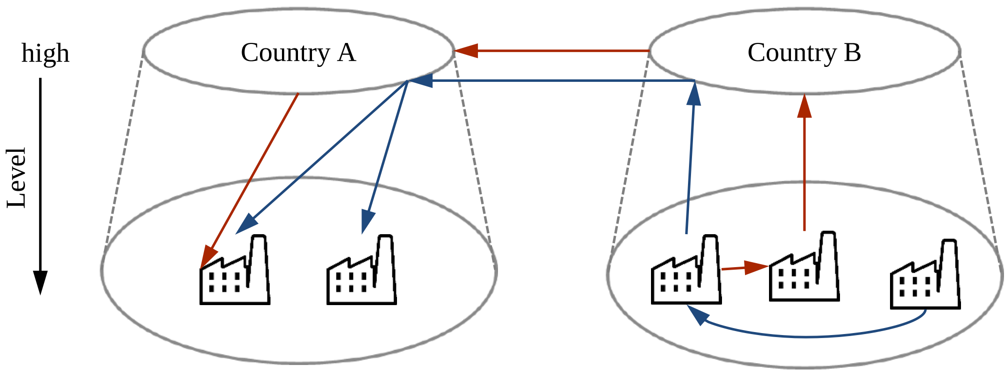

Figure 4.25: Dimensions and their levels

4.2.3 Problem Formulation

The before mentioned issues related to the three dimensions, taken individually, are more or less evaluable, quantitative or qualitative. If they can be rated quantitative it is more easy to weigh and compare them among each other. At this point the question arises in terms of appropriate measurements, which can be used. If the evaluation can only be done qualitative, it will be more difficult to find proper indicators. Often this topics are assessed based on the experience and knowledge of the employees involved, which relates always on the individual opinion and is always subjective in a certain way. Much more difficult is the evaluation of linked issues, because with the number of issues, which should be considered, the complexity increases. On the one hand by the heterogeneous types of the topics and on the other hand by the mixture of the various types and their inter-dependencies.

At this point it is necessary to discuss the types of systems respectively the terms complicate and complexity. Following Haberfellner et al. (2012) a simple system consists of few elements, which are rigidly connected and have a low dynamic intensity. These types of systems can be described explicitly, and change in two directions: on the one hand by increasing the numbers and diversity of elements and on the other hand by increasing dynamics in terms of time and linkages between these elements. Therefore, three further types can be defined. Massive interconnected, complicated systems are characterized by many elements and a great variety. Although these elements are still statically connected, the systems behavior can hardly be described explicitly because of the system size. A dynamic, complicated system is specified by temporary, often non-linear, changes of the connections between the elements regarding type of interaction, strength and structure. Despite less and weak interactions a quantitative system description can hardly be made. Does a simple system modify in both above mentioned directions, a complex system emerges. It has a large number and variety of elements and connections. This connections can change temporary, respectively they are dynamic. The description of such systems is much more difficult. A graphical illustration is given in figure 4.26.

The three dimensions introduced in section 4.2.2 country, route and company describe a complex system, not necessarily because the number of elements, but their variety respectively underlying risks and the changes over time. Therefore, methods are needed to handle this complexity, to analyze the system and to understand the system and its behavior. The method respectively tool is requested to support the evaluation of the system and consequently decision making.

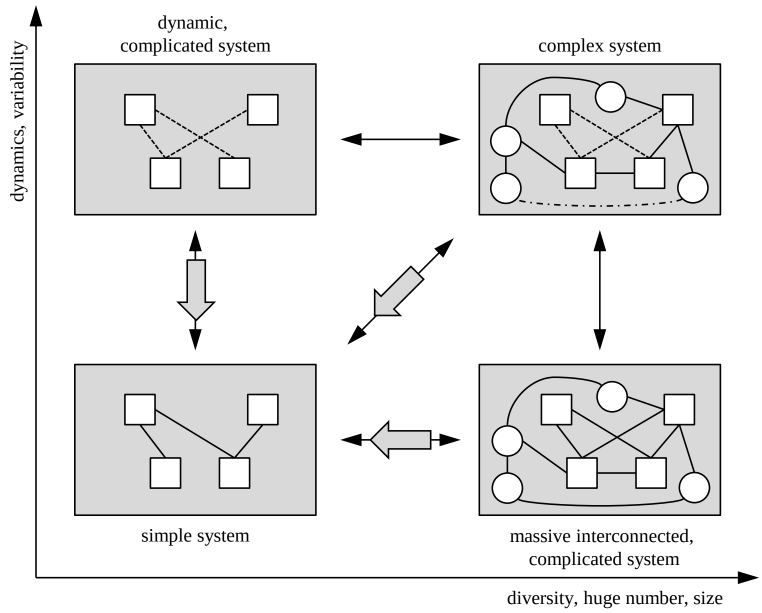

Figure 4.26: System types (Haberfellner et al., 2012, p.40)

4.3 Definition of Input and Output

In section 3.1.2 different types of problems and their components were explained. The component 'system' was interpreted in the previous section. Furthermore, the other two components 'input' and 'output' need to be detailed too. The input factors to the current system are on the one hand various risks related to the before introduced three dimensions. On the other hand the design of the network and the mass flows (quantities of parts, assemblies or products) between the nodes of the network belong to the input factors. The output factors are probability distributions of the various risks, network designs and mass flows that can be compared to each other. With reference to the SCRMP, described in section 2.5, the definition of input and output belongs to the process of risk identification of phase one.

4.3.1 Risk Factors

In the described system the input factors are the various risks related to the different dimensions of the system. Thus, the input factors have to be identified. For that, in a first step a criteria matrix was used, based on Vester (2015), who considers in total 18 criteria, which should be covered by the variables respectively input factors. The criteria contain seven areas of life (economy, participants, space, utilization, feeling, environmental awareness, infrastructure, rules/law), three physical entities (matter, energy, information), four aspects of the dynamics of the system (flow, structure, time and space) and four types of system relations (opens the system by input / by output, control by internal / external processes). In the investigated system, the areas of life are described by the processes of the SC. Therefore, the criteria matrix was adjusted to the application and the variables are put in context to these processes. The variables are related to the risk triggers, which were listed in the first column of the criteria matrix. The risk triggers were based on the risk triggers of the SCRMP (see table 2.3 on page 20). They were completed by elements of a supplier evaluation of LD[1]. In the first column the processes of the SCOR model were listed (see table 4.7). With this matrix the importance of the various risks to the individual process steps was evaluated by choosing one of three possible values: '0' for 'not relevant', '0.5' for 'partly relevant' and '1' for 'fully relevant'. This matrix should ensure completeness and relevance of the risks and therefore it was accomplished for all processes. As the main focus in this thesis are purchasing processes, the completeness and relevance for these processes were important particularly. For reasons of simplicity only an extract is shown in figure 4.27. The complete impact matrix can be found in the Appendix.

Table 4.7: SCOR processes

Level One		
Plan	Demand/supply planning	Access supply resources aggregate and prioritize demand requirements conduct inventory planning assess distribution requirements determine production, material, and rough-cut capacity for all products and all channels
	Plan infrastructure	Make/buy decisions supply chain configuration long-term capacity and resource planning business planning product phase-in/phase-out manufacturing ramp-up end-of-life management product line management
Source	Sourcing/material acquisition	Obtain, receive, inspect, hold and issue material
	Source infrastructure	Vendor certification and feedback sourcing quality inbound freight component engineering vendor contracts initiation of vendor payment

(*table continues*)

[1] As this 'Supplier Evaluation Form' is a confidential internal document, it is not explained in detail in this thesis.

Table 4.7: SCOR processes (continued)

Level One		
Make	Production execution	request and receive material manufacture and test product package hold and/or release product
	Make infrastructure	engineering changes facilities and equipment production status production quality shop scheduling/sequencing short-term capacity
Deliver	Demand management	Conduct forecasting plan promotions plan projects plan sales campaigns collect and analyze point of sale (POS) data and actual customer orders promote products price products measure customer satisfaction execute efficient customer response (ECR)
	Order management	Enter and maintain orders generate quotations configure product create and maintain customer database manage allocations maintain product/price database manage accounts receivables, credits, collections and invoicing
	Warehouse management	receive and stock finished goods pick and pack configure products ship products create customer specific package labeling consolidate orders
	Transportation management	Manage traffic manage freight manage product import/export
	Installation management	schedule installation activities perform installation verify performance
	Deliver infrastructure	Channel business rules order rules management of deliver inventories management of deliver quantity

Next, to investigate the influence of the various risks on each other an impact matrix was prepared, following Vester (2015). This matrix gives information on the inter-dependencies of the variables. The impact of variable A on variable B, C, etc. was evaluated by the following scale: 0 - no dependency, 1 - very small dependency (big change of A results only in a little change of B), 2 - medium dependency (proportional change), 3 - strong dependency (little

Criteria Matrix			Plan												
			Demand/supply planning					Plan infrastructure							
		Identifier	Access supply ressources	aggregate and prioritize demand requirements	conduct inventory planning	assess distribution requirments	determine production, material, and rough-cut capacity for all products and all channels	Make/buy decisions	supply chain configuration	long-term capacity and resource planning	business planning	product phase-in/phase-out	manufacturing ramp-up	end-of-life management	product line management
Demand risks	Order fulfillment errors	C01	0.5	0.5	1	0.5	1	1	1	1	0	0	0.5	0	0.5
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	1	1	1	1	1	1	1	1	0.5	0	0.5	0	0.5
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0.5	1	1	1	1	1	1	1	0.5	0	0.5	0	0.5
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	1	0	0	0.5	0.5	0	1	0.5	0	0	0	0	0
	Port capacity and congestion	C05	1	0	0.5	0	0.5	0	1	0.5	0	0	0	0	0
	Custom clearances at ports	C06	1	0	0	0	0	0	1	0	0	0	0	0	0
	Transportation breakdowns	C07	1	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.27: Criteria Matrix - Plan (Extract)

change of A results in a big change of B). An extract of the impact matrix is shown in figure 4.29. The complete matrix can be found in the Appendix. Variables with a big impact on others have a high active sum (AS), variables strongly influenced by others have a big passive sum (PS). Therefore, the variables can be distinguished in active elements, critical elements, reactive elements, buffering elements and neutral elements.

$$x_{ij} = \text{impact of i to j}$$

$$AS = \sum_{i=1}^{m} x_{ij}$$

$$PS = \sum_{j=1}^{n} x_{ij}$$

The result is shown in figure 4.28. As critical element 'Quality of service, including responsiveness and delivery performance' turned out, also very close to critical is 'Order fulfillment errors'. These critical elements are characterized by a high active sum and a high passive sum. This means, these variables are strongly influencing other variables, but they are also strongly influenced by other variables. To variables with a strong impact on others count 'Terrorism and Wars', 'Labor disputes', 'Regional instability' and 'Supplier bankruptcy'. These are the variables with very high active sums. They can hardly be influenced by the focal company.

Buffering elments are elements with a little active sum and a little passive sum, as for example 'Openess to name customers, suppliers and competitors'. This element does not influence others a lot and is not influenced by others. At this point it has to be noted that it is not influenced by variables that are included in the present criteria matrix, which does not mean it is not influenced at all. But this is not relevant in the investigated context. A special buffering element is the input factor 'Natural disasters' with a high active sum, but no passive sum. The reason for this appears to be that natural disasters have certainly a big influence on other variables as for example production sites can be damaged or destroyed and this would lead to a loss of production or transport routes can be demolished, for example. Whereas other factors can not influence this variable, particularly the investigated ones not. Natural disasters are beyond control, they just happen. Two reactive factors are 'Excessive handling due to border crossings or change in transportation mode' and 'Demand and supply uncertainty'. These elements have little active sums and are mainly influenced by others.

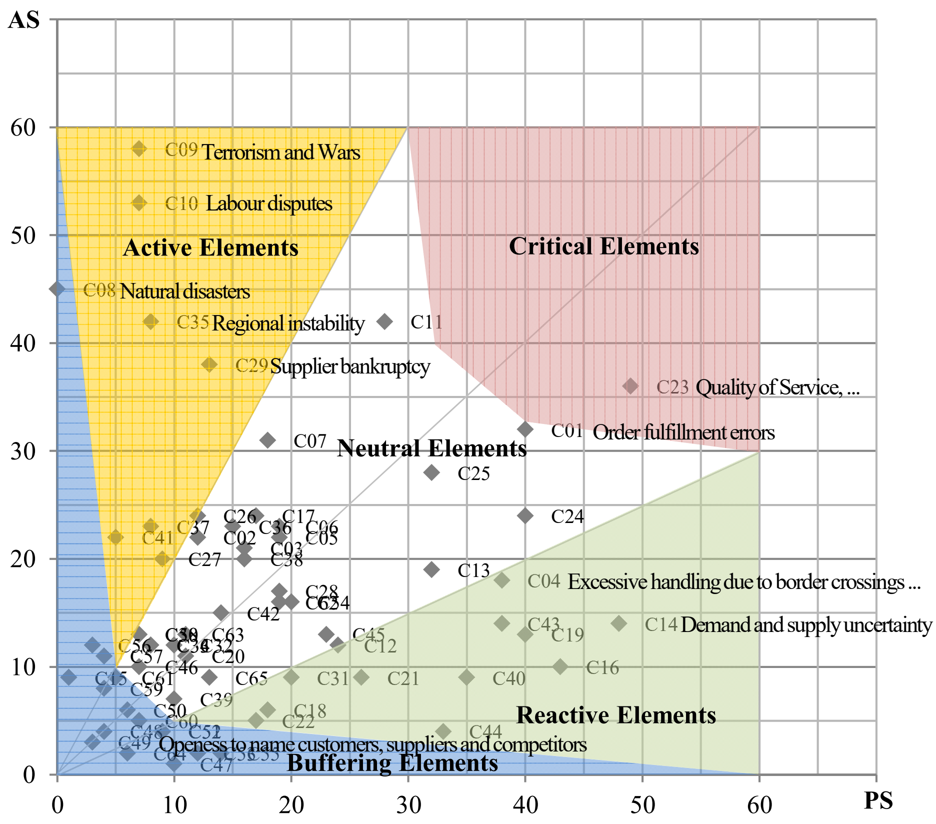

Figure 4.28: Impact Diagram

The gained insights from the criteria matrix and impact matrix has been discussed with experts and was considered of good quality. Based on these insights subsequently, the results were discussed with the business partner and reevaluated. Some risks were assessed as not important or not applicable, some others were added. An emerging issue during the discussions was 'cultural matching'. This also shows that with global sourcing totally new issues arise, which can result in unexpected difficulties. For example problems due to language differences, or due to distinctions in code of behavior, that means different cultural understanding between Europeans and Asians for instance, can be a big issue. The result of this expert discussion and evaluation can be seen in table 4.8. The individual risk triggers are assigned to different risk categories. In the column 'Include' the result is noted of the discussion, if the variable should be included or excluded in the further risk evaluation. If it has been decided to exclude the variable, a justification has been noted, so that it can be understood later why the risk trigger was excluded. Additional information is given in the column 'Remark'. This procedure has been suggested also by Stewart Robinson (2008b).

