Supply Chain Risk Analysis – Common Flaws, Core Areas, & Main Tasks

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Abstract. Supply chain networks are globalized and complex systems. Due to unexpected deviations and disruptions, which are subsumed under the notion of supply chain risk, the planning and optimizing of such systems is harder than ever. Therefore, making well-informed decisions requires risk analysis. In some areas such as finance, insurance, crisis management and health care, the importance of considering risk is largely acknowledged and well-elaborated, yet rather heterogeneous concepts and approaches for risk management have been developed. The increased frequency and the severe consequences of past supply chain disruptions have resulted in an increasing interest in risk. This development has led to the adoption of the risk concepts, terminologies and methods from related fields, which most often do not fit for risk consideration in the supply chain context. This paper consists of a theoretical discussion on common risk biases and main elements tailored for supply chain risk analysis.

Keywords: supply chain risk, analytics, risk assessment, risk definition, resilience, disruption

1 Introduction

On March 11th, 2011, a marine earthquake offshore the Japanese islands reached magnitude 9 on the Richter scale. The waves of the unleashed tsunami reached height up to 14 meter. More than 25.000 people were killed due to this natural catastrophe and its immediate consequences. Additionally, several nuclear power plants were affected by the quake and/or by the tidal wave. The emergency power generators of the Fukushima-Daiichi plant were destroyed such that they provoked the failure of the cooling system. Due to this failure a series of reactions lead to a partial core meltdown in three reactors and the escape of radioactive material to the environment.
While the name "Fukushima" epitomizes the limitations of risk analysis in regards of public security and safety [5], events like the West coast port lockout or the European ash-cloud put the validity of contemporary supply chain risk analysis into question. The prevailing perception of risk derived from engineering assesses risk as the product of probability and impact both related to the occurrence of a disruptive event [9]. Risk analysis, thus, values expectations about future hazards. They constitute the attempt to rationalize the uncertainty of potential perils. As such, supply chain risk analysis is used as a basis for specifying mitigation options, contingency or emergency plans. Often the value of expectations provided by contemporary risk analysis is misinterpreted, because they neither predict the exact level of damage nor the precise point in time of its occurrence. The management of risks evaluated by the prevailing concept of risk analysis is therefore incomplete and non-satisfying. The benefit of contemporary risk analysis is up for debate:

- Is event-based risk analysis good enough for risk management?
- Which conclusions can be drawn from probabilistic risk analysis?
- How can risk analysis provide insights for the formulation of mathematical decision models?

In this paper we approach the answers to the aforementioned questions with special focus on supply chains by identifying existing flaws related to the perception of risk analysis. We do not limit ourselves to the discussion of misinterpretations and missing aspects, but rather provide insights of the underlying dynamics that result in the supply chain risks. Based on our new formulated definition of supply chain risk [7] we present the influence of core characteristics and their interactions on the extent of supply chain risk. For a profound and detailed explanation of these dynamics that drive the quality of risk-aware solution models we refer to [6].

2 The risk of supply chain risk analysis

Definitions of concepts related to supply chain risk depend on the methodological background and interest of research scientists as well as on cultural, industrial or geographical differences, as pointed out by [7]. As the concept of supply chain risk is heterogeneously defined, so are derivative functions such as supply chain risk assessment, supply chain risk analysis or supply chain risk management. Often these terms are used interchangeably [13], compare for example [2, 9, 20, 15].
In order to limit the confusion related to concepts and definitions we abstract commonly used steps for the analysis of supply chain risk based on the definition of managerial process steps often referred to as supply chain risk management. Correspondingly, supply chain risk analysis addresses distinct steps of the supply chain risk management cycle, see Figure 1.These tasks are connected to a continuously executed process.

