2 Literature Review

This research aims to providing models of theoretical literature and frameworks which are related to the topic of the research. The findings of the past studies and researches also examined and evaluated for the supply chain risk mitigation within manufacturing of new product development strategies.

2.1 New Product Development in Manufacturing

NPD describes the development of a new product or service, which is going to be sold in the market. Preliminary, several steps need to be completed before the company can offer the product to the market. NPD is also defined by the "transformation of a market opportunity into a product available for sale" [3]. From figure 1, the process begins with an idea screening and evaluation followed by detailed investigation of market opportunities and customer needs. Then, product is being developed and important test regarding product quality and functionality are carried out. As soon as all requirements are fulfilled the product can be launched into the market. NPD is needed to develop products to compete in a specific market or to improve existing items, which are already established in the market. NPD is essential to any kind of business to keep and gain market share and to don't lose track when the market changes or new trends occur.

Figure 1: New product development process [4].

Supply chains describe the process of producing any kind of product beginning with the raw materials leading to the end customer. The manufacturer is part of a supply chain and is responsible for adding value to the product with processes or services. Within the supply chain the manufacturer is linked to a supplier of semi-finished goods or even raw material supplier via inbound logistics and on the other side with a retailer or the customer itself to deliver finished goods via outbound logistics. This literature review focuses on the manufacturing aspect of a supply chain, which is linked to SCRM.

Developed markets and globalization lead to shorter product life cycles and increased complexity. Therefore, companies are faced with rapid technological change, shorter development cycles and more complex products. CE or also called simultaneous engineering has been introduced as part of NPD. It provides an approach where different stages of the development are run simultaneously instead of carrying them out one after another. "In CE, product and process designs are generated simultaneously in the early stages of the product development (PD)" [5]. Cross-functional teams working on the development process at the same time enable an accelerated PD [5]. CE leads to a reduction of the time to market, enhances product quality, and productivity, decreases design and development times and reduces the overall cost, leading to a competitive advantage [6]. Sequential engineering also called traditional engineering avoids collaborative development processes. Figure 2 shows the differences between sequential engineering and CE leading to more efficient processes and shorter PD cycles.

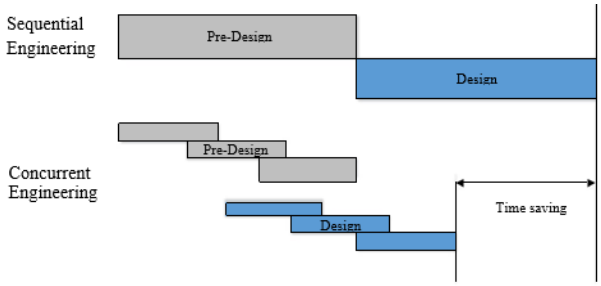

Figure 2: Sequential engineering vs. concurrent engineering [7].

NPD is always accompanied with risks. According to [8] NPD risks have been identified as NPD project risk, research and development risk, supply risk, product reliability risk and production risks, which are defined as followed. "NPD project risk is defined here as the probability that the NPD project cannot be executed within the expected duration." [8]. "Research and development (R&D) risk is the likelihood that product specifications cannot be fulfilled within the expected schedule." [8]. "Supply risk is the likelihood that the supplier is not able to deliver quality raw materials/components within the expected schedule [8]. "Product reliability risk is the likelihood that a stable production process and an expected product performance in its service lifetime cannot be fulfilled." [8]. "Production risk is the likelihood that the production requirements cannot be met within the expected schedule." [8]. Furthermore, earlier studies agreed on defining NPD risks as supply and process risks and add technology, management, labour and demand (customer) risks [9].

2.2 Supply Chain Risk Management

In this section, firstly the term of SCRM is defined. The paper further discusses different supply chain risks, supply chain drivers, risk exposition and risk measurements. Generally, risk management is defined as risk identification in combination with their analysis and control. In the context of SCRM, risk management became an important tool to focus on entire value chains instead of managing risks related to one company like traditional risk management worked. Studies identified the control and mitigation of vulnerabilities as the aim of SCRM [10]. SCRM further has been introduced as "coordination or collaboration among the supply chain partners [to] ensure profitability and continuity" [11] and four different objectives of the SCRM have been pointed out. Continuous availability and supply need to be ensured, the ability of the supply chain to face severe disruptions to product supply need to be enhanced, the supply chain need to be made more resilient to disrupting events and finally the management need to be aware to avoid domino effects throughout the entire supply chain. In addition, [12] agrees in failures or disruptions at one stage of a supply chain are being able to disrupt the partner companies both downstream and upstream as well.