Impact Matrix (Impact on →)			Demand risks			Delay risks			
			Order fulfillment errors	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	Excessive handling due to border crossings or change in transportation mode	Port capacity and congestion	Custom clearances at ports	Transportation breakdowns
			C01	C02	C03	C04	C05	C06	C07
Demand risks	Order fulfillment errors	C01		1	1	2	0	1	0
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	2		2	0	0	0	0
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	2	2		0	0	0	0
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	1	0	0		0	0	0
	Port capacity and congestion	C05	1	0	0	2		2	1
	Custom clearances at ports	C06	1	0	0	2	2		0
	Transportation breakdowns	C07	1	0	0	3	1	1	

Figure 4.29: Impact Matrix (extract)

Table 4.8: Evaluated risk triggers

ID	Risk category	Risk trigger	Include	Justification	Remark
C01	Demand risks	Order fulfillment errors	No	Expert Judgment	
C02	Demand risks	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	No	Expert Judgment	

(*table continues*)

Table 4.8: Evaluated risk triggers (continued)

ID	Risk category	Risk trigger	Include	Justification	Remark
C03	Demand risks	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	No	Expert Judgment	
C04	Delay risks	Excessive handling due to border crossings or change in transportation mode	Yes		
C05	Delay risks	Port capacity and congestion	No	Expert Judgment	
C06	Delay risks	Custom clearances at ports	Yes		Not only referring to ports; including costs
C07	Delay risks	Transportation breakdowns	Yes		
C08	Disruption risks	Natural disasters	Yes		
C09	Disruption risks	Terrorism and wars	Yes		
C10	Disruption risks	Labor disputes	Yes		
C11	Disruption risks	Single source of supply	?		undecided
C12	Disruption risks	Capacity and responsiveness of alternate suppliers	?		undecided
C13	Inventory risks	Costs of holding inventories	Yes		
C14	Inventory risks	Demand and supply uncertainty	No	Expert Judgment	
C15	Inventory risks	Rate of product obsolescence	No	Expert Judgment	
C16	Inventory risks	Supplier fulfillment	No	Included in Category "LD Supplier Evaluation"	
C17	Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	Yes		
C18	Manufacturing (process) breakdown risks	Lower process yields	Yes		
C19	Manufacturing (process) breakdown risks	Higher product cost	Yes		
C20	Manufacturing (process) breakdown risks	Design changes	No	Not important	
C21	Physical plant (capacity) risks	Lack of capacity flexibility	Yes		
C22	Physical plant (capacity) risks	Cost of capacity	Yes		
C23	Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	Yes		
C24	Supply (procurement) risks	Supplier fulfillment errors	?		undecided
C25	Supply (procurement) risks	Selection of wrong partners	No	Expert Judgment	
C26	Supply (procurement) risks	High capacity utilization supply source	No	Expert Judgment	
C27	Supply (procurement) risks	Inflexibility of supply source	Yes		
C28	Supply (procurement) risks	Poor quality or process yield at supply source	No	Expert Judgment	
C29	Supply (procurement) risks	Supplier bankruptcy	Yes		

(*table continues*)

Table 4.8: Evaluated risk triggers (continued)

ID	Risk category	Risk trigger	Include	Justification	Remark
C30	Supply (procurement) risks	Rate of exchange	Yes		
C31	Supply (procurement) risks	Percentage of a key component or raw material procured from a single source	No	Expert Judgment	
C32	System risks	Information infrastructure breakdowns	Yes		
C33	System risks	Lack of effective system integration or extensive system networking	No	Expert Judgment	
C34	System risks	Lack of compatibility in IT platforms among SC partners	Yes		
C35	Sovereign risks	Regional instability	Yes		
C36	Sovereign risks	Communication difficulties	Yes		
C37	Sovereign risks	Government regulations	Yes		
C38	Sovereign risks	Loss of control	No	Not important	
C39	Sovereign risks	Intellectual property breaches	Yes		
C40	Transportation risks	Paperwork and scheduling	Yes		
C41	Transportation risks	Port strikes	No	Expert Judgment	
C42	Transportation risks	Delay at ports due to port capacity	No	Expert Judgment	
C43	Transportation risks	Late deliveries	No	Expert Judgment	
C44	Transportation risks	Higher costs of transportation	Yes		
C45	Transportation risks	Depends on transportation mode chosen	Yes		
C45.1	Transportation risks	Distance	Yes		New
C45.2	Transportation risks	Change of transportation mode necessary	Yes		New
C46	LD Supplier Evaluation	Financial stability	Yes		
C47	LD Supplier Evaluation	References	Yes		
C48	LD Supplier Evaluation	Friendliness	Yes		
C49	LD Supplier Evaluation	Openness to name customers, suppliers and competitors	Yes		
C50	LD Supplier Evaluation	Acceptance of defined LD-Standards (NDA, CSR,. . .)	Yes		
C51	LD Supplier Evaluation	Ranking of offer in comparison to others (price per unit)	Yes		
C52	LD Supplier Evaluation	TCO-Ranking in comparison to others (tooling, quality-costs,. . .)	Yes		
C53	LD Supplier Evaluation	Payment Terms	Yes		
C54	LD Supplier Evaluation	Traffic connection (airport, port, motorway,. . .)	Yes		
C55	LD Supplier Evaluation	Conditions of payment	No	twice	
C56	LD Supplier Evaluation	Defined complaint handling process with customers and suppliers	Yes		
C57	LD Supplier Evaluation	All necessary quality and ecological certificates available	Yes		
C58	LD Supplier Evaluation	Experience with modern quality techniques	Yes		
C59	LD Supplier Evaluation	Capacity of R&D/Engineering-Department	Yes		

(*table continues*)

Table 4.8: Evaluated risk triggers (continued)

ID	Risk category	Risk trigger	Include	Justification	Remark
C60	LD Supplier Evaluation	General impression of innovation	Yes		
C61	Others	Taxes	Yes		
C62	Others	Transport infrastructure (railway, port, airport, ...)	No	twice	
C63	Others	Labor costs	Yes		
C64	Others	Labor productivity	Yes		
C65	Others	Trade restrictions	Yes		
C65.1	Others	Cultural Matching	Yes		New
C65.2	Others	Legal compliance	Yes		New

4.3.2 Risk Types

Based on the discussions with LD an adapted list with risks was prepared. The various risks were grouped according to different categories and also assigned to the different dimensions. The result is shown in table 4.9.

Table 4.9: Risk Types

Dimension	**Risk category new**	**Risk trigger**
Country	Delay risks	Custom clearances and costs
	Disruption risks	Labor disputes Natural disasters Terrorism and wars
	Sovereign risks	Communication difficulties Cultural Matching Government regulations Intellectual property breaches Labor costs Labor productivity Legal compliance Regional stability Taxes Trade restrictions
Company	Inventory risks	Costs of holding inventories
	Manufacturing (process) breakdown risks	Process yields Product cost Quality (ANSI or other compliance standards)
	Physical plant (capacity) risks	Capacity flexibility Cost of capacity

(*table continues*)

Table 4.9: Risk Types (continued)

Dimension	Risk category new	Risk trigger
	Supply (procurement) risks	Acceptance of defined LD-Standards (NDA, CSR,. . .)
		All necessary quality and ecological certificates available
		Capacity of R&D/Engineering-Department
		Defined complaint handling process with customers and suppliers
		Experience with modern quality techniques
		Financial stability
		Flexibility of supply source
		Friendliness
		General impression of innovation
		Openness to name customers, suppliers and competitors
		Payment Terms
		Quality of service, including responsiveness and delivery performance
		Ranking of offer in comparison to others (price per unit)
		Rate of exchange
		References
		Supplier bankruptcy
		TCO-Ranking in comparison to others (tooling, quality-costs,. . .)
	System risks	Compatibility in IT platforms among SC partners
		Information infrastructure
Route	Delay risks	Excessive handling due to border crossings or change in transportation mode
		Transport (distance, breakdowns)
	Supply (procurement) risks	Traffic connection (airport, port, motorway,. . .)
	Transportation risks	Change of transportation mode necessary
		Cost of transportation
		Distance
		Paperwork and scheduling
		Transportation mode

4.3.3 Risk Measurement

The next step of phase one in the SCRMP is 'risk measurement', that means how can the before identified risks be assessed as objectively as possible by using indicators. At this point some questions arises: Which indicators are available? Which indicator can represent which risk factor or risk type? Besides, more technically questions turned up as: In which format are the data available? How should the data be stored and processed?

Table 4.10: Dimension 'Route' - Indicators

Risk type	Risk trigger	Indicator
Delay risks	Excessive handling due to border crossings or change in transportation mode	Trading Across Borders[d]
	Transport (distance, breakdowns)	No of km, No of borders, No of transportation modes
Supply (procurement) risks	Traffic connection (airport, port, motorway,. . .)	Distance to Motorway, port, airport, railway
Transportation risks	Change of transportation mode necessary	
	Cost of transportation	No of km, No of borders, No of transportation modes
	Distance	No of km
	Paperwork and scheduling	No of km, No of borders, No of transportation modes
	Transportation mode	No of transportation modes

For finding appropriate indicators a research on the the world wide web was done. There are various sources available. Some companies provide aggregated and edited data for various issues, but they are almost only pay-for-services. For example, *ControlRisks* (2016) provides information on security risks, integrity risks, political risks, a risk map and so on. Some information are available for free, but for the most an access is needed, which requires payment. Other sources provide their data for free, certainly the data are not as well-structured as provided by pay-for-services. In this thesis the focus was on free available data.

In table 4.10 the identified indicators for the various risk triggers of the dimension 'Route' are shown. The superscripts refer to sources which can be found in 4.13. Indeed some indicators can be used for various risk triggers. Obviously risk triggers regarding the dimension 'Route' often depend on the distance between the individual SC members. Consequently it depends on the location of the SC partner, because it makes a big difference, if the partner is situated in the West of China or in the Northeast for example. It is rather negligible, if the partner is located in the West of Hungary or in the East. Therefore, this matter needs to be considered in each individual case.

Next, the risk triggers of dimension 'Country' were studied and appropriate indicators analyzed. The assigned indicators are shown in table 4.11. Sometimes more than one indicator was found, sometimes it was really hard to find an appropriate indicator. It has to be mentioned, that available data change and improve and thus, it is suggested to repeat the research on indicators

Table 4.11: Dimension 'Country' - Indicators

Risk type	Risk trigger	Indicator
Delay risks	Custom clearances and costs	Trading Across Borders[d]
Disruption risks	Labor disputes	Social Progress Index (SPI)[e], Strikes and lockouts by economic activity[b]
	Natural disasters	World Risk Index (WRI)[f]
	Terrorism and wars	Conflict Barometer[g]
Sovereign risks	Communication difficulties	Native language[t], Share English speaking people, Literacy rate[i]
	Cultural Matching	Hofstede's 6D Model[o], Religion[t], Language[t]
	Government regulations	Transparency in Business Regulation[d]
	Intellectual property breaches	International Property Rights Index[n], Global Innovation Index[l], Total patent applications[m]
	Labor costs	Income groups[a]
	Labor productivity	Gross Domestic Product (GDP) per hour worked[c], Mean nominal hourly labor cost per employee by economic activity[b]
	Legal compliance	Corruption Perception Index[k]
	Regional stability	Political and Security Risk[h], Travel warnings[j]
	Taxes	Paying Taxes Indicator[d]
	Trade restrictions	Trading Across Borders[d], Trade agreements

within a reasonable time. However, it is important to proof the timeliness of the data. Especially for some risk triggers this can be essential, for instance for the regional stability which can end up in a higher exposure for employees on site.

At last the indicators for 'Company' related risk triggers were investigated. As a result it can be noted that most of the risk triggers depend on the supplier evaluation and there are only less other data sources available, which can also be seen in table 4.12.