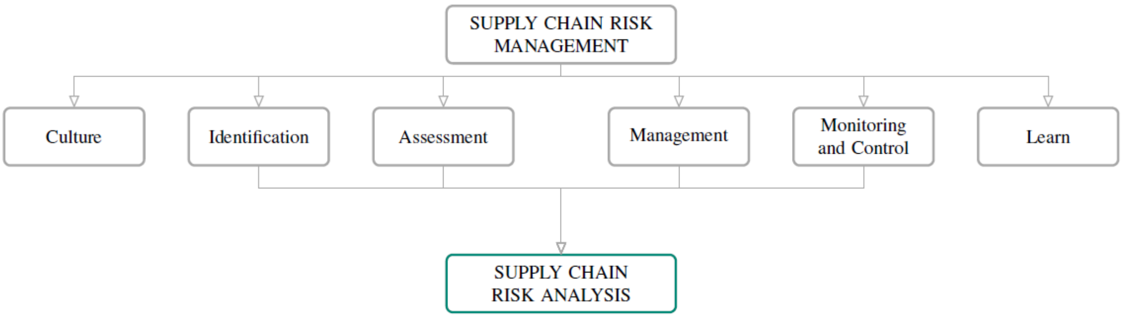

Figure 1: Formation of Supply Chain Risk Analysis.

The effective and efficient practice of this process in today's globalized world depends on the collaboration between geographically dispersed organizations [10]: (local) information must be collected, evaluated and shared across organizational boundaries [4]. Yet information processing needs to be aware of uncertainty. The status and the development of situations can be uncertain or fast-changing. The degree of relevance and reliability of information describing both status and development can be dynamic or uncertain, too.
These characteristics pose particular problems to supply chain managers as they make it impossible to process all available information prior to choice [12]. To deal with such situations people use heuristic forms of thinking that are relatively simple; they involve processing less of the available information and doing so in a simpler way. In the following we present biases of analysis of supply chain risk which originated from heuristic thinking. We emphasize that biases of risk identification mainly arise from the definitional fiat of supply chain risk and from the simplified interpretation of probability. Biases of risk countermeasures originate from an oversimplification of risk treatment.

2.1 Biases of risk identification

The definitional fiat The prevalent perception of risk, including supply chain risk, is event-related. Supply chain risk evaluation and assessment, therefore, focus on an event-by-event analysis and assume that the consequences of an initial triggering event can be uniquely determined. The level of deterioration of relevant key performance indicators, like supplier's reliability, service-level, logistics costs, capacity utilization, production output, or inventory throughput time, are used to quantify the extent of impact on the supply chain performance.
A single event, however, may lead to several distinct extents of impact on supply chain performance. An earthquake, for example, can affect production lines at core suppliers, which result in a decrease of produc-

tion output at own facilities, or destroy important transportation links to customer markets, which lead to a decrease of service-level. The reverse exists too: several events may result in the same single consequence for a supply chain. The reason for this ambiguity arises due to the fact that the triggering event is only the root cause of performance deterioration. The dynamics that yield to negative developments need to be carefully examined and understood.

The probability trap Particularly when assessing supply chain risk, probability – as measure of uncertainty – is often inappropriately simplified or inadvertently misapplied. We denote this biased practice as *probability trap*. In the context of probability what is most often neglected is the dynamic nature of probability: uncertainty evolves, thus, changes over time, which implies that since risk is assessed with probability, its extent changes over time, too. Additionally, when information about uncertainty are missing, probability is hard to capture and risk most often ignored. Less-frequent or less-probable events can have a tremendous impact on the supply chain, such that the continued non-consideration of these *unknown-unknown* events [14] can lead to the same devastating consequences as intentionally or unintentionally ignoring of risks.

2.2 Biases of risk countermeasures

Assignment bias The contemporary supply chain risk analysis strictly follows the stepwise process of supply chain risk management. Therein, each disruptive trigger is declared to be identified, assessed, and mitigated separately. Figure 2 highlights the allocation possibilities of identified risks – in terms of identified disruptive triggers – to available reduction strategies. Figure 2 (a) shows the situation where identified risks can be reduced by one or several distinct mitigation options. A profound discussion of different mitigation options, their characteristics as well as their effect on risk, is offered by [18, 19, 16]. It might also be the case that available risk countermeasures are not appropriate for all identified risks. Only a subset of risks can be treated. This situation is depicted by Figure 2 (b). Figure 2 (c) then highlights the situation where no countermeasures are available for reducing identified risks.