Earlier studies provided a critical review about supply chain risks, based on 162 publications with different "existing approaches for quantitative supply chain risk management, reviewed by setting the focus on the definition of supply chain risk and related concepts" [13]. Therefore, it gives an extensive overview about the available literature and shows relationships, differences as well as similarities of the different approaches. It indicates trends, clusters the approaches based on different aspects like definition of risk, objectives and quantitative models and concludes weaknesses, which can be investigated in further research [13]. Moreover, research investigated the history of academic papers regarding SCRM by undertaking a literature survey. They worked out that the amount of those papers increased significantly between 2000 and 2005 [14]. The development went from mitigating the impact of interruptions to a proactive risk management system caused by severe consequences of interrupting events that led to loss of profitability and market share. However, risk mitigation can include proactive risk management as well. That studies further outlined the importance managing risks related to information, cash and material flows [14]. Furthermore, robust planning, revenue management, agency theory, system dynamics and reverse logistics are the outcomes of this journal article as approaches for quantitative risk management [14].

Figure 3: A systematic approach to SCRM [15].

Literature provides different supply chain risk strategies like risk avoidance, which can also be described as proactive risk management [16], risk mitigation [17], risk sharing [18] and risk adoption [19]. However, for this literature review the focus is set to the strategy of risk mitigation. However, risk mitigation may include proactive characteristics. In the following the other strategies won't be discussed in further details. As figure 3 shows in a descriptive manner, a general systematic approach to mitigate supply chain risks consists of identification of the risks, quantification of their impacts, mitigation of the disruption's impacts and the responses to the disrupting event to recover the supply chain.

2.2.1. Supply Chain Risks

A definition of risks in general is provided by [20] before deriving to risk definitions in the context of supply chain given in literature. Risk in general is defined as "the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decisions will be realised" [20]. Supply chain risks refers to the understanding of risks in the supply chain management (SCM) context, which has been outlined earlier. Supply chain risks have been determined as "outcome of unexpected variations" [12]. Those could be quality problems, uncertain yields, machine breakdowns or capacity constraints. Moreover, natural disasters or a fire occurring in one of the supplier's facility can be an unexpected variation as well [21]. Researchers added that that alternatives need to be identified to prevent and protect the companies' businesses. A loss of value and reputational damage need to be avoided [13]. Furthermore, [22] agrees in the statement risk being interpret as "the potential occurrence of an incident or failure to seize opportunities with inbound supply in which its outcomes result in a financial loss for the firm" [22]. Earlier studies contribute a general

risk model as shown in figure 4 [23]. The risk event is influenced by the probability of the risk event itself and the risk event driver. The occurrence of the risk lead to an impact, which again is influenced by the probability of the impact and the impact driver. Finally, the impact caused by the risk event lead to a total loss.

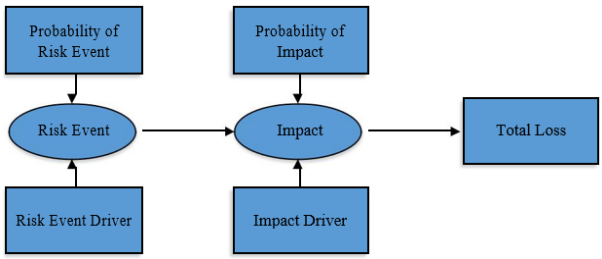

Figure 4: Standard risk model [23].

Researchers agrees in distinguishing supply chain risks in internal and external supply chain risks [24]. Internal supply chain risks are divided into cross-company-based risks, which can be further separated into purchasing risks and demand risks, and internal company risks. On the one hand, purchasing risks are related to the suppliers and therefore concerning to the upstream activities of the supply chain [22]. Demand risks are related to customer activities on the other hand and therefore they refer to downstream processes like distribution or demand forecasting [25]. On the contrary, external supply chain risks can hardly be influenced, because they refer to environmental causes and are caused by either geographical, technological, economical or socio-political reasons. Summarising, figure 5 shows a descriptive depiction of the classification of supply chain risks.

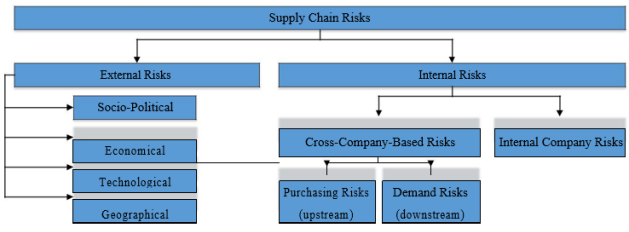

Figure 5: Supply chain risks [24].

In addition, [26] provide nine categories of risks in the supply chain context, which are called disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory and capacity. Based on the differentiation of [24], researchers worked out that "internal supply chain risks have a higher likelihood to occur than external supply chain risks" [10]. Moreover, they refuted the hypothesis that "external supply chain risks have a greater impact on the supply chain than internal supply chain risks" [10].

2.2.2 Supply Chain Risk Drivers

Before companies can operate efficient SCRM, they need to understand the risk driving factors. Just identifying risks is useless if the management board doesn't understand crucial conditions, which lead to an occurrence of identified risks. As soon as enough internal and external information about driving aspects have been transferred into knowledge, the company is able to make suitable decisions regarding an efficient risk mitigation strategy. In the following the most important supply chain risk driver are provided by referring to existing literature [26]. As shown earlier, researcher designed nine categories of supply chain risks, and provided risk drivers for each category extensively, as shown in table 1 [26].