4.4 Design Model

Now the individual risks, discussed before, are considered in the context of a SC setting. From purchasing the individual parts on different markets, to the delivery to the end customer, there are a lot of steps in between and consequently many potential risks could arise. Risks appear

Table 4.12: Dimension 'Company' - Indicators

Risk type	Risk trigger	Indicator
Inventory risks	Costs of holding inventories	
Manufacturing (process) breakdown risks	Process yields	
	Product cost	
	Quality (ANSI or other compliance standards)	
Physical plant (capacity) risks	Capacity flexibility	
	Cost of capacity	
Supply (procurement) risks	Acceptance of defined LD-Standards (NDA, CSR,. . .)	LD Supplier Evaluation
	All necessary quality and ecological certificates available	LD Supplier Evaluation
	Capacity of R&D/Engineering-Department	LD Supplier Evaluation
	Defined complaint handling process with customers and suppliers	LD Supplier Evaluation
	Experience with modern quality techniques	LD Supplier Evaluation
	Financial stability	LD Supplier Evaluation, KSV[t], Creditreform[r], d&b[u]
	Flexibility of supply source	LD Supplier Evaluation
	Friendliness	LD Supplier Evaluation
	General impression of innovation	LD Supplier Evaluation
	Openness to name customers, suppliers and competitors	LD Supplier Evaluation
	Payment Terms	LD Supplier Evaluation
	Quality of service, including responsiveness and delivery performance	LD Supplier Evaluation
	Ranking of offer in comparison to others (price per unit)	LD Supplier Evaluation
	Rate of exchange	UN Operational Rates of Exchange[s]
	References	LD Supplier Evaluation
	Supplier bankruptcy	KSV[t], Creditreform[r]
	TCO-Ranking in comparison to others (tooling, quality-costs,. . .)	LD Supplier Evaluation
System risks	Compatibility in IT platforms among SC partners	LD Supplier Evaluation
	Information infrastructure	LD Supplier Evaluation

not only linear, but rather they overlap. For instance, five parts have to be purchased, two parts of them have to be assembled to an intermediate product. After that this assembly and the remaining three parts have to be assembled to the final product. Regarding purchasing three parts are bought in China, one is bought in Germany and one in Austria. This results in at least three overlapping country risks. Moreover, two parts, one purchased in China and one purchased in Austria, have to be delivered to Hungary to supplier A for assembling the intermediate product. Two route risks are added, as well as one supplier risk. Further on this assembly as well as the remaining parts are delivered to the manufacturer B in Hungary. Therefore, another three routing risks and one more company risk are included. Before the product is delivered to the end customer in Denmark, the part has to be transferred to LD DL for final distribution. That means another two routing risks and one more country risk have to be added. To conclude, there are already four country risks overlapping with two company risks and seven route risks, even in this very simple example. Moreover each risk dimension consists of several risk types and triggers. Therefore, a lot of variables determine the emerging total risk of a SC.

Based on the previously defined quantitative indicators before risks belonging to the distinctive dimensions can be described and measured. Next, these indicators have to be scaled based on an objective scaling matrix. Furthermore, the indicators can be weighted using a weighing matrix, that can be adapted individually according to the specific scenario. This might be for instance a rough set up for a new product or a modification of an existing SC. Afterwards the product streams can be taken into account by estimated quantities and the results obtained in the value stream analysis in section 4.1.4 on page 61. Also constraints can be considered, as for example the PCB assembled (PCBA) has to be made by supplier C in country X. All these assumptions and simplifications result in a probability distribution of several risks included in the setting.

A simplified example is shown in figure 4.30. In the upper part of the picture a simple product is illustrated, consisting of three parts and two assemblies. In the lower part of the illustration the suppliers and manufacturers are shown as squares. The ellipses represent the countries, where the parts are purchased. The arrows stand for the connections between the SC members, the distance and the risk associated with the route. The thickness of the arrows symbolize the value stream, which results from the quantity and price per piece. The value stream is an suitable indicator, as it makes a difference if there is a huge amount of parts needed, but the price per piece is very low or there are only few, but very expensive ones, needed.

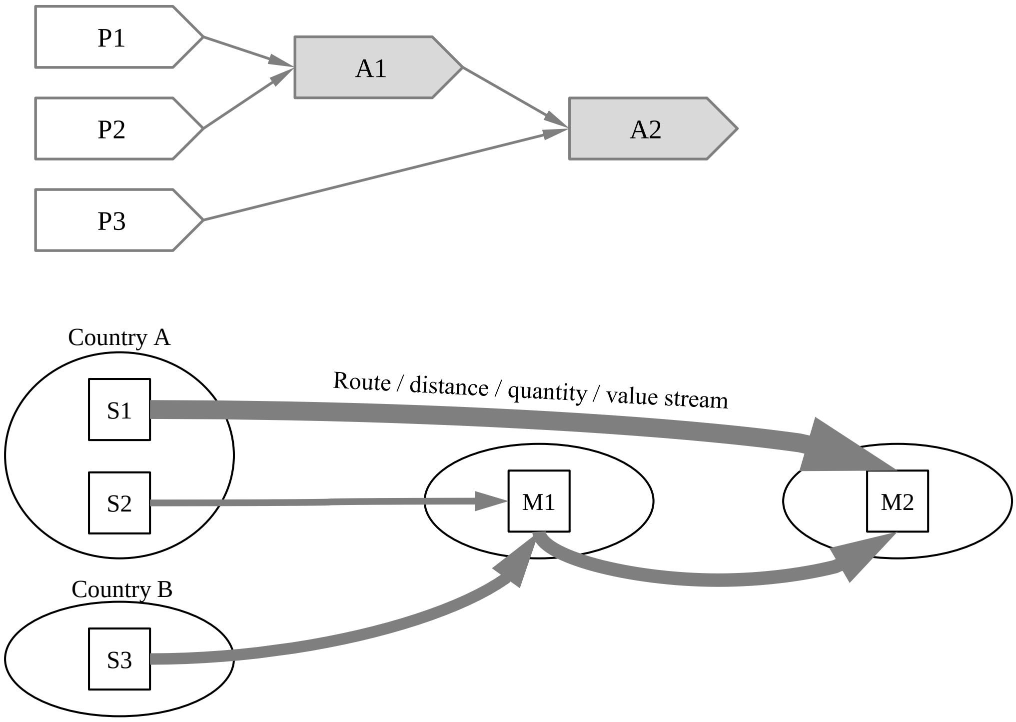

Figure 4.30: Design Model

By varying the settings of the considered SC, for instance by using another supplier or purchasing from a different country, distinctive results are gained and can be compared to each other. The outcomes can serve as a basis for discussions and at the end, decisions.

4.5 Implemented Model

The before examined design model needs to be translated into a computer model, which can be used for simulations in the end. In this thesis activities in preparation of such a simulation model are addressed.

In preparation of a computer model, an important step is to gather the data of the risk indicators. It is supposed to use a database to store the data from the different sources. As there is no standardized interface and each data set looks different, this is not a simple task. Data administration is an important issue in this case. Using a data base for the adminstration of the risk indicators is also suggested by Deleris and Erhun (2005), who points out also the importance of currency of the data and therefore, the need of regular updates. In figure

Table 4.13: Indicators and sources

Indicator	Source ID	Source
Conflict Barometer	g	www.hiik.de/en/konfliktbarometer/index.html
Corruption Perception Index	k	transparency.org
Country profiles	t	www.wko.at/Content.Node/Interessenvertretung/ZahlenDatenFakten/Laenderprofile_weltweit
Creditreform	r	www.creditreform.de/leistungen/wirtschaftsinformationen/bonitaetspruefung-unternehmen-b2b.html
Distance to Motorway, port, airport, railway		
dun & bradstreet	u	www.dnb.co.uk/
GDP per hour worked	c	stats.oecd.org
Global Innovation Index	l	globalinnovationindex.org
Hofstede's 6D Model	o	geerthofstede.nl
Income groups	a	worldbank.org
International Property Rights Index	n	internationalpropertyrightsindex.org
KSV	q	www.ksv.at/bonitaetspruefung-international
Language		
LD Supplier Evaluation		
Literacy rate	i	unesco.org
Mean nominal hourly labor cost per employee by economic activity	b	ilo.org
Native language		
No of borders		
No of km		
No of transportation modes		
Paying Taxes Indicator	d	doingbusiness.org
Political and Security Risk	h	controlrisks.com
Religion		
Share English speaking people	i	unesco.org
SPI	e	socialprogressimperative.org
Strikes and lockouts by economic activity		
Total patent applications	m	wipo.int
Trading Across Borders	d	doingbusiness.org
Transparency in Business Regulation	d	doingbusiness.org
Travel warnings	j	bmeia.gv.at
UN Operational Rates of Exchange	s	treasury.un.org/operationalrates/OperationalRates.php
WRI	f	worldriskreport.org

4.31 a proposal for a data base layout is shown, which was used for a prototype of country information. The prototype database has been realized by using `MySQL` . The tables 'gis_countries' and 'spatial_ref_sys' can be used for map illustration in combination with appropriate software. The other tables are related to the risk indicators.

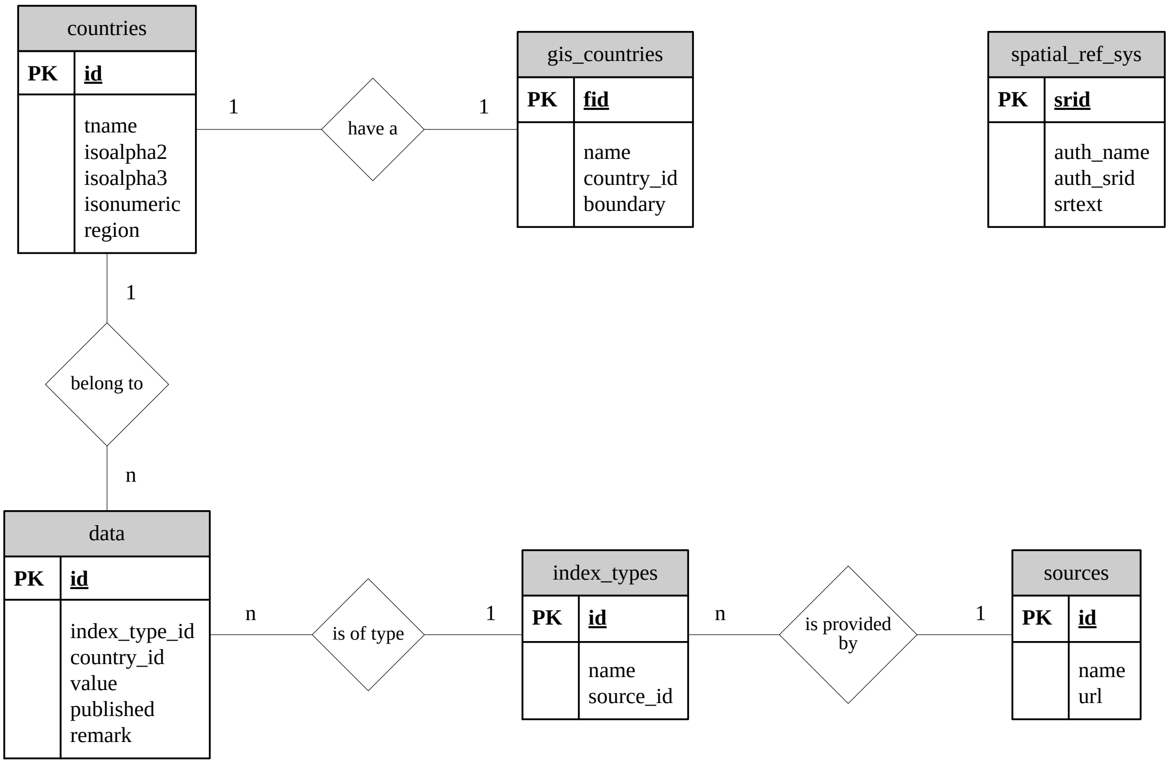

Figure 4.31: ERM

Two indicators used for the prototype should be presented in more detail at this point. The first indicator is the 'Political Risk' provided by *ControlRisks* (2016). The data are available only in printed form without a payed access. Therefore, the indicators have been transferred manually from the printed version to the prototype database. First, in the table 'sources' the source 'Control Risks' has been created. Next, the indicator 'Political Risk' has been inserted into the table 'index_types'. The various values for the different countries have been gathered in an Excel-file and then exported to a comma-separated file (*.csv). This file has been imported to the database using the following Standard Query Language (SQL) statement:

```
load data local infile '\dots/Database/RISKMAP 2016 REPORT_bearb.csv'
into table data
fields terminated by ';' optionally enclosed by '\"'
    lines terminated by '\r\n'
    ignore 1 lines
    (@col1, @col2, @col3, @col4, @col5, @col6, @col7, @col8)
    SET index_type_id = 1,
     country_id = (select countries.id from countries where @col1 =
     countries.isoalpha2),
    value = @col4, remark = @col5, published = '2016-01-01'
```

As part of the data import the field 'published' has been filled. This field is very important to describe the currency of the data. The indicator 'Political Risk' uses a five part scale to categorize the risks: extreme, high, medium, low and insignificant. After the data import they can be used in different ways. For example, they can be illustrated in a map, which was done by using the software QGIS and is shown in figure 4.32. The drawback of using this combination of `MySQL` database and QGIS software is, that there is no interface for a direct database access implemented, as for other data bases like PostgreSQL with the spatial database extension PostGIS. Therefore, a indirection by using a csv-file was necessary.