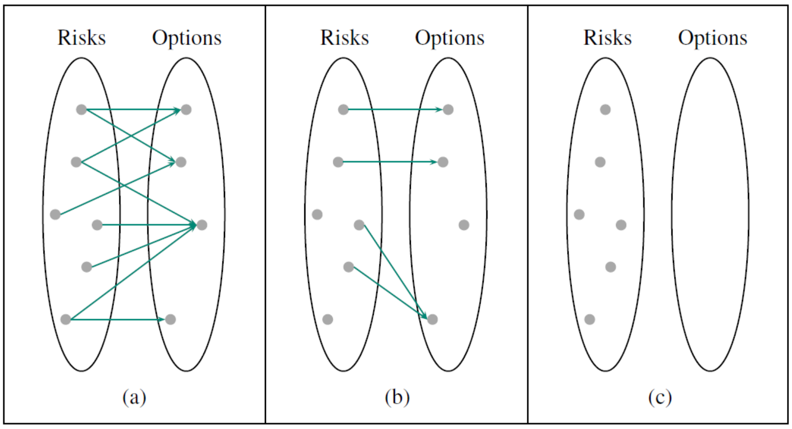

Figure 2: Possible functional relations between the set of identified supply chain risks and potential mitigation options (*SCP*).

Not only are disruptive triggers handled individually, but also related countermeasures. The decision maker, therefore, pre-determines which type of risk countermeasure he is willing to accept. Generally, countermeasures are categorized upon the type of supply chain process they address or upon the scope they affect. Countermeasures are not limited to supply chain processes, but can also determine engineering options for product design and production technology which in turn affect supply chain processes. Tang gives a detailed overview of prominent quantitative approaches for mitigating the impact of supply chain risks and categorize them in accordance to supply, product, demand, and information management [17, 18, 19].

Limited uncertainty Uncertainty is a concept closely related to risk. In the context of supply chain management uncertainty refers to the degree of not-knowing. Information about future developments within the supply chain, the occurrence of triggering-events, and the impact of any changes on supply chain performance is often limited or *uncertain*. In order to limit the size of the decision problem decision makers limit the consideration of uncertainty to a (very) small amount of parameter types, for example customer demand or transportation lead times. The consideration of interactions between distinct uncertain and certain parameters across different parameter types is not applied. Consider the situation, where the demand of one specific type of customers is highly erratic, while the demand of another type of customers is endowed with less uncertainty. Or consider the case, where the lead times of container ships leaving the Asian region are more volatile than those of container ships leaving North America. Both cases demonstrate that approaches need to be carefully adjusted to the underlying situations. Prior to model formulation it is indispensable to analyze not only which type of parameters is endowed with uncertainty, but rather which group of parameters is erratic. Similarly, the formulation of decision variables restricts the set of potential countermeasure types in advance.

Time horizon & planning level Often decision makers argue that risks yielding to *huge* performance deteriorations should be handled on a strategic, *medium* risks on a tactical and *small* risks on an operational planning level. However, to overcome incidents like the European ash cloud in 2011 prominent strategic instruments like increased inventory levels – which are installed over the entire planning horizon – also lead to increased tied-up capital and consequently to an increase of overall logistic costs. It is naive to believe that so-called strategic instruments are only useful for the incidents with large impacts, especially because decision makers do not know how disruptions evolve over time.

3 Main elements of supply chain risk analysis

The exclusive probabilistic and event-related understanding of supply chain risk leads to an incomplete and insufficient perception and impedes the appropriate management of supply chain risks. In this section we present main elements that are needed to understand the dynamics of supply chain risk and to design appropriate risk-aware decision models.