Category of Risk	Drivers of Risk
Disruptions	- Natural disaster
	- Supplier bankruptcy
	- War and terrorism
Delays	- High capacity utilization at supply source
	- Inflexibility of supply source
	- Poor quality or yield at supply source
Systems	- Information infrastructure breakdown
	- System integration or extensive systems networking
	- E-commerce
Forecast	- Inaccurate forecasts
	- Bullwhip effect
Intellectual Property	- Lack of supply-chain visibility
	- Vertical integration of supply chain
	- Global outsourcing and markets
Procurement	- Exchange rate risk
	- Percentage of raw material procured from a single source
	- Long-term versus short-term contracts
Receivables	- Number of customers
	- Financial strength of customers
Inventory	- Inventory holding cost
	- Product value
Capacity	- Demand and supply uncertainty
	- Cost of capacity
	- Capacity flexibility

Table 1: Supply chain risk driver [26]

Moreover, [10] confirmed their hypothesis of efficiency and complexity being supply chain key drivers. Further studies classified risk driver into PEST classes, which stands for political, economic, social and technological [27, 28]. Hence, this approach is focusing on external risk drivers in figure 5 [24]. Commodity markets, supply chain execution, global environment, supplier relationship management and supplier selection are risk driver contributed by [29]. In contrast to [27], this approach doesn't categorize into internal or external risk drivers derived by the earlier studies of [26] and [10].

2.2.3 Risk Exposition

In their extensive literature review, researchers classified the risk expositions in terms of supply chain risks of existing literature in three categories: disruptive triggers, time-based characteristics and the affected supply chain [13]. Disruptive triggers are defined as "unplanned events that may occur in the supply chain which might affect the normal or expected flow of materials and components" [30]. Disruptive triggers are further divided into triggering events characterised by interruptions of low likelihood but severe impacts and probability, which describes the continuous uncertainty of the businesses within the supply chain and their environment. To give some practical examples, a study characterizes disruptive events as supplier strikes, bomb explosions and other terror attacks or natural catastrophes like tornado hits [31]. Operational difficulties, accidents, direct or industrial action, terrorist incidents or natural disasters are mentioned in this context.

Furthermore, time-based characteristics haven't been considered in literature of SCRM in depth yet and are already identified as research gaps [13]. Hence, further research is urgently needed to address this research area. Therefore, this study aims to focus on existing approaches in time-based supply chain risk mitigation to identify common gaps and to define further research objectives. The aspect of the affected supply chain consists of the conceptualities of vulnerability and resilience, which are outlined in the following. Vulnerability need to be introduced in terms of SCRM. Supply chain vulnerability has been identified as important business issue [11]. Other studies discuss vulnerability concerning of a company or a supply chain network [31]. An enterprise should consider building resilience as a strategic initiative, which is needed to increase the companies' competitiveness. Researchers [26] and [31] consent to provide two strategies to respond to disruptive events within a supply chain. They recommend building flexibility and to add redundancy to mitigate supply chain risks and to achieve resilience. Flexibility can be enhanced either internally within the company by using various equipment and multi-skilled operators or externally between the different players of the supply chain by improving the supplier and customer relationships to enable last minute changes. In addition, studies comment flexibility as being able to facilitate the coordination of procedures and processes and to manage operating and environmental uncertainties [32]. Adding redundancy includes different sourcing strategies and the availability of redundant resources such as capacity inventory [12]. Well performing companies in supply chains need to monitor the environment and their suppliers to identify changes to prevent disruptions [33]. However, adding redundancy can be costly, because strategic stocks and redundant processes are inefficient.

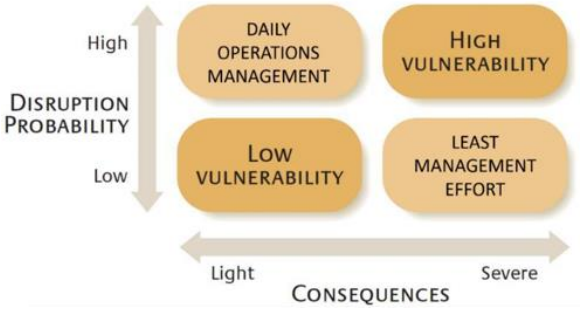

Figure 6: Vulnerability Map [31].