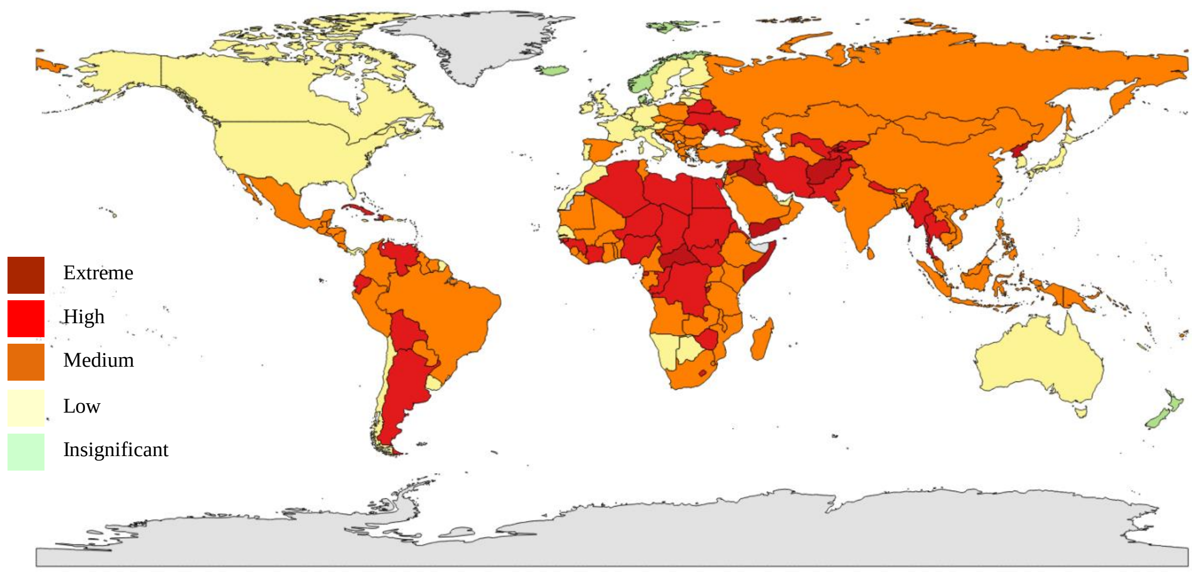

Figure 4.32: Political Risk Map

As second example the 'WRI' is explained. The 'World Risk Report', which describes the WRI is published by 'Bündnis Entwicklung Hilft & United Nations University - Institute for Environment and Human Security (UNU-EHS)'. (*World Risk Index* 2016) The WRI intends to give answers to natural hazards and the ability of the affected society to cope with it.

$$WRI = Exposure \times Vulnerability$$

$$Vulnerabilty = f(Susceptibility, Coping, Adaptation)$$

The data are available as Excel file. After some modifications (add the ISO 3166 ALPHA-3 country code) the data could be imported.

A simple prototype for country information, that means only for risks belonging to the dimension country, was realized in Microsoft Excel. It shows exemplary some indicators for some risks and is illustrated in figure 4.33. On the left side the risks and their indicators are listed. On the upper side there are two drop-down fields which allow choosing various countries from the list in order to compare them against each other. On the right side the scaling matrix is shown, which is fixed. In this case a five part scale is used. This country information gives a fast overview on various issues. Because of using a coloring for the various values in the style of traffic light systems it is intuitive to interpret and can also be used as a tool in discussions with others.

Country Information

			Austria	Belarus					
Sovereign risks	Regional stability	Political Risk	L	H	Extreme	High	Medium	Low	Insignificant
		Security Risk	L	L	Extreme	High	Medium	Low	Insignificant
	Labor costs	Income Group	OEC	UMC	Low Income	Lower middle income	Upper middle income	High income non OECD	High income OECD
Disruption risks	Natural disasters	World Risk Index	3.61	3.07	10.4-36.72	7.31-10.39	5.47-7.3	3.47-5.46	0.08-3.46
	Labor disputes	Social Progress Index	84.45	64.98	very low	low	lower middle / upper middle	high	very high
		Basic Human Needs	95.04	83.03					

Figure 4.33: Country Information

In a further step the various risk types within a group can be weighted. This allows to modify the importance of risks depending on the scenario. Therefore, the weighing matrix is adjustable by the user in contrast to the scaling matrix.

Country Information

		Weight		Austria	weighted	Belarus	weighted	
Sovereign risks	Regional stability	80%	Political Risk	L	1.6	H	3.2	1
			Security Risk	L	1.6	L	1.6	2
	Labor costs	20%	Income Group	OEC	0.2	UMC	0.6	3
Disruption risks	Natural disasters	30%	World Risk Index	3.61	0.6	3.07	0.3	4
	Labor disputes	70%	Social Progress Index	84.45	1.4	64.98	2.1	5
			Basic Human Needs	95.04	0.7	83.03	1.4	
					6.1		**9.2**	

Figure 4.34: Country Information - weighted values

5 Discussion and Outlook

5.1 Findings

Risks along the entire SC have been investigated and assigned to different dimensions. To enable the evaluation of risks appropriate indicators have been identified. The country information based on these risk indicators allows a first rough assessment of the overall situation. The use of a scaling matrix suggests an evaluation by good and bad values. But this has to be treated with caution. The data model only shows available information, but does not put the information into relations. Therefore, the given information need to be analyzed and evaluated by experts.

In a further step the countries and their risks can be considered not only individually, but rather as a network of risks overlapping and influencing each other. The SC partners can be seen as nodes in the system connected by different possible routes between these nodes. Hence, further risks concerning routes and companies are added to the system. For these two dimensions risk indicators have been identified too to enable measuring of risks. Moreover, the flow between the nodes can be estimated by data from the value stream analysis.

The indicators are an important basis for the tools and therefore data management is an significant issue. It is needed to save the data in an appropriate manner, for example using a database. Only up-to-date data can provide useful insights. For this reason a kind of automation should be considered by using available interfaces or import macros to ease the update of data. Furthermore, a regularly administration and update of data is needed.

5.2 Interpretation

Considering the initial question, if modeling and simulation are appropriate methods for the evaluation of SC configurations this can be answered with yes, they are. In particular SCs are often or can become very complex systems and for this reason methods are needed to simplify and abstract the system to be able to evaluate them properly. With the focus on risks related to countries the process of identifying and evaluating indicators have been shown. The found indicators are the basis for further investigations, which are discussed in the last section. A second important information could be gained by carrying out the value stream analysis. Even when little is known of a new product in development, the acquired data allow a first assessment. Although no BOM is available at this point of time, the main components are known and can be estimated based on experience and historical data.

5.3 Summary

It can be summarized that modeling and simulation are useful tools also for a middle-size company as the Business Partner, because it depends less on the company size as on the system that should be investigated. As SCs are becoming more and more complex because of changing requirements as increasing customer expectations and globally distributed SCs. In preparation of a computer simulation a value stream analysis was carried out to enable the evaluation of mass streams between the network nodes. Furthermore, risk indicators to quantify arising risks along the SC have been identified. A data model prototype has been implemented by using a MySQL database. Moreover, to illustrate risks related to countries a prototype for country information has been developed.

5.4 Future Perspective

Based on the findings of this thesis a computer model for a simulation study should be set up. For this kind of problems with high and diverse uncertainties a Monte-Carlo simulation would be appropriate. It could provide insights into a complete SC with the various risks and uncertainties. By running a lot of simulations a probability distribution of the resulting risks of a certain set up can be gained. Different scenarios can be simulated an compared to each other. Especially for the set-up of new SC settings this could be a very useful tool to assist as a decision support tool. In further progress steps it can be considered to include other simulation techniques if it seems to be useful to make further improvements.

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Appendix

Questionnaire

Answers of respondent A are marked with 'A' and of respondent B with 'B'.

Supply Chain Analytics					
Please mark the most suitable answer with "x".	Not at all	To a limited extend	To a moderate extent	To a great extend	To a very great extend
	1	2	3	4	5
1 Service Level Management					
1.1 Customer and Service Level Segmentation					
Do you classify your customers systematically after their logistical service requirements?	A B				
Do you know the main factors for the purchase decisions of your particular customer segments, and do you know how you compare with your competitors?	A B				
Do you identify customer service breakpoints, i.e. critical service levels, where purchase decisions of customers change obviously if you are below or above a certain level?	A	B			
Do you have different (pre-configured) supply chains to serve individual customer segments with their respective service requests in an optimal way?		A B			
Do you request different prices for express and standard deliveries?				A	B
Is there a procedure established in your company to reject unprofitable (e.g. very small) orders?	A			B	
Do you know current and desired service levels of your competitors?	A		B		
1.2 Service level measurement					
Do you know the total cost of your supply chain for different service levels (real and potential)?		A		B	
Do you consider the costs associated with the service level requirements, when you evaluate the profitability of customers or products?	A				B
Are measures of supply chain service levels clearly defined and are they calculated regularly?		A			B
Is customer satisfaction measured regularly, especially with regard to the performance of your supply chain?			A		B
2. Order Processing and Demand Planning					
2.1 Principles of Order Processing					
Have you specified clear guidelines for order processing, e.g. for order sizes, for the determination of the delivery date or the consideration of late change requests?			A		B

	1	2	3	4	5
Do all employees involved in the order processing know these guidelines?			A	B	
Do you check regularly whether the guidelines of the order processing are met?			A		B
2.2 Demand Planning					
Do you develop demand forecasts company-wide and adopt them together regularly e.g. every month or quarter?				A	B
Do you regularly perform logistics planning (e.g. every quarter, every month)?		B	A		
Does your planning process consider actually existing as well as required resources and capacities due to demand, and compare them with each other?			A		B
Does your planning process assign resources and capacities correctly and as far as possible automatically to the current demand?	A				B
Do you use a formal planning model based on statistical methods?	A B				
Do you measure and evaluate the accuracy of planning, especially the accuracy of sales planning?		A			B
Will your planning model regularly be modified in order to achieve a higher accuracy?			A		B
2.3 Order Generation and Processing					
Is there a standard format for customer specific order information, which is used by all sales employees?				A	B
Are orders for stock replenishment automatically created by an IT system based on parameters and methods for optimized inventory management?	A B				
Are optimal order sizes and delivery frequencies calculated automatically as well as the amount of safety stock and updated regularly in the operational systems?	A	B			
Do all organizational functions have access to current inventory information along the entire supply chain?			A	B	
Are the numbers of unintended ”0”-stock levels tracked and are the causes investigated?		A			B
Have your customers electronic access to product data of your company (e.g. product numbers, properties, prices)?	A		B		
Is it possible for your customers to input data of their orders by EDI or internet directly in your order processing system?	A B				
Does your organization have electronic access to the MRP or stocks of their up- or downstream supply chain partners and can you use this information directly as input variables for your own planning system?	A B				
Are replies to inquiries as well as order confirmations for order quantities and delivery date fast enough from your customers point of view?				A B	
Is the availability of bottleneck capacities and materials checked during order processing to ensure that the delivery date and order quantities are met?			B	A	

	1	2	3	4	5
Is it possible to track all the information about the customer order and its status online?	B		A		
Is the percentage of express orders less than 1 %?			B		
Are stability and reliability of your delivery times measured and depending on the result corrective actions taken?	A				B
Is order planning based on known and present lead times of every step in the process?		A		B	
Is the order process supported by appropriate IT systems?			A B		
Are failures in order processing measured and therefore arising delays and costs recorded?		A			B
Do your customers have electronic access to invoices or do you forward invoices electronically?	A				B
3 Production Management					
3.1 Production Planning					
Are "Freeze Points" determined and enforced, after them changes of the production plan are no longer permitted?			A		B
Are there clear economic objectives for stocks of raw, semi-finished and finished goods?			A	B	
Do the physical inventories correspond to them reported in the IT systems?			A B		
Does your IT-system provide a detailed and up-to-date overview of the key figures (dates, quantities) of transactions along the entire supply chain?		B	A		
Do your IT planning tools consider limited capacity?		A B			
Do the users of your IT-based planning systems see it as a support or as an obstacle in daily work?			A B		
3.2 Capacity Management					
Are there clear guidelines and priorities in order to schedule bottleneck resources, and are they adhered to?			A		B
Is it possible to give reliable information on the delivery date on the day of the order receipt?	B			A	
Are capacity reservations made in order to serve key customers at the best?		B		A	
Is there an emergency plan for suddenly occuring bigger production losses?		B	A		
Do you regularly execute improvement programs, which explicitly include network optimization and outsourcing options?			A	B	
4 Procurement Management					
4.1 Supplier Management					
Do you have less than three suppliers per material group?	B		A		
Is the selection of suppliers done based on a defined procedure, that also considers supply chain criteria?		A			B
Do you have agreements with your suppliers in terms of "Intellectual property rights"?				A	B
Have you set up cooperative, mutual value-creation oriented relationships with your suppliers, and do you maintain them?			A	A	B
Are long-term framework agreements with preferred suppliers periodically renegotiated?			A	A	B

	1	2	3	4	5
Do long-term framework agreements with suppliers include elements to optimize the supply chain process, e.g. on order demand strategies such as just-in-time delivery or cross-docking?			A B		
Are indicators of delivery performance such as delivery times or deadline compliance measured systematically for each supplier?			A		B
Do you (re-)evaluate your suppliers regularly?		B		A	
Do you evaluate your suppliers in terms of quality, flexibility, modern technologies and ecological standards?			A	A	B
Do suppliers obtain feedback on their supply chain performance?			A		B
4.2 Inbound Logistics					
Is it possible for consumers in materials scheduling and production to call production material directly from the supplier based on framework contracts, without calling for the purchasing department?	A		B		
Are supplier-side material flows systematically and regularly divided by logistical categories and assigned to standardized processes, e.g. of warehousing, or just-in-time and just-in-sequence deliveries?	B	A			
Does your organization exchange business documents such as orders, delivery notes or invoices electronically with its suppliers?		B	A		
Are incoming materials automatically synchronized with electronically transmitted delivery data to increase efficiency of goods receipt process-es using machine-readable identification (bar codes, transponders)?	A	B			
Is it possible to access stocks or production plans from suppliers electronically and can these information be used as input for your own planning systems?	A B				
Do suppliers obtain information about your demand plans, inventories or production plans?		A	A	B	
Are safety stocks calculated for supply materials and are they updated regularly?		A		B	
5 Distribution Management					
5.1 Distribution Network					
Are the locations of warehouses and stocks determined from the point of view to reach the required customer service level at minimum costs?		A			B
Do you look for synergies in transport and warehousing with various business areas or with other external market players and do you use them (e.g. pick-up or distribution rounds, shared stocks)?		A		B	
Is cross-docking taken into consideration as an alternative to supplies from regional warehouses and - as possible - used in practice?	B	A	A		
Is the share of direct deliveries to end customers optimized, by avoiding stocks?			A B		