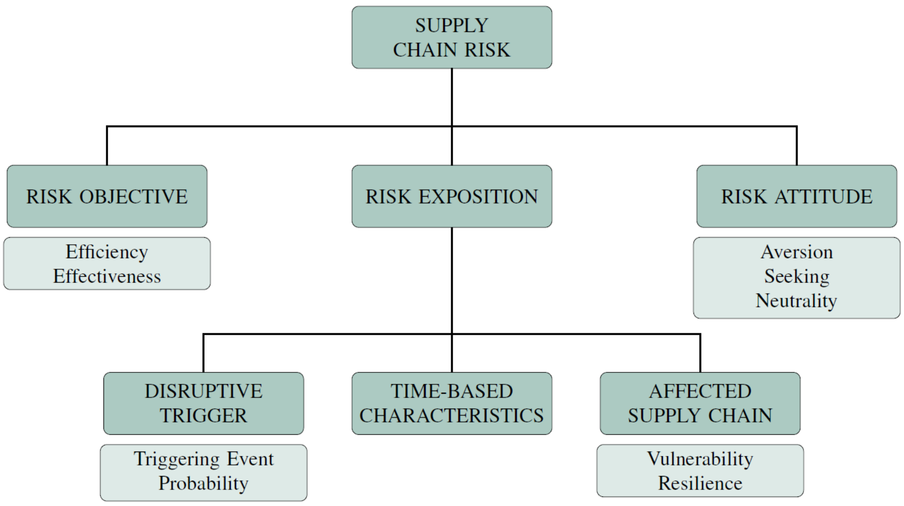

Figure 3: Core Characteristics of Supply Chain Risk (CCSCR) [7].

Given the re-definition from a previous publication [7], the level of supply chain risk is affected by three core characteristics: the risk objectives, the risk attitude of the decision maker, and the risk exposition of the underlying supply chain, which is further specified by disruptive triggers occurring within or exterior to the supply chain, time-based aspects having tremendous impact on the severity and characteristics of the affected supply chain, see Figure 3. Having defined supply chain risk as a construct of interdependent elements, a profound understanding of each basic element is required as well as the analysis of their interrelations. The main tasks of supply chain risk analysis, therefore, need to be applied to these elements. In the following we concentrate on the description of the risk objective, disruptive triggers and the affected supply chain. For explanations on time-based characteristics we refer to [3] and for a more profound discussion of each element to [6].

3.1 Analysis of potential triggers

Events most often related to supply chain risk are referred to as *triggering events*. Such events have impact on the environment of the affected supply chain and consequently on the network itself. Instead of using triggering events as a concept, we distinguish between a *potential trigger* and a *disruptive trigger*. While the former refers to each incident that has the potential to negatively affect supply chain objectives, the latter effectively results in a performance deterioration. Consider the Icelandic volcano eruption of 2011: In this example the eruption imposes the disruptive trigger, its ash cloud affected supply chains environment, which had a huge impact on air transportation. Individual activities involved in procuring, producing, storing, and distributing goods as well as services for the sake of goal achievement of the underlying supply chain are referred to as *supply chain processes* [3, 6]. Each supply chain process can further be described through additional characteristics, such as costs or capacities, which we call *supply chain factors*. The ash cloud incident could have had an influence on the lead time or the capacity of that process. Precisely, we could capture the consequences through a lead time increase or a capacity decrease. Assuming that: what decision makers would like to find out is and what they need to figure out is, which factors are critical for the performance of the supply chain and which factor modifications lead to performance deterioration.
Thus, instead of identifying triggering events, the determination of modifications of supply chain factors is of vital interest.

3.2 Analysis of performance measurement

Supply chain objectives can be classified into two major groups: effectiveness and efficiency [1]. Effectiveness refers to the availability of resources and the functionality of supply chain processes. Effective processes are able to fulfill their functions of sourcing, producing and delivering products a.o., which results in the satisfaction of customer demands on time. Whenever supply chain processes are interfered in fulfilling their functions, it could be possible that supply chain effectiveness can not be ensured. The eruption of the volcano, for example, lead to a decrease of effectiveness in terms of missing supply parts that resulted in production halt. Efficiency refers to the profitable execution of supply chain processes. The efficient achievement of customer satisfaction and value creation is threatened by disruptions and failure or increasing volatility of important supply chain factors directly or indirectly related to logistics costs. The evaluation of supply chains efficiency and effectiveness is conducted through the assessment of selected supply chain KPIs. Having identified which performance measures best reflect and assess supply chain strategy and related objectives of efficiency and effectiveness, it becomes necessary to determine the targeted level of these performance measures as well as the acceptable degree of level deterioration. Most often decision makers are well aware of the extent of performance deterioration – in terms of efficiency or effectiveness – they still can accept.
Supply chain risk analysis should assist to uncover the influence of factor modifications on selected supply chain objectives.

3.3 Analysis of supply chain constitution

The discussion so far shows, that the development of factor uncertainties has an influence on the degree of performance achievement. However, it is the supply chain resilience that determines whether the targeted performance value of the decision maker can still be met. Supply chains are differentially endowed with the ability to absorb the consequences of potential triggers. Elements of supply chain constitutions that favor the