The maturity of vulnerability is defined by the two parameters disruption probability and resulting consequences. The highest vulnerability occurs, when a high probability of disruption correlates with severe consequences. Thus, the lowest vulnerability arises when the disruption probability is low, and consequences are light. However, companies are putting least effort in managing interruptions of severe impacts but low disruption probability because of the low likelihood of occurrence. Furthermore, the most planning and managing work is done by companies due to disruptions of high probability of occurrence and light impacts, which can also be called the management of daily operations. This approach is called the vulnerability framework and is shown in figure 6 to indicate the different areas of vulnerability, which have been explained above [31]. Moreover, [34] discusses robust strategies to prevent the impacts of disruptive events with two major aspects. First, a supply chain is created by these strategies to manage native fluctuations in an appropriate way without focusing on disruptive events. The second aspect deals with making the supply chain more resilient to withstand major disruptions. In addition, the costs of implementing these strategies can be defrayed by the customer at the same time, because the strategies enable selling points before and after a disruptive event. The paper provides three strategies to reduce impacts of occurring disruptive events, which are identified as recovery planning systems, lead time reduction and supply alliance network. "Although robust supply chain strategies enable companies to deploy the corresponding contingency plans when disruptions occur, these companies would become less vulnerable if they could reduce their exposure to

risk" [34]. According to [26] and [34] robustness and efficiency of the supply chain must be weighted. Therefore, it has impact on distribution strategies, product design and finally on the relationship to the suppliers and customers. The most common problem of preventing supply chain disruptions and disturbances consists of the economic legitimation [35]. Many companies are not willing to spend vast amount of money to prevent events that not necessarily occur.

2.2.4 Risk Measurement

Risk measurement is an essential part of SCRM aiming to describe the correlation between existing uncertainty and its potential harm or benefit. Those descriptions need to be converted into qualitative or quantitative models [30]. According to [13], criteria such as the extent of loss, probability or severity of impact may be used to measure supply chain risks. The investigation lead to a summary of commonly used approaches of risk measurement in SCM [13].

Studies differentiate SCRM instruments in preventive and reactive tools [10]. Despite both kind of instruments are initialised prior any occurrence of an incident, only preventive instruments make it possible to display their impact beforehand. Preventive tools are designed to lower the probability of the occurrence of specific risks. Hence, they are cause-related tools. Contrarily, reactive instruments are designed to show the impact after a disruption to mitigate negative outcomes caused by the incident. Thus, those measurements are affected oriented. Studies confirm two important hypothesises according to risk measurements. First, "companies with a high degree of supply chain risk management show a higher performance than companies with a low degree" [10] and second, "there is a difference between companies using preventive instruments contrary to those using reactive instruments in terms of performance criteria" [10].

In the following paragraphs two practical tools for risk measurements are introduced. Failure Mode and Effects Analysis (FMEA) is a tool designed for the identification and fully understanding of probable failure modes and the correlated causes related to a given system process or product. Risks are assessed numerically and associated with causes, effects and failure modes that have been identified. Based on those assessments' decision can be made for corrective actions. A cross-functional team of experts gathers to identify critical conditions and facets. System FMEA, design FMEA and process FMEA are the most common types of FMEAs. On the one hand, the most important type in terms of SCRM is the system FMEA trying to improve the design or the performance of the system. On the other hand, for NPD the design and the process FMEA are even more important to enhance the design of the product's components or the manufacturing process. Moreover, FMEAs need to be done process-accompanying to identify weaknesses during the development process before the customers get in touch with the product. FMEAs offer high potential for an anticipation and prevention of problems, cost reductions, shorter time to market and the achievement of highly reliable and safe systems, processes and products [36].

Graphical Evaluation and Review Technique (GERT) has been introduced by [37] as an analysis technique for networks predominantly used in project management. The function of GERT consists in the depiction of both activity duration and network logic and allows probabilistic treatments. The application of GERT generally includes five steps. First, the system of investigation needs to be converted into a generalised network. Then the functions of the network's components are characterised by collected data followed by the third step, which combines the network components to an entire function of the network. In the fourth step the performance is measured based on the equivalent network function. Finally, the performance measurement is used to find conclusions for improvements. GERT still can be used for predictions of innovative development projects and for the identification mistaken predictions [5].

2.3 Risk Mitigation in New Product Development (NPD)

This paper aims to review several approaches that combine risk mitigation strategies in NPD. An innovative risk mitigation methodology for NPD in CE was derived in earlier studies [38]. The approach should be used as a supporting tool in decision making of the most suitable risk management strategy for managers based on their financial resources, strategies and objectives. They started identifying the most prominent risk concerning the entire product lifecycle and developed a systematic approach to map all identified risks related to processes, product, project and organisation. The evaluation of the risks has been done based on the three parameters risk consequence, risk likelihood and a subjective weighted score. The risks are assessed in both quality and quantity. Hence, this approach addresses both risk assessment strategies introduced by previous studies earlier in the paper [30]. Furthermore, that studies developed five different algorithms that follow several aspects: Genetic, Random-Search, Minimum-Cost-Risk-Ratio-First (MCRRF), Highest-Risk-First and Least-