	1	2	3	4	5
5.2 Warehouse management					
Have been storage facilities and processes systematically developed with the objective of optimum performance (i.e. lead time, flexibility) and minimal costs for handling, storage and order picking at the same time?		A	B		
Are product damages and picking errors reduced to a minimum?			A B		
Is the material flow automatically tracked within the storage using barcodes or transponders?	A	B			
Are the processes in the incoming goods widely automated, e.g. based on in advance electronically transmitted delivery information and loading and packaging units equipped with barcodes?	A	B			
Are the value-creating steps in warehousing, additional to the logistics core tasks, generated in the optimum range and at the optimal locations?		A B			
5.3 Transport					
Is a cost-optimized mix of different transport modes used and regularly adapted to the changing distribution requirements and capabilities of logistics service providers?			A	B	
Is the utilization of transport systematically checked and empty runs are thereby avoided as far as possible by utilizing internal and external synergies?		B	A		
Does your company use a few logistics service providers, but having a comprehensive international logistics network?			A	A B	
6 General Topics					
6.1 Supply Chain Organization					
Are there explicit agreements on service levels in your company between different business areas within the supply chain and do the parties adhere to the agreements made?			A	B	
Does at the highest corporate level exist a clear responsibility for achieving overall supply chain objectives?		A B			
6.2 Supply Chain Controlling					
Do you measure the overall performance of your supply chain after every significant step from the starting point of the supply chain to the end customer?	A				B
Are the information from the supply chain controlling condensed to few, but meaningful key figures per functional area?	A	A			B
Do you use financial figures as well as operational figures equally and within an integrated indicator system?			A		B
Is customer satisfaction part of the operational performance evaluation?		A	B		
Do you set specific objectives based on performance reports and do you define determined activities to achieve them?			A	B	
6.3 Risk Management					
Does your organization have a risk management?			B	A	
Do you monitor the risks along the entire supply chain?			A B		
Do you monitor individual risks along the supply chain?			A	B	

	1	2	3	4	5
6.4 eSC - IT Business Use					
The questions in this sections you were asked before already. You see your given answers as proposal. You can modify your answers.					
Does your planning process consider actually existing as well as required resources and capacities due to demand, and compare them with each other?			A		B
Does your planning process assign resources and capacities correctly and as far as possible automatically to the current demand?	A				B
Do you use a formal planning model based on statistical methods?	A B				
Are orders for stock replenishment automatically created by an IT system based on parameters and methods for optimized inventory management?	A B				
Are optimal order sizes and delivery frequencies calculated automatically as well as the amount of safety stock and updated regularly in the operational systems?	A	B			
Do all organizational functions have access to current inventory information along the entire supply chain?			A	B	
Are the numbers of unintended "0"-stock levels tracked and are the causes investigated?	A				B
Have your customers electronic access to product data of your company (e.g. product numbers, properties, prices)?	A		B		
Is it possible for your customers to input data of their orders by EDI or internet directly in your order processing system?	A B				
Does your organization have electronic access to the MRP or stocks of their up- or downstream supply chain partners and can you use this information directly as input variables for your own planning system?	A B				
Is the availability of bottleneck capacities and materials checked during order processing to ensure that the delivery date and order quantities are met?			A B		
Is it possible to track all the information about the customer order and its status online?	B		A		
Is the order process supported by appropriate IT systems?			A B		
Do your customers have electronic access to invoices or do you forward invoices electronically?	A				B
Do the physical inventories correspond to them reported in the IT systems?			A B		
Does your IT-system provide a detailed and up-to-date overview of the key figures (dates, quantities) of transactions along the entire supply chain?		B	A		
Do your IT planning tools consider limited capacity?	A	B			
Do the users of your IT-based planning systems see it as a support or as an obstacle in daily work?			A B		
Does your organization exchange business documents such as orders, delivery notes or invoices electronically with its suppliers?		B	A		

	1	2	3	4	5
Are incoming materials automatically synchronized with electronically transmitted delivery data to increase efficiency of goods receipt process-es using machine-readable identification (bar codes, transponders)?	A	B			
Is it possible to access stocks or production plans from suppliers electronically and can these information be used as input for your own planning systems?	A B				
Do suppliers obtain information about your demand plans, inventories or production plans?			A	B	
Are safety stocks calculated for supply materials and are they updated regularly?		A	B		
Is the material flow automatically tracked within the storage using barcodes or transponders?	A	B			
Are the processes in the incoming goods widely automated, e.g. based on in advance electronically transmitted delivery information and loading and packaging units equipped with barcodes?	A	B			

Turnover Classification

Categories	Grouped Category 1	Grouped Category 2
4 ‰Transport Insurance	Transport	Transport
Accessories	Accessories	Accessories
ACS	ACS	ACS
ACS-CB-SENS	ACS	ACS
ACS-CB-USBPROG	ACS	ACS
ACS-CB-WIFI	ACS	ACS
Cable	Cable	Cable
Carton & Pallet	Transport	Transport
CBC-KB-3	Compact	Control unit
CBC-KB-e-xxx-EU	Compact	Control unit
CBC-KB-e-xxx-US	Compact	Control unit
CBC-Suspa-2	Compact	Control unit
CBC-Suspa-3	Compact	Control unit
Compact-e+-2L-xxx-EU	Compact	Control unit
Compact-e+-3-xxx-EU	Compact	Control unit
Compact-e-2L-xxx-EU	Compact	Control unit
Compact-e-2L-xxx-US	Compact	Control unit
Compact-e-2-xxx-EU	Compact	Control unit
Compact-e-2-xxx-US	Compact	Control unit
Compact-e-3-DIN-OK-EU	Compact	Control unit
Compact-e-3-DIN-OK-US	Compact	Control unit
Compact-e-3-DIN-xxx-EU	Compact	Control unit
Compact-e-3-DIN-xxx-US	Compact	Control unit
Compact-e-3-xxx-EU	Compact	Control unit
Compact-e-3-xxx-US	Compact	Control unit
Customized Plastic Parts	Misc	Misc
Customized Screw	Misc	Misc
DMS Sensors	Misc	Misc
Documents	Misc	Misc
FlexC-6-RF-TP	Control Unit Home	Control unit
Flex-LAZ	Control Unit Home	Control unit
HSC-KB	HandSwitch	Handsets
HSC-LAZ	HandSwitch	Handsets
HSC-LAZ-1HL	HandSwitch	Handsets
HSC-LAZ-1ML	HandSwitch	Handsets
HSCO	HandSwitch	Handsets
HSC-OMT	HandSwitch	Handsets
HSC-STC	HandSwitch	Handsets
HSC-TOUCH-UD-WRK	HandSwitch	Handsets
HSC-TP-RF-GBTAES	HandSwitch	Handsets
HSC-TP-RF-TAES	HandSwitch	Handsets
HSD-V2	HandSwitch	Handsets
HSE	HandSwitch	Handsets
HSF	HandSwitch	Handsets
HSM	HandSwitch	Handsets
HSU-MDF	HandSwitch	Handsets

Categories	Grouped Category 1	Grouped Category 2
HSU-OD	HandSwitch	Handsets
HSX	HandSwitch	Handsets
IRR-DSK-SET-light		Handsets
Key Membrane & Plexi	Misc	Misc
LIBERTYControl-2M3	Control Unit Home	Control unit
LIBERTYControl-4M3	Control Unit Home	Control unit
LOG-CBL-PWK	Cable	Cable
LOG-CBL-xxx	Cable	Cable
LogicB-4-xxx-EU		Control unit
LogicB-4-xxx-US		Control unit
Logicpower-e+-EU		Control unit
LogicS-2-xxx-EU		Control unit
LogicS-2-xxx-US		Control unit
LogicS-3-xxx-EU		Control unit
Miscellaneous		Misc
MRO Component		Misc
Not assigned		Misc
One-Off-Costs		Misc
Power Cords		Cable
PowerConverter-Light-ZH-BAT		Misc
Samples		Misc
SET		Misc
Slimdrive-500-603-N-N-C00	Slimdrive	Drives
Slimdrive-660-N-A-E00-C01-KIN	Slimdrive	Drives
Slimdrive-660-N-N-N-C00	Slimdrive	Drives
Slimdrive-660S-N-A-E00-C01-KIN	Slimdrive	Drives
Slimdrive-660-S-N-N-C00	Slimdrive	Drives
Slimdrive-660S-N-N-E01-C00-HMI	Slimdrive	Drives
Slimdrive-660S-N-N-N-C00	Slimdrive	Drives
SLIMdrive-660S-N-N-N-C00-WRK	Slimdrive	Drives
Slimdrive-660S-S-N-N-C00	Slimdrive	Drives
SMARTbasic-e-1-xxx-EU	Smart	Control unit
Smart-e+-2-xxx-EU	Smart	Control unit
Smart-e-1-xxx-EU	Smart	Control unit
Smart-e-1-xxx-US	Smart	Control unit
Smart-e-2-xxx-EU	Smart	Control unit
Smart-e-2-xxx-US	Smart	Control unit
Smarttouch		Control unit
Smotion		Control unit
Switch		Handsets
Touch-Basic-IL	HandSwitch	Handsets
Touch-Basic-UD	HandSwitch	Handsets
Touch-FX	HandSwitch	Handsets
Touch-IL	HandSwitch	Handsets
Touch-UD	HandSwitch	Handsets
Transport Costs	Transport	Transport
Type Plates & Label	Misc	Misc
Warranty 5 Years	Misc	Misc
(Leer)		Misc

Criteria Matrix

Criteria Matrix			Plan												
			Demand/supply planning					Plan infrastructure							
		Identifier	Access supply ressources	aggregate and prioritize demand requirements	conduct inventory planning	assess distribution requirments	determine production, material, and rough-cut capacity for all products and all channels	Make/buy decisions	supply chain configuration	long-term capacity and resource planning	business planning	product phase-in/phase-out	manufacturing ramp-up	end-of-life management	product line management
Demand risks	Order fulfillment errors	C01	0.5	0.5	1	0.5	1	1	1	1	0	0	0.5	0	0.5
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	1	1	1	1	1	1	1	1	0.5	0	0.5	0	0.5
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0.5	1	1	1	1	1	1	1	0.5	0	0.5	0	0.5
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	1	0	0	0.5	0.5	0	1	0.5	0	0	0	0	0
	Port capacity and congestion	C05	1	0	0.5	0	0.5	0	1	0.5	0	0	0	0	0
	Custom clearances at ports	C06	1	0	0	0	0	0	1	0	0	0	0	0	0
	Transportation breakdowns	C07	1	0	0	0	0	0	0	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	1	0	0	0	0	0	1	1	1	0	0	0	0
	Terrorism and wars	C09	1	0	0	0	0	0	1	1	1	0	0	0	0
	Labor disputes	C10	1	0	0	0	0	0	1	0	0	0	1	0	0
	Single source of supply	C11	1	0	0	0	0	1	1	1	1	0	0	0	0
	Capacity and responsiveness of alternate suppliers	C12	1	0	0	0	0	1	1	1	1	0	0	0	0
Inventory risks	Costs of holding inventories	C13	0.5	0	1	0.5	0.5	1	1	1	1	0	0	0	0
	Demand and supply uncertainty	C14	0	1	1	1	1	1	1	1	1	0	0	0	0
	Rate of product obsolescence	C15	0	0	0.5	0	0	0	0.5	0.5	1	1	1	1	1
	Supplier fulfillment	C16	1	1	1	1	0.5	1	1	1	1	0	0	0	0
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	0	0	0	0	1	1	1	1	0	0	0	0
	Lower process yields	C18	0	0	0	0	0	0.5	0.5	1	1	0	0	0	0
	Higher product cost	C19	0	0	0.5	0	0	0.5	0.5	1	0.5	0	0	0	0
	Design changes	C20	0	0	0.5	0	0.5	0	0.5	0.5	0	1	0.5	0	0.5
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0	1	1	0.5	1	1	1	0.5	0.5	0	0.5	0	0.5
	Cost of capacity	C22	0.5	0.5	1	0.5	0.5	1	1	1	1	0	0	0	0.5
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	0	0	0.5	0	0	0.5	0.5	0.5	0.5	0	0.5	0	0
	Supplier fulfillment errors	C24	0	0	0.5	0	0	0.5	0.5	0.5	0.5	0	0	0	0
	Selection of wrong partners	C25	1	0.5	0	0	0	0.5	0.5	0.5	0	0	0	0	0
	High capacity utilization supply source	C26	1	0.5	0.5	0.5	0	1	1	0.5	0.5	0	0.5	0	0.5
	Inflexibility of supply source	C27	1	1	0.5	0.5	0	0	0.5	0.5	0	0	0	0	0.5
	Poor quality or process yield at supply source	C28	0.5	0	0	0	0	1	1	1	1	0	0	0	0
	Supplier bankruptcy	C29	1	0	0	0	0.5	1	1	1	1	0	0.5	0	0
	Rate of exchange	C30	0.5	0	0	0	0	1	1	1	1	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	1	0	0.5	0	0	1	1	1	1	0	0	0	0.5
System risks	Information infrastructure breakdowns	C32	1	0	0	0	0	0	0.5	0.5	0.5	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	1	0	0.5	0.5	0.5	0	0	0	0.5	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	1	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0	0	0	0
Sovereign risks	Regional instability	C35	1	0	0	0	0	0	1	1	1	0	0	0	0
	Communication difficulties	C36	1	0	0	0	0	0	1	0	0.5	0	0	0	0
	Government regulations	C37	1	0	0	0	0	0	1	0	1	0	0	0	0
	Loss of control	C38	1	0.5	0.5	0.5	0.5	0.5	1	1	1	0	0	0	0
	Intellectual property breaches	C39	0.5	0	0	0	0	1	1	1	1	0.5	0	0	0
Transportation risks	Paperwork and scheduling	C40	0.5	0.5	0.5	0.5	0	0	0.5	0.5	0.5	0	0	0	0
	Port strikes	C41	0.5	0.5	0	0.5	0	0	0.5	0	0	0	0	0	0
	Delay at ports due to port capacity	C42	0.5	0.5	0.5	0.5	0	0	0.5	0	0	0	0	0	0
	Late deliveries	C43	0	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0
	Higher costs of transportation	C44	1	0	0	0	0	0	1	0	1	0	0	0	0
	Depends on transportation mode chosen	C45	1	0	0	0	0	0	0.5	0.5	0.5	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0.5	0	0	0	0	0	0	0	0	0	0	0	0
	References	C47	0.5	0	0	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	0	0	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0.5	0	0	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA,	C50	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per	C51	0	0	0	0	0	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	1	0	0	0	0	0	0	0	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0	0	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0	0	0
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	0	0	0	0	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	1	0	0	0	0	0	0.5	0	0	0	0	0	0
	Labor costs	C63	0	0	0	0	0	0	0	0	0	0	0	0	0
	Labor productivity	C64	0	0	0	0	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	1	0	0	0	0	0	0	0	0	0	0	0	0
Sum - Completeness / Balance			34.5	11	15.5	11	10	20	35.5	28	26.5	2.5	6	1	5.5

Criteria Matrix - Plan

Criteria Matrix			Source							Make									
			Sourcing/ material acquisition	Source infrastructure						Production execution				Make infrastructure					
		Identifier	Obtain, receive, inspect, hold and issue material	Vendor certification and feedback	sourcing quality	inbound freight	component engineering	vendor contracts	initiation of vendor payment	request and receive material	manufacture and test product	package	hold and/or release product	engineering changes	facilities and equipment	production status	production quality	shop scheduling/sequencing	shortterm capacity
Demand risks	Order fulfillment errors	C01	1	1	1	1	0	0.5	0.5	1	1	1	1	0	0.5	0.5	0.5	1	0.5
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	1	0	0	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0	0.5	0	0.5	0.5	0
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	1	0.5	0.5	0	0	0.5	0	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0.5
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	1	0.5	0	1	0	1	0.5	1	0	0	0	0	1	0	0	0	0
	Port capacity and congestion	C05	1	0	0	1	0	0	0	0.5	0	0	0	0	0	0	0	0.5	0
	Custom clearances at ports	C06	0.5	0	0	1	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	Transportation breakdowns	C07	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	1	0	0	0.5	0	0	0	0.5	0.5	0	0	0	1	0	0	0	0.5
	Terrorism and wars	C09	1	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0
	Labor disputes	C10	1	1	0	0	0	1	0.5	0.5	0.5	0.5	0.5	0	0	0.5	0.5	1	1
	Single source of supply	C11	1	1	1	0	0	1	1	1	0.5	0	0	0.5	0.5	0	0.5	1	1
	Capacity and responsiveness of alternate suppliers	C12	1	1	0	0	0	1	0.5	0.5	0.5	0	0	0	0	0	0.5	1	0.5
Inventory risks	Costs of holding inventories	C13	1	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	1
	Demand and supply uncertainty	C14	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0
	Rate of product obsolescence	C15	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
	Supplier fulfillment	C16	1	1	1	1	0	1	1	1	0	0	0	0	0	0	1	0.5	0.5
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	1	1	0	0	1	0.5	0	0	0	0	0.5	0	0	1	0	0.5
	Lower process yields	C18	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
	Higher product cost	C19	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
	Design changes	C20	0.5	0.5	0.5	0	0.5	0.5	0	0	0	0	0	1	0	0	0.5	0	0
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0.5	0.5	0	0	0	0.5	0	0.5	0	0	0.5	0	0.5	0.5	0	0.5	1
	Cost of capacity	C22	0.5	1	0	0	0	1	0	0.5	0	0	0	0	0.5	0	0	0	0
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	1	1	1	1	1	1	1	1	0.5	0	0	0	0	0	0.5	0	0
	Supplier fulfillment errors	C24	1	1	1	1	1	1	1	0.5	0	0	0	0	0	0.5	0.5	0.5	0.5
	Selection of wrong partners	C25	0.5	1	1	1	1	1	0.5	0.5	0.5	0	0	0	0.5	0.5	0.5	0.5	0.5
	High capacity utilization supply source	C26	1	1	1	0	0	1	0.5	0.5	0.5	0	0	0	0.5	0	0	0.5	1
	Inflexibility of supply source	C27	0.5	0.5	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0.5	1
	Poor quality or process yield at supply source	C28	0.5	1	1	1	1	1	0.5	0	0	0	0	0	0	0	1	0	0
	Supplier bankruptcy	C29	1	1	0	0	0	1	1	1	1	0	0	0	0	1	0	1	1
	Rate of exchange	C30	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	0	1	1	1	1	1	1	0.5	0.5	0	0	0	0	0	0	0	0
System risks	Information infrastructure breakdowns	C32	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	0.5	1	0	0	0	1	0	0.5	0	0	0	0	0	0	0	0	0
	Communication difficulties	C36	0	1	0	0	0.5	1	0	0	0	0	0	0.5	0	0	0	0	0
	Government regulations	C37	0	1	0	1	0	1	1	0	0	0	0	0.5	0	0	0	0	0
	Loss of control	C38	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0	1	1	0.5	0.5	0.5	0.5	0.5
	Intellectual property breaches	C39	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	0.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Port strikes	C41	0.5	0	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0.5	0.5
	Delay at ports due to port capacity	C42	0.5	0	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0.5	0.5
	Late deliveries	C43	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1
	Higher costs of transportation	C44	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Depends on transportation mode chosen	C45	0.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0	1	0	0	0	1	0.5	0	0	0	0	0	0	0	0	0	0
	References	C47	0	1	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	1	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA,	C50	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per	C51	0	0.5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	1	0.5	0.5	0.5	1	0	0	0	0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0.5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	1	0	0.5	0	0	0	0	0	0	0	0	0	0	0
	Conditions of payment	C55	0	0.5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	All necessary quality and ecological certificates available	C57	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Experience with modern quality techniques	C58	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Labor costs	C63	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Labor productivity	C64	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sum - Completeness / Balance			25	40.5	18.5	23	11	38.5	15	18.5	8.5	2.5	4.5	5.5	7.5	4.5	9	12	13.5

Criteria Matrix - Source & Make

Criteria Matrix			Deliver															
			Demand management									Order management						
		Identifier	Conduct forecasting	plan promotions	plan projects	plan sales campaigns	collect and analyse point of sale (POS) data and actual customer orders	promote products	price products	measure customer satisfaction	execute efficient customer response (ECR)	Enter and maintain orders	generate quotations	configure product	create and maintain customer database	manage allocations	maintain product/price database	manage accounts receivables, credits, collections and invoicing
Demand risks	Order fulfillment errors	C01	0	0	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	1	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0.5	0	0	0	0	0
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	1	1	1	1	0.5	0.5	0.5	0	0	0.5	0.5	0	0	0	0	0
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Port capacity and congestion	C05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Custom clearances at ports	C06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Transportation breakdowns	C07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
	Terrorism and wars	C09	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
	Labor disputes	C10	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
	Single source of supply	C11	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	Capacity and responsiveness of alternate suppliers	C12	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Demand and supply uncertainty	C14	1	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0
	Rate of product obsolescence	C15	1	1	1	1	0.5	1	1	0.5	0.5	1	1	1	0	1	1	1
	Supplier fulfillment	C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manufacturing (process)	Poor quality (ANSI or other compliance standards)	C17	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0
breakdown risks	Lower process yields	C18	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	Higher product cost	C19	0	0	0	0	0	0	0.5	0.5	0.5	0	0	0	0	0	0	0
	Design changes	C20	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0	0	0	0
Physical plant	Lack of capacity flexibility	C21	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
(capacity) risks	Cost of capacity	C22	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Supply	Quality of service, including responsiveness and delivery performance	C23	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0
(procurement) risks	Supplier fulfillment errors	C24	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0
	Selection of wrong partners	C25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High capacity utilization supply source	C26	0	0.5	0	0.5	0	0	0	0.5	0	0.5	0	0	0	0	0	0
	Inflexibility of supply source	C27	0	0.5	0	0.5	0	0.5	0	0	0	0.5	0	0	0	0	0	0
	Poor quality or process yield at supply source	C28	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0
	Supplier bankruptcy	C29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rate of exchange	C30	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
System risks	Information infrastructure breakdowns	C32	0.5	0	0	0	0.5	0	0	0	0	0	0	0	1	0	1	1
	Lack of effective system integration or extensive system networking	C33	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0.5	1	1	0.5
	Lack of compatibility in IT platforms among SC partners	C34	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0.5	0	1	0.5
Sovereign risks	Regional instability	C35	1	1	1	1	1	1	0.5	0	0	1	1	0	0	0.5	0	0
	Communication difficulties	C36	0.5	0.5	0.5	0.5	1	1	0	1	0.5	1	1	0.5	0	0.5	0	0
	Government regulations	C37	0	0.5	0.5	0.5	0	0.5	0	0	0	0.5	0.5	0	0	1	0	0
	Loss of control	C38	0.5	0.5	0.5	0.5	0	0.5	0	0.5	0.5	0.5	0.5	0	0	1	0.5	0
	Intellectual property breaches	C39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Port strikes	C41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Delay at ports due to port capacity	C42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Late deliveries	C43	0	0	0	0	0	0	0	1	1	0.5	0.5	0	0	0.5	0	0
	Higher costs of transportation	C44	0	0.5	0.5	0.5	0	0.5	0.5	0	0	0.5	0.5	0	0	0	0	0
	Depends on transportation mode chosen	C45	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	References	C47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA,	C50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per	C51	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Labor costs	C63	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Labor productivity	C64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Sum - Completeness / Balance			8.5	7	6	7.5	5.5	7	12	7	5	7.5	6	1.5	2	6.5	4.5	3

Criteria Matrix - Deliver (Part 1)

Criteria Matrix		Identifier	Deliver: Warehouse management: receive and stock finished goods	pick and pack	configure products	ship products	create customer specific package labelling	consolidate orders	Transportation management: Manage traffic	manage freight	manage product import/export	Installation management: schedule installation activities	perform installation	verify performance	Deliver insfrastructue: Channel business rules	order rules	management of deliver inventories	management of deliver quantity	Sub Total - Relevance
Demand risks	Order fulfillment errors	C01	0.5	0.5	0	0.5	1	0	0.5	0.5	0.5	0	0	0	0	0.5	0.5	0.5	26
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	0.5	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0	0.5	0.5	0.5	0.5	24
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0.5	0	0	0	0	0.5	0.5	0.5	0.5	0	0	0	0	0	0.5	0.5	26
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0.5	0	0	0.5	0	0	1	1	1	0	0	0	0	0.5	0.5	0.5	15
	Port capacity and congestion	C05	0.5	0	0	0.5	0	0	1	1	1	0	0	0	0	0.5	0.5	0.5	12
	Custom clearances at ports	C06	0.5	0	0	0.5	0	0	1	1	1	0	0	0	0	0.5	0	0	8.5
	Transportation breakdowns	C07	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	9
Disruption risks	Natural disasters	C08	0.5	0	0	0.5	0	0	0.5	0.5	0	0	0	0	0.5	0.5	0	0	11.5
	Terrorism and wars	C09	0.5	0	0	0.5	0	0	0.5	0.5	1	0	0	0	0.5	0.5	0	0	13.5
	Labor disputes	C10	0.5	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	13.5
	Single source of supply	C11	0.5	0	0	0	0	0	0.5	0.5	0	0	0	0	0.5	0.5	0	0	18
	Capacity and responsiveness of alternate suppliers	C12	0.5	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	13.5
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
	Demand and supply uncertainty	C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5
	Rate of product obsolescence	C15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21.5
	Supplier fulfillment	C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.5
Manufacturing (process)	Poor quality (ANSI or other compliance standards)	C17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.5
breakdown risks	Lower process yields	C18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.5
	Higher product cost	C19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
	Design changes	C20	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	11
Physical plant	Lack of capacity flexibility	C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.5
(capacity) risks	Cost of capacity	C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11.5
Supply	Quality of service, including responsiveness and delivery performance	C23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
(procurement) risks	Supplier fulfillment errors	C24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
	Selection of wrong partners	C25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5
	High capacity utilization supply source	C26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
	Inflexibility of supply source	C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
	Poor quality or process yield at supply source	C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5
	Supplier bankruptcy	C29	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	16
	Rate of exchange	C30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.5
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
System risks	Information infrastructure breakdowns	C32	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	8.5
	Lack of effective system integration or extensive system networking	C33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.5
	Lack of compatibility in IT platforms among SC partners	C34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Sovereign risks	Regional instability	C35	0.5	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	20.5
	Communication difficulties	C36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
	Government regulations	C37	0	0	0.5	0.5	0.5	0	0.5	0.5	1	0	0	0	0	0	0	0	15
	Loss of control	C38	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0	0	0	0.5	0.5	0.5	0.5	27
	Intellectual property breaches	C39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Transportation risks	Paperwork and scheduling	C40	0.5	0	0	1	0	0	1	1	1	0	0	0	0.5	0.5	0.5	0.5	11.5
	Port strikes	C41	0.5	0	0	1	0	0	1	1	1	0	0	0	0.5	0.5	1	1	12
	Delay at ports due to port capacity	C42	0.5	0	0	1	0	0	1	1	1	0	0	0	0	0	1	1	11.5
	Late deliveries	C43	0.5	0	0	0.5	0	0	1	1	1	0	0	0	0.5	0.5	1	1	17
	Higher costs of transportation	C44	0	0	0	0.5	0	0	1	1	1	0	0	0	0.5	0.5	0.5	0.5	13
	Depends on transportation mode chosen	C45	0	0	0	1	0	0	1	1	1	0	0	0	1	1	0.5	0.5	11.5
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	References	C47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Friendliness	C48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5
	Acceptance of defined LD-Standards (NDA,	C50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Ranking of offer in comparison to others (price per	C51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Others	Taxes	C61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5
	Transport infrastructure (railway, port, airport, …)	C62	0.5	0	0	0	0	0	1	1	1	0	0	0	0	0.5	0.5	0.5	8
	Labor costs	C63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Labor productivity	C64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Trade ristrictions	C65	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4.5
Sum - Completeness / Balance			12	1.5	1.5	12.5	2.5	1	16.5	16.5	17	0	0	0	5.5	8	8	8	