Cost-First. The approach of [38] was tested in practice and has been validated as well. They worked out that MCRRF is the most cost-effective solution [38]. Moreover, the earlier studies discuss risk management for NPD based on a case study [9]. The authors investigate the SCRM in development of the Boeing 787 and describe Boeing's risk mitigation strategies to overcome the challenges during the process. This case study explains Boeing suffering with risks management in technology, supply, process, management, labour and demand. Furthermore, it concludes actions for manufacturer, which must be considered before starting NPD. Such aspects are assembling an experienced leadership team, obtaining the internal support, improving supply chain visibility and proactive management to satisfy customer's expectations [9].Studies provide a risk analysis system in CE PD, which is provided in a three-dimensional manner by using GERT and FMEA, as well as product database management (PDM) [5]. The risk analysis system focuses on quality risks, cost risks and scheduling risks. The main contributions of [5] can be summarised in three aspects. First, they provide a conceptual framework to cluster risks within the CE PD. The second aspect consists of the combination of GERT, FMEA and PDM to propose the utilization of quantitative approaches for risk management of CE PD. Finally, they show the advantages of applying their framework to a case study from a Chinese company [5].

As transition to the literature concerning time-based supply chain risk mitigation, [21] provides a methodology for supplier risk assessment in automotive industry for CE in NPD. The aim of the approach is to monitor and analyse different risks over time. Therefore, a system has been developed to realize monitoring and assessing the identified risks in a permanently manner. The framework makes it possible to analyse and identify critical supplier or parts that might pose a problem in the continuing development process. This information lead to the opportunity to proactively evaluate mitigation strategies concerning critical parts or suppliers to prevent disruptions. The paper is based on a literature review, which identifies risk monitoring as research area that received limited attention yet. "The proposed methodology in this paper is a first step in the development of methodologies to assess and monitor supply chain risk, especially in a temporal fashion" [21]. The prediction of supplier-based disruptions can be enhanced as an outcome of this paper, if the company introduces a risk monitoring system. Concluding, the approach has potential to serve one of a company's key functions [21].

2.4 Time Based Supply Chain Risk Mitigation

Literature offers different approaches, which discuss time-based SCRM. First, the principle of postponement has been identified as a relevant time-based mitigation strategy and is introduced earlier in the paper. Other existing approaches concerning time-based risk mitigation are discussed here.

2.4.1 Principle of Postponement as Mitigation Strategy

Studies identify the principle of postponement as useful tool to manage disruptive events and supply chain risks, which has originally been released as marketing strategy [12]. They define postponement as "processing or distributing activities (e.g. as to the form and/or the place of goods) until precise customer order information becomes available" [12]. In addition, [39] defined postponement as "a deliberate action to delay final manufacturing or distribution of a product until receipt of a customer order." [39]. Postponement in SCRM lead to less mis planning in manufacturing and less incorrect inventory deployment, because products are only manufactured to replenish inventory stocks if the company receives customer orders [39]. The approach is related to time-based SCRM by mitigating supply chain risks by delaying processes as long as possible to face uncertainties in customer demand and to prevent disruptions, which [12] defined as "failures at a supplier facility that results in the inability of the purchasing company to meet its customers' demands." Postponement is related to a differentiation between push and pull strategy as well. The push strategy is based on demand prediction to forecast procurement and production; the pull strategy deals with depicting real demand by customer orders. The principle of postponement tries to shift the push/pull boundaries more to the manufacturer of the supply chain, which means an adoption of the pull strategy trying to satisfy the real demand instead of trust in demand predictions. This adoption leads to the disadvantage of increased costs caused by building more flexibility and implementing added buffer [40]. In competitive markets, it's not possible to increase the product prices to equal those costs. Hence, the approach of [12] consisted of a theoretical model of how to understand postponement regarding the mitigation of supply chain disruptions. Normal Accident Theory (NAT) has been applied, which considers catastrophic accidents characteristics in high complex systems. Theoretical principles of NAT are used to discuss two different strategies of supply chain risk mitigation – building flexibility and adding redundancy [12]. It concluded by pointing out three

main aspects. First, postponement has been explored to apply it to SCRM to mitigate disruptive events by introducing NAT to reduce levels of couplings and complexity. Second, they encourage companies to avoid disruptions to the operating systems by simplifying them, if it is economical not possible to release those couplings. Finally, they advise companies to evaluate the complexity of their supply chain before choosing an appropriate strategy to mitigate risks [12].

2.4.2 Time-based Risk Mitigation

Especially in financial management time-based aspects are already considered. Contrarily, the importance of time in supply chain risk is pointed out in literature but has not been considered in depth yet [13]. However, a few articles discuss time-based mitigation strategies in SCM already. The paper reviewed studies from [26], [31], [42] and [41] here and related to the research purpose of this study. The article "Managing Risk to Avoid Supply-Chain Breakdown" by [26] discusses several successful and unsuccessful case studies of companies' behaviours in a risk-affected supply chain. The most important aspect regarding this research concerns strategies to mitigate supply chain risks without decreasing profits. Studies clarified the relationships between risk and reward by providing a model of two strategies as it can be seen in figure 7 [26].

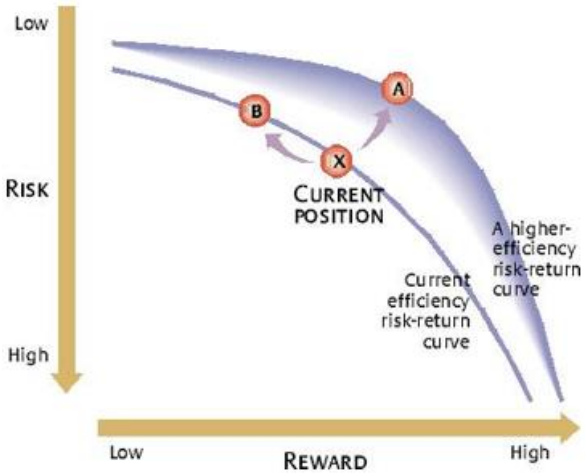

Figure 7: Supply chain risk/reward trade-offs [26].

The first strategy increases efficiency by minimizing risk of disruptions as well as by increasing rewards (A). The second one remains at the recent level of efficiency realizing reduced risk as well as rewards (B). Different mitigation strategies are outlined in their paper [26]. Studies worked out a typical disruption profile according to the performance of a company to an appearing disruptive event [31]. The profile is provided in a graph showing the performance, which can be any relevant metric such as profits, production levels, sales or even a supply chain performance on a timeline. It is separated into eight steps. In addition to the explanations, the profile is shown in Figure 8 as well. In some cases, the disruption can be foreseen. Hence, the first step concerns a little time to prepare to the imminent event. Step two describes the disruptive event, which can occur in different ways as explained earlier in the paper. The first response needs to be taken to bring the situation under control to prevent further damage. The initial impact leads the full impact as soon as all consequences of the disruptions are examined. The sixth step consider the preparation for recovery. Typically, the planning of the recovery starts as soon as the first response has been done.

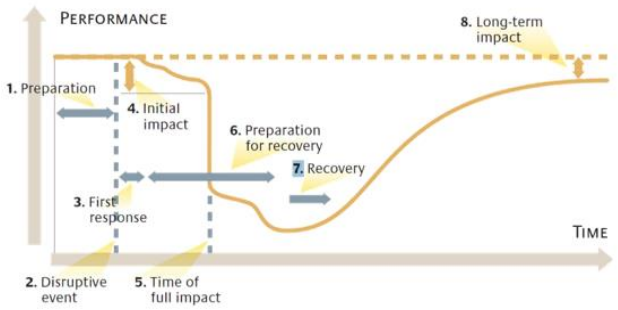

Figure 8: Typical disruption profile [31].

Over time the recovery strategy is applied to lead to an increase of performance. However, a long-term impact remains mostly as a deviation from the origin performance. As outcome of the graphs the affected company or supply chain suffers massively in short-term but can't even reach their originally performance in long-term as well. Furthermore, the paper offers a practical description how to minimize damage of performance in short- and long-term by providing the vulnerability framework as introduced and describes how to increase flexibility and redundancy to build resilience [31].

Moreover, studies [42] have provided a concept of time-based risk mitigation in supply chains based on the achievements of [26] and [31] to complement existing literature, which is more related to risk prevention rather than on mitigating occurring events. "Although there have been efforts to prescribe effective recovery plans for reducing the impact of supply chain […], the focus is on recovery after the event has occurred." [42]. This paper proposes a framework to reduce the impact of disruptive events of low risks but severe impact to the supply chain by enhancing the responsiveness. Prevention to such events is costly. Therefore, time-

based risk management is introduced leading to low need of risk management investments, while the competitiveness of the company increases. Responsiveness can be improved by more visibility of supply chain processes and interruptions and better communication by enabling constant flows of information. The focus of this approach is set to the response time R1, which equals the sum of the time to detect the disruptive event across the supply chain D1, the time D2 to design a response and time D3 to apply the response plan to the upcoming event (R1 = D1 + D2 + D3). It's called the 3D framework. The theory concentrates on preparedness for occurring disruptive events to the supply chain to instantly interact, countering the event and reduce its impact. Hence, three aspects must be considered to reduce those times:

- Working detection systems are needed to reduce R1
- Pre-packaged responses should be designed to reduce D2
- Communication channels to apply the responses should already be identified to reduce D3

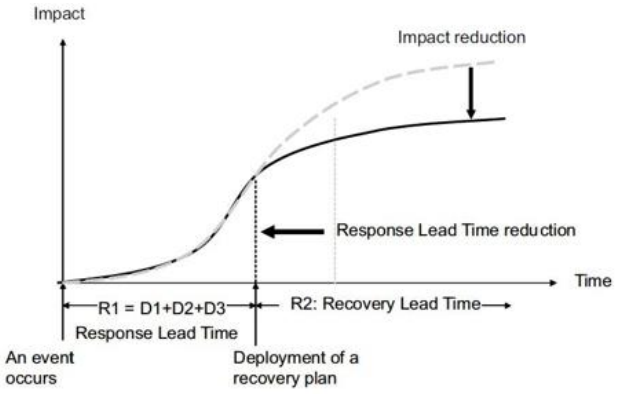

Figure 9: Reducing impact by reducing response time [42]