Criteria Matrix - Deliver (Part 2)

Impact Matrix

Impact Matrix	Impact on		Demand risks			Delay risks				Disruption risks				
			Order fulfillment errors	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	Excessive handling due to border crossings or change in transportation mode	Port capacity and congestion	Custom clearances at ports	Transportation breakdowns	Natural disasters	Terrorism and wars	Labor disputes	Single source of supply	Capacity and responsiveness of alternate suppliers
			C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12
Demand risks	Order fulfillment errors	C01		1	1	2	0	1	0	0	0	0	1	1
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	2		2	0	0	0	0	0	0	0	0	1
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	2	2		0	0	0	0	0	0	0	0	1
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	1	0	0		0	0	0	0	0	0	0	0
	Port capacity and congestion	C05	1	0	0	2		2	1	0	0	0	0	0
	Custom clearances at ports	C06	1	0	0	2	2		0	0	0	0	0	0
	Transportation breakdowns	C07	1	0	0	3	1	1		0	0	0	3	0
Disruption risks	Natural disasters	C08	0	0	0	2	2	0	3		1	0	3	2
	Terrorism and wars	C09	0	0	0	2	2	1	3	0		0	3	2
	Labor disputes	C10	0	0	0	2	2	2	3	0	1		3	2
	Single source of supply	C11	1	1	1	1	0	0	1	0	0	0		2
	Capacity and responsiveness of alternate suppliers	C12	1	0	0	0	0	0	0	0	0	0	1	
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	0	0	0	0	0	0	0
	Demand and supply uncertainty	C14	1	2	2	1	0	0	0	0	0	0	1	0
	Rate of product obsolescence	C15	0	1	1	0	0	0	0	0	0	0	0	0
	Supplier fulfillment	C16	2	0	0	2	0	0	0	0	0	0	0	0
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	0	0	0	0	0	0	0	0	0	0	2
	Lower process yields	C18	0	0	0	0	0	0	0	0	0	0	0	0
	Higher product cost	C19	0	0	0	0	0	0	0	0	0	0	0	1
	Design changes	C20	1	0	0	0	0	0	0	0	0	0	1	0
Physical plant (capacity) risks	Lack of capacity flexibility	C21	2	0	0	0	0	0	0	0	0	0	0	0
	Cost of capacity	C22	0	0	0	0	0	0	0	0	0	0	0	0
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	1	0	0	0	0	0	0	0	0	0	0	0
	Supplier fulfillment errors	C24	1	0	0	0	0	0	0	0	0	0	0	0
	Selection of wrong partners	C25	2	0	0	0	0	0	0	0	0	0	1	1
	High capacity utilization supply source	C26	1	1	1	0	0	0	0	0	0	0	2	1
	Inflexibility of supply source	C27	1	0	0	0	0	0	0	0	0	0	2	2
	Poor quality or process yield at supply source	C28	1	0	0	0	0	0	0	0	0	0	0	0
	Supplier bankruptcy	C29	0	0	0	0	0	0	0	0	0	0	0	3
	Rate of exchange	C30	1	0	0	0	0	0	0	0	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	0	0	0	0	0	2	1
System risks	Information infrastructure breakdowns	C32	2	1	2	0	0	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	2	1	2	0	0	0	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	2	1	2	0	0	0	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	2	0	0	2	0	0	0	0	2	2	2	2
	Communication difficulties	C36	2	1	2	2	0	1	0	0	0	0	1	0
	Government regulations	C37	0	0	0	2	0	2	0	0	2	2	0	0
	Loss of control	C38	2	0	0	2	0	0	0	0	1	1	0	0
	Intellectual property breaches	C39	2	0	0	0	0	0	0	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	2	0	0	2	0	0	0	0	0	0	0	0
	Port strikes	C41	0	0	0	1	2	2	2	0	0	1	0	0
	Delay at ports due to port capacity	C42	0	0	0	0	2	1	1	0	0	0	0	0
	Late deliveries	C43	0	0	0	2	1	1	1	0	0	0	0	0
	Higher costs of transportation	C44	0	0	0	2	0	0	0	0	0	0	0	0
	Depends on transportation mode chosen	C45	0	0	0	2	2	2	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	0	0	0	0	0	2	0
	References	C47	0	0	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	0	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	0	0	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per unit)	C51	0	0	0	0	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	2	1	1	1	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0	0
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	0	0	0	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	2	0	2	0	0	0	0	0
	Labor costs	C63	0	0	0	0	0	0	0	0	0	1	0	0
	Labor productivity	C64	0	0	0	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	2	0	0	0	0	0	0
Passive sum (PS)			40	12	16	38	19	19	18	0	7	7	28	24
P = AS*PS			1280	264	336	684	418	437	558	0	406	371	1176	288

Impact Matrix (Part 1)

Impact Matrix	Impact on		Inventory risks				Manufacturing (process) breakdown risks				Physical plant (capacity) risks	
			Costs of holding inventories	Demand and supply uncertainty	Rate of product obsolescence	Supplier fulfillment	Poor quality (ANSI or other compliance standards)	Lower process yields	Higher product cost	Design changes	Lack of capacity flexibility	Cost of capacity
			C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Demand risks	Order fulfillment errors	C01	2	1	0	0	0	0	2	0	2	1
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	3	2	0	1	1	0	2	1	1	1
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	3	2	0	0	0	0	2	1	1	1
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0	2	0	0	0	0	0	0	1	0
	Port capacity and congestion	C05	0	1	0	0	0	0	0	0	0	0
	Custom clearances at ports	C06	0	1	0	0	0	0	0	0	0	0
	Transportation breakdowns	C07	0	2	0	0	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	0	3	0	2	0	0	1	0	2	0
	Terrorism and wars	C09	0	3	0	2	0	0	1	0	2	0
	Labor disputes	C10	2	3	0	3	1	1	1	0	2	0
	Single source of supply	C11	2	3	0	3	2	0	1	0	2	0
	Capacity and responsiveness of alternate suppliers	C12	0	0	0	2	0	1	0	0	0	0
Inventory risks	Costs of holding inventories	C13		1	0	2	0	2	2	0	2	2
	Demand and supply uncertainty	C14	1		0	1	0	0	0	0	1	1
	Rate of product obsolescence	C15	2	1		0	0	1	0	0	0	0
	Supplier fulfillment	C16	0	0	0		0	0	0	0	0	2
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	0	0	2		0	0	1	0	0
	Lower process yields	C18	0	0	0	0	0		1	1	0	0
	Higher product cost	C19	2	0	0	0	0	2		1	0	0
	Design changes	C20	0	0	1	0	0	0	2		0	0
Physical plant (capacity) risks	Lack of capacity flexibility	C21	1	2	0	0	0	0	1	0		2
	Cost of capacity	C22	2	0	0	0	0	1	1	0	1	
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	2	2	0	2	2	1	1	1	1	0
	Supplier fulfillment errors	C24	1	2	0	2	2	2	2	0	1	0
	Selection of wrong partners	C25	0	1	0	2	2	2	2	1	1	0
	High capacity utilization supply source	C26	2	2	0	2	1	0	1	0	2	1
	Inflexibility of supply source	C27	1	1	0	2	0	0	0	0	2	1
	Poor quality or process yield at supply source	C28	0	0	0	2	2	2	2	0	0	0
	Supplier bankruptcy	C29	2	3	0	3	0	2	2	0	2	2
	Rate of exchange	C30	0	0	0	0	0	0	2	0	0	2
	Percentage of a key component or raw material procured from a single source	C31	0	2	0	1	0	0	0	0	0	0
System risks	Information infrastructure breakdowns	C32	0	2	0	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	0	1	0	1	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	0	1	0	1	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	0	0	0	1	0	0	0	0	0	0
	Communication difficulties	C36	0	0	0	1	0	1	1	0	0	0
	Government regulations	C37	0	0	0	0	0	0	1	0	0	0
	Loss of control	C38	0	0	0	2	0	0	0	0	0	0
	Intellectual property breaches	C39	0	0	0	0	0	0	0	2	0	0
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	0	0	0	0	0
	Port strikes	C41	0	1	0	0	0	0	0	0	0	0
	Delay at ports due to port capacity	C42	0	1	0	0	0	0	0	0	0	0
	Late deliveries	C43	1	1	0	0	0	0	0	0	0	0
	Higher costs of transportation	C44	0	0	0	0	0	0	0	0	0	0
	Depends on transportation mode chosen	C45	0	0	0	0	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0	0	0	1	0	0	0	0	0	0
	References	C47	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per unit)	C51	0	0	0	0	0	0	2	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	2	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	1	0	0	0	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	2	0	0	0	0	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	2	0	0	0	0	0
	Experience with modern quality techniques	C58	0	0	0	0	2	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	2	0	0
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	1	0	0	0	0	0	2	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	0	0	0	0	0	0
	Labor costs	C63	2	0	0	0	0	0	2	0	0	1
	Labor productivity	C64	0	0	0	0	0	0	1	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	0	0	0	0	0
Passive sum (PS)			32	48	1	43	17	18	40	11	26	17
P = AS*PS			608	672	9	430	408	108	520	121	234	85

Impact Matrix (Part 2)

Impact Matrix	Impact on		Supply (procurement) risks								
			Quality of service, including responsiveness and delivery performance	Supplier fulfillment errors	Selection of wrong partners	High capacity utilization supply source	Inflexibility of supply source	Poor quality or process yield at supply source	Supplier bankruptcy	Rate of exchange	Percentage of a key component or raw material procured from a single source
			C23	C24	C25	C26	C27	C28	C29	C30	C31
Demand risks	Order fulfillment errors	C01	2	2	2	0	1	0	0	0	1
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	0	1	0	0	0	0	0	0	1
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	1	1	1	0	0	0	0	0	1
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	2	0	0	0	0	0	0	0	0
	Port capacity and congestion	C05	0	1	1	0	0	0	0	0	0
	Custom clearances at ports	C06	1	1	1	0	0	0	0	0	0
	Transportation breakdowns	C07	1	2	1	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	2	0	0	0	0	0	1	1	0
	Terrorism and wars	C09	2	0	0	0	0	0	1	2	0
	Labor disputes	C10	2	0	1	0	2	1	1	0	0
	Single source of supply	C11	1	2	2	0	1	3	2	0	0
	Capacity and responsiveness of alternate suppliers	C12	1	0	0	0	1	0	0	0	2
Inventory risks	Costs of holding inventories	C13	2	1	0	0	2	0	0	0	1
	Demand and supply uncertainty	C14	0	1	1	0	0	0	0	0	0
	Rate of product obsolescence	C15	0	0	0	0	0	0	0	0	0
	Supplier fulfillment	C16	2	2	0	0	0	0	0	0	0
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	2	2	1	0	0	2	0	0	3
	Lower process yields	C18	0	0	1	0	0	0	0	0	0
	Higher product cost	C19	0	0	0	0	0	0	0	0	2
	Design changes	C20	0	2	0	0	0	1	0	0	1
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0	0	1	0	0	0	0	0	0
	Cost of capacity	C22	0	0	0	0	0	0	0	0	0
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23		2	1	2	0	2	0	0	1
	Supplier fulfillment errors	C24	2		1	1	0	2	1	0	1
	Selection of wrong partners	C25	3	2		1	1	2	2	1	1
	High capacity utilization supply source	C26	2	1	0		1	1	1	0	0
	Inflexibility of supply source	C27	2	1	0	2		0	0	0	3
	Poor quality or process yield at supply source	C28	2	2	2	2	0		0	0	0
	Supplier bankruptcy	C29	3	3	2	2	0	0		0	0
	Rate of exchange	C30	0	0	0	0	0	0	1		0
	Percentage of a key component or raw material procured from a single source	C31	0	2	0	0	0	0	0	0	
System risks	Information infrastructure breakdowns	C32	0	1	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	0	1	0	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	0	1	0	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	0	0	2	2	0	0	1	1	1
	Communication difficulties	C36	2	2	0	0	0	1	0	0	0
	Government regulations	C37	0	0	1	0	0	0	0	1	0
	Loss of control	C38	0	0	0	0	0	0	0	1	0
	Intellectual property breaches	C39	0	0	2	0	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	0	0	0	0
	Port strikes	C41	0	0	0	0	0	0	0	0	0
	Delay at ports due to port capacity	C42	0	0	0	0	0	0	0	0	0
	Late deliveries	C43	0	0	0	0	0	0	0	0	0
	Higher costs of transportation	C44	0	0	0	0	0	0	0	0	0
	Depends on transportation mode chosen	C45	0	0	0	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	0	2	0	0
	References	C47	0	0	0	0	0	0	0	0	0
	Friendliness	C48	1	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	2	1	1	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per unit)	C51	0	0	1	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	1	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	1	0	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	2	2	1	0	0	2	0	0	0
	All necessary quality and ecological certificates available	C57	2	0	1	0	0	0	0	0	0
	Experience with modern quality techniques	C58	2	1	1	0	0	2	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	3	0	1	0	0	0	0	0	1
Others	Taxes	C61	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	0	0	0	0	0
	Labor costs	C63	0	0	0	0	0	0	0	0	0
	Labor productivity	C64	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	0	0	0	0
Passive sum (PS)			49	40	32	12	9	19	13	7	20
P = AS*PS			1764	960	896	288	180	323	494	91	180

Impact Matrix (Part 3)