The reduction of impact by reducing the response time R1 according to the approach of [31] is shown in figure 9. The different between the depiction of [31] in Figure 8 and [42] in Figure 9 insists in portraying the 'performance' on the one hand (figure 8) and the 'impact' on the other hand (figure 9). Thus, the approach discussed in the studies [42] tries to reduce the long-term impact introduced by [31]. This coherence is eminently important to understand the purpose of the approach of [42]. Moreover, the correlations between response time R1 and the recovery time R2 to restore the supply chain tend to be exponentially dependent on the 'time', which again makes it possible to reduce impact massively by shorten the response time R1. Hence, two statements are made concerning figure 9:

- "The recovery lead time R2 and cost can be significant higher if the deployment of a recovery plan is delayed." [42];
- "The execution of a recovery plan can become much more difficult if its deployment is delayed." [42]

Earlier studies provided five practical management activities to improve R1:

- Risks across the supply chain need to be mapped collaboratively with suppliers and customers;
- Responsibilities and roles need to be defined;
- Detection systems need to be developed to monitor risks and foresee interruptions;
- Recovery plans need to be designed in advance;
- Scenarios need to be sketched and the supply chain need to be undergone by stress tests [42].

Moreover, [26] identified one of the biggest challenges as maximizing profit while minimizing risks. Most companies are not willing to prevent risks by investing in actions to be taken. Studies figured out that in 2004 60% of the firms of Computer Science Corporation's supply chains were vulnerable to disruptive events, for instance [43]. As a benefit of [42] approach companies may be able to concentrate on minimizing the impact of events by shorten the response time as well as avoiding expensive risk prevention activities. Therefore, proceedings must be developed, which both simultaneously mitigate supply chain risks and increase rewards, such as shown in figure 10, which also shows the correlation between risk and reward such as [31] in Figure 7.

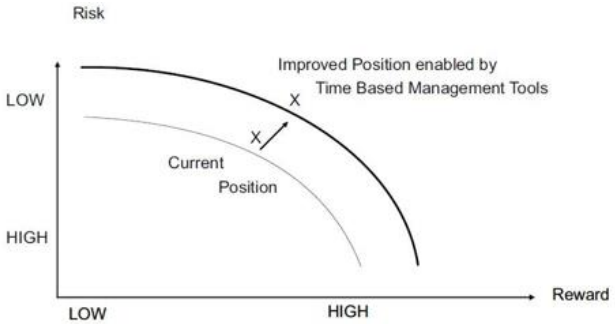

Figure 10: Decreasing risk while increasing rewards [42].

However, [42] decided to follow only strategy A according to [31] in Figure 7 of increase efficiency level by minimising risk of disruptions and by increasing rewards. Even though that study provided a time-based management concept trying to shorten response lead time as well as restoring lead time further research is required [42]. They consider models from epidemiology-based literature. Similar

models must be developed for supply chains. In addition, they identify time-based risk management in general as a valuable area for further research [42]. In addition, [41] investigated supply chain risks of low probability but severe impacts trying to mitigate them by a short respond time to the occurring disruptive event. A framework of time-based risk management is proposed, which is based on existing literature as well as interviews within pharmaceutical manufacturing companies. To reduce the response time to a catastrophic event four different categories of factors have been introduced, which are organisational structure, preparation, partnership and reserve. This theory expresses a grounded theory of a potentially rich research [41].

3 Research Gaps and Analysis

This part of the paper, research gaps of the investigated articles are discussed and identified trying to find common gaps for further research. The study [14] identified literature mainly discussing SCRM in material flows. There is lack of discussing information flows, which lead to a gap that need to be addressed by further research. Another aspect is related to the type of approaches that exist for SCRM. Most models are descriptive and conceptual instead of addressing quantitative approaches. Their studies concluded that there is high demand for applied SCRM, however approaches need to be developed to make number-based decisions [14]. Finally, further research is needed to satisfy increasing practical demand as well as theoretical aspects in mitigation of supply chain risks.

The shortcoming from [38] is related to consider time as an aspect with regards to time to market but does not include time-based aspects in the strategy of mitigating risks. Further research needs to address the implementation of time-based aspects within the SCRM in NPD. According to [34], SCRM has been identified as a recent research area, that has not been fully exploited yet. Therefore, further research can address especially two aspects based on this article. Empirical data need to be collected to investigate the reasons why mitigating supply chain risks became such an important issue for enterprises and secondly quantitative models need to be worked out to measure robust strategies properly. The study by [9] discussed risk mitigation strategies in NPD related to the aircraft manufacturing industry. It must be figured out whether the approaches work in the same way in other industries like the automotive or shipping manufacturing industry. The transformation of time-based characteristics is not fully transpired to quantitative approaches yet, which leads to a gap and provides an edge for further research. Additionally, one of the limitations of the approach is the application only in the automotive industry. The approach should be transferred to other industries to prove validity [13]. This approach of this paper uses several perspectives like FMEA and GERT models to propose a risk analysis system, which is applied to a risk definition as “the possibility that an undesired outcome or the absence of a desired outcome disrupts your project” [5], which tend to be a negative understanding of risk. Further research needs to apply their model on definitions of risk, which are positive verbalized to consider opportunity risk management [5]. Postponement is identified as an approach to mitigate supply chain risks. However further research needs to address the integration process of complexity to enhance complexity and its performance metrics [12]. The study by [21] does not describe how to practical determine the weightings of risks.

Therefore, further research needs to address the development of practical weighting tools. Moreover, the proposed methodology needs to be tested. Hence, prototype models need to be implemented in some companies to validate the approach. Finally, tools are necessary to implement the companies’ data to run the tool. Research need to address the development of data collection and data implementation tools. Even though study by [42] provided a time-based management concept trying to shorten response lead time as well as restoring lead time, further research is required. They consider models from epidemiology-based literature. Similar models must be developed for supply chains. In addition, they identify time-based risk management in general as a valuable area for further research [42]. The approach of [41] has been applied in just two industries. Further research needs to investigate the utilization in other industries for further validation of the methodology. Appropriate detection methods for occurring disruptive events have not been considered in this paper, which need to be researched to realize the shortest possible response time. Another aspect is related to the low risk probability. Because those risks are unlikely to happen, costs and benefit factors need to be explored as well [41].

Based on this paper’s study, a common gap has been identified. Time-based risk management has not been considered in manufacturing and NPD yet and need to be linked in further research projects. Studies by [21] is the only reviewed paper that targeted both NPD and time-based risk management. The other articles discuss either NPD or time-based risk mitigation. Furthermore, the approaches of [42] based on [26] and [31] identified time-based SCRM of severe disruptive events with low probability as an

unexplored research area. Moreover, their approaches must be applied to other industries like the automotive industry linking it to NPD as well. Additionally, the implementation of postponement may help to mitigate supply chain risks, however it must be addressed by researcher as well. How further research can address the gaps is outlined in the conclusion.

4 Conclusions and Recommendations

Literature already regarded risk management in supply chains, however [13] worked out that time-based aspects have not been considered in SCRM fully yet. In addition, studies identified risk mitigation as important area for further research [42]. The literature review provides an understanding of time-based characteristics of risk mitigation in SCRM in correlation with NPD. Therefore, the terminologies of NPD and CE are discussed and existing risks for NPD are identified within this paper. SCRM is explained in general before outlining definitions of supply chain risks, important supply chain risk driver and risk expositions based on common supply chain risk literature. In addition, different approaches for risk measurement were also examined and presented within our study. After introducing all important terms and conceptualities regarding the research area, relevant approaches have been investigated according to risk mitigation in CE and NPD to link NPD to SCRM. However, least of them address time-based aspects. This paper also reviewed different frameworks related to time-based SCRM, which has been further separated into the principle of postponement as mitigation strategy and time-based risk mitigation. The research gaps resulting from the literature review were briefly explained within our paper.

The common gap consists of a lack of consideration of time-based SCRM in New Product Development (NPD). Out of the investigated approaches, [21] was the only study that combined time-based aspects with NPD. Moreover, the approaches of [42] are grounded on study by [31]. They contribute to time-based risk mitigation by providing a model that reduces long-term impact of interruptive events. The response lead time has been introduced, which need to be shortened by focusing on time and response processes instead of considering only cost, probabilities or impacts like conventional risk management does. Therefore, it's recommended to use either one of the models mentioned above or to develop a common approach trying to apply it to a manufacturing company to address the gap and to contribute to the given research area. Thus, a case study should be carried out to prove the validity of the approach in a manufacturing environment. It has to be estimated whether the approach can be applied in praxis or whether other changes need to be done to realised an application to improve the company's efficiency and to build resilience against disrupting events. Moreover, the principle of postponement is identified as risk mitigation strategy, but literature studies have not focused on this aspect in our current findings.

Building flexibility and adding redundancy are identified as important strategies to enhance resilience and to decrease vulnerability for companies and supply chains. Hence, further research should examine how those strategies can be integrated in time-based risk mitigation according to the approaches of [21] concerning NPD and [31] and [42] with a focus on time-based approaches. Finally, companies may be more competitive if time-based risk mitigation is considered, tested and applied to the existing workflows. Moreover, outsourcing need to be regarded, which lead to more interfaces and therefore causes higher complexity. Time-based risk mitigation can enhance information flows and workflows even across the entire supply chain.

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