Impact Matrix	Impact on		System risks			Sovereign risks					Transportation risks					
			Information infrastructure breakdowns	Lack of effective system integration or extensive system networking	Lack of compatibility in IT platforms among SC partners	Regional instability	Communication difficulties	Government regulations	Loss of control	Intellectual property breaches	Paperwork and scheduling	Port strikes	Delay at ports due to port capacity	Late deliveries	Higher costs of transportation	Depends on transportation mode chosen
			C32	C33	C34	C35	C36	C37	C38	C39	C40	C41	C42	C43	C44	C45
Demand risks	Order fulfillment errors	C01	0	0	0	0	0	0	0	2	2	0	0	1	2	2
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	0	0	0	0	0	0	0	0	1	0	0	1	1	0
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0	0	0	0	0	0	1	0	3	0	0	3	2	2
	Port capacity and congestion	C05	0	0	0	0	0	0	0	0	2	1	2	2	1	1
	Custom clearances at ports	C06	0	0	0	0	0	0	0	0	2	1	2	2	1	1
	Transportation breakdowns	C07	0	0	0	0	0	0	0	0	3	0	1	3	3	2
Disruption risks	Natural disasters	C08	3	0	0	1	2	1	2	0	2	0	1	2	2	0
	Terrorism and wars	C09	3	0	0	3	2	2	3	0	2	0	1	2	2	0
	Labor disputes	C10	1	0	0	1	1	1	2	0	1	1	1	2	2	0
	Single source of supply	C11	0	2	2	0	0	0	1	0	0	0	0	0	0	0
	Capacity and responsiveness of alternate suppliers	C12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	0	0	0	0	0	0	2	0	0
	Demand and supply uncertainty	C14	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Rate of product obsolescence	C15	0	1	1	0	1	0	0	0	0	0	0	0	0	0
	Supplier fulfillment	C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	1	1	0	0	0	0	0	0	0	0	0	0	0
	Lower process yields	C18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Higher product cost	C19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Design changes	C20	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cost of capacity	C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	0	0	0	0	0	0	0	0	1	0	0	2	1	1
	Supplier fulfillment errors	C24	0	0	0	0	0	0	0	0	1	0	0	1	1	0
	Selection of wrong partners	C25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High capacity utilization supply source	C26	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Inflexibility of supply source	C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Poor quality or process yield at supply source	C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Supplier bankruptcy	C29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rate of exchange	C30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	0	0	0	0	0	0	1	0	0
System risks	Information infrastructure breakdowns	C32		0	0	0	2	0	2	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	0		2	0	2	0	0	0	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	0	2		0	2	0	0	0	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	1	0	0		1	2	2	2	2	1	0	1	1	0
	Communication difficulties	C36	0	0	0	0		0	1	1	1	0	0	0	0	0
	Government regulations	C37	1	1	1	1	0		1	1	1	0	0	0	0	0
	Loss of control	C38	1	1	1	1	1	2		1	0	0	0	0	0	0
	Intellectual property breaches	C39	0	0	0	0	0	0	1		0	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	0	0	0		0	1	1	1	2
	Port strikes	C41	0	0	0	0	0	0	0	0	1		2	2	2	2
	Delay at ports due to port capacity	C42	0	0	0	0	0	0	0	0	0	1		2	1	2
	Late deliveries	C43	0	0	0	0	0	0	0	0	1	0	1		1	2
	Higher costs of transportation	C44	0	0	0	0	0	0	0	0	0	0	0	0		2
	Depends on transportation mode chosen	C45	0	0	0	0	0	0	0	0	2	0	1	2	2	
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	References	C47	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Friendliness	C48	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per unit)	C51	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	0	0	0	0	0	2	0	0	1	2	2
	Conditions of payment	C55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	Taxes	C61	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	0	0	0	0	2	0	1	1	2	2
	Labor costs	C63	0	0	0	1	0	0	0	0	0	0	0	0	1	0
	Labor productivity	C64	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	0	0	0	2	0	0	1	1	0
Passive sum (PS)			10	8	8	8	15	8	16	10	35	5	14	38	33	23
P = AS*PS			120	96	96	336	345	184	320	70	315	110	210	532	132	299

Impact Matrix (Part 4)

Impact Matrix	Impact on		LD Supplier Evaluation														
			Financial stability	References	Friendliness	Openess to name customers, suppliers and competitors	Acceptance of defined LD-Standards (NDA, CSR,…)	Ranking of offer in comparison to others (price per unit)	TCO-Ranking in comparison to others (tooling, quality-costs,…)	Payment Terms	Traffic connection (airport, port, motorway,…)	Conditions of payment	Defined complaint handling process with customers and suppliers	All necessary quality and ecological certificates available	Experience with modern quality techniques	Capacity of R&D/Engineering-Department	General impression of innovation
			C46	C47	C48	C49	C50	C51	C52	C53	C54	C55	C56	C57	C58	C59	C60
Demand risks	Order fulfillment errors	C01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Port capacity and congestion	C05	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Custom clearances at ports	C06	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
	Transportation breakdowns	C07	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Disruption risks	Natural disasters	C08	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Terrorism and wars	C09	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
	Labor disputes	C10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Single source of supply	C11	0	0	0	0	2	1	1	1	0	1	0	0	0	0	0
	Capacity and responsiveness of alternate suppliers	C12	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Demand and supply uncertainty	C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rate of product obsolescence	C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Supplier fulfillment	C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	2	0	0	0	0	0	0	0	0	1	1	1	0	0
	Lower process yields	C18	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	Higher product cost	C19	1	0	0	0	0	2	2	0	0	0	0	0	0	0	0
	Design changes	C20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cost of capacity	C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	0	2	2	0	2	1	1	0	0	0	2	0	0	0	0
	Supplier fulfillment errors	C24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Selection of wrong partners	C25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	High capacity utilization supply source	C26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inflexibility of supply source	C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Poor quality or process yield at supply source	C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Supplier bankruptcy	C29	3	2	0	0	0	0	0	2	0	2	0	0	0	0	0
	Rate of exchange	C30	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
System risks	Information infrastructure breakdowns	C32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lack of effective system integration or extensive system networking	C33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lack of compatibility in IT platforms among SC partners	C34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sovereign risks	Regional instability	C35	1	1	0	0	0	0	0	0	2	0	0	0	0	0	0
	Communication difficulties	C36	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
	Government regulations	C37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loss of control	C38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Intellectual property breaches	C39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Port strikes	C41	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Delay at ports due to port capacity	C42	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Late deliveries	C43	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
	Higher costs of transportation	C44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Depends on transportation mode chosen	C45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LD Supplier Evaluation	Financial stability	C46		1	0	0	0	0	0	2	0	2	0	0	0	0	0
	References	C47	0		0	0	0	0	0	0	0	0	0	0	0	0	1
	Friendliness	C48	0	1		1	0	0	0	0	0	0	0	0	0	0	0
	Openess to name customers, suppliers and competitors	C49	0	1	1		0	0	0	0	0	0	0	0	0	0	0
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	0	0	0	0		1	1	0	0	0	0	0	0	0	0
	Ranking of offer in comparison to others (price per unit)	C51	0	0	0	0	0		1	0	0	0	0	0	0	0	0
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	1		0	0	0	0	0	0	0	0
	Payment Terms	C53	0	0	0	0	0	0	0		0	2	0	0	0	0	0
	Traffic connection (airport, port, motorway,…)	C54	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	Conditions of payment	C55	0	0	0	0	0	0	0	2	0		0	0	0	0	0
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	0	0	0	0	0		0	2	0	0
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	0	0	0	0	0	0		2	2	2
	Experience with modern quality techniques	C58	0	0	0	0	0	0	0	0	0	0	0	1		2	2
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	0	0	0	0	0	0	2	2		2
	General impression of innovation	C60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Others	Taxes	C61	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
	Transport infrastructure (railway, port, airport, …)	C62	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0
	Labor costs	C63	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
	Labor productivity	C64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Trade ristrictions	C65	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Passive sum (PS)			7	10	4	3	6	9	9	12	20	14	3	4	7	4	7
P = AS*PS			70	10	16	9	36	36	36	24	320	28	36	44	91	32	35

Impact Matrix (Part 5)

Impact Matrix	Impact on		Others: Taxes (C61)	Transport infrastructure (railway, port, airport, …) (C62)	Labor costs (C63)	Labor productivity (C64)	Trade ristrictions (C65)	Active sum (AS)	Q = AS/PS
Demand risks	Order fulfillment errors	C01	0	0	0	0	0	32	0.80
	Inaccurate forecasts due to longer lead times, product variety, swing demands, seasonality, short life cycles, and small customer base	C02	0	0	0	0	0	22	1.83
	Information distortion due to sales promotions and incentives, lack of SC visibility, and exaggeration of demand during product shortage	C03	0	0	0	0	0	21	1.31
Delay risks	Excessive handling due to border crossings or change in transportation mode	C04	0	0	0	0	1	18	0.47
	Port capacity and congestion	C05	0	2	0	0	0	22	1.16
	Custom clearances at ports	C06	0	1	0	0	1	23	1.21
	Transportation breakdowns	C07	0	2	0	0	0	31	1.72
Disruption risks	Natural disasters	C08	0	2	0	0	0	45	#DIV/0!
	Terrorism and wars	C09	1	3	1	1	3	58	8.29
	Labor disputes	C10	0	0	2	2	0	53	7.57
	Single source of supply	C11	0	0	0	0	0	42	1.50
	Capacity and responsiveness of alternate suppliers	C12	0	0	0	0	0	12	0.50
Inventory risks	Costs of holding inventories	C13	0	0	0	0	0	19	0.59
	Demand and supply uncertainty	C14	0	0	0	0	0	14	0.29
	Rate of product obsolescence	C15	0	0	0	0	0	9	9.00
	Supplier fulfillment	C16	0	0	0	0	0	10	0.23
Manufacturing (process) breakdown risks	Poor quality (ANSI or other compliance standards)	C17	0	0	1	1	0	24	1.41
	Lower process yields	C18	0	0	0	0	0	6	0.33
	Higher product cost	C19	0	0	0	0	0	13	0.33
	Design changes	C20	0	0	0	0	0	11	1.00
Physical plant (capacity) risks	Lack of capacity flexibility	C21	0	0	0	0	0	9	0.35
	Cost of capacity	C22	0	0	0	0	0	5	0.29
Supply (procurement) risks	Quality of service, including responsiveness and delivery performance	C23	0	0	0	0	0	36	0.73
	Supplier fulfillment errors	C24	0	0	0	0	0	24	0.60
	Selection of wrong partners	C25	0	0	0	0	0	28	0.88
	High capacity utilization supply source	C26	0	0	0	0	0	24	2.00
	Inflexibility of supply source	C27	0	0	0	0	0	20	2.22
	Poor quality or process yield at supply source	C28	0	0	0	0	0	17	0.89
	Supplier bankruptcy	C29	0	0	0	0	0	38	2.92
	Rate of exchange	C30	1	0	2	0	0	13	1.86
	Percentage of a key component or raw material procured from a single source	C31	0	0	0	0	0	9	0.45
System risks	Information infrastructure breakdowns	C32	0	0	0	0	0	12	1.20
	Lack of effective system integration or extensive system networking	C33	0	0	0	0	0	12	1.50
	Lack of compatibility in IT platforms among SC partners	C34	0	0	0	0	0	12	1.50
Sovereign risks	Regional instability	C35	0	2	1	1	1	42	5.25
	Communication difficulties	C36	0	0	0	0	0	23	1.53
	Government regulations	C37	2	0	1	0	2	23	2.88
	Loss of control	C38	0	0	0	0	3	20	1.25
	Intellectual property breaches	C39	0	0	0	0	0	7	0.70
Transportation risks	Paperwork and scheduling	C40	0	0	0	0	0	9	0.26
	Port strikes	C41	0	2	0	0	0	22	4.40
	Delay at ports due to port capacity	C42	0	2	0	0	0	15	1.07
	Late deliveries	C43	0	0	0	0	0	14	0.37
	Higher costs of transportation	C44	0	0	0	0	0	4	0.12
	Depends on transportation mode chosen	C45	0	0	0	0	0	13	0.57
LD Supplier Evaluation	Financial stability	C46	0	0	0	0	0	10	1.43
	References	C47	0	0	0	0	0	1	0.10
	Friendliness	C48	0	0	0	0	0	4	1.00
	Openess to name customers, suppliers and competitors	C49	0	0	0	0	0	3	1.00
	Acceptance of defined LD-Standards (NDA, CSR,…)	C50	0	0	0	0	0	6	1.00
	Ranking of offer in comparison to others (price per unit)	C51	0	0	0	0	0	4	0.44
	TCO-Ranking in comparison to others (tooling, quality-costs,…)	C52	0	0	0	0	0	4	0.44
	Payment Terms	C53	0	0	0	0	0	2	0.17
	Traffic connection (airport, port, motorway,…)	C54	0	2	0	0	0	16	0.80
	Conditions of payment	C55	0	0	0	0	0	2	0.14
	Defined complaint handling process with customers and suppliers	C56	0	0	0	0	0	12	4.00
	All necessary quality and ecological certificates available	C57	0	0	0	0	0	11	2.75
	Experience with modern quality techniques	C58	0	0	0	0	0	13	1.86
	Capacity of R&D/Engineering-Department	C59	0	0	0	0	0	8	2.00
	General impression of innovation	C60	0	0	0	0	0	5	0.71
Others	Taxes	C61		0	2	0	2	9	1.80
	Transport infrastructure (railway, port, airport, …)	C62	0		0	0	0	16	0.84
	Labor costs	C63	0	0		1	0	13	1.18
	Labor productivity	C64	0	0	1		0	2	0.33
	Trade ristrictions	C65	1	1	0	0		9	0.69
Passive sum (PS)			5	19	11	6	13		
P = AS*PS			45	304	143	12	117		

Impact Matrix (Part 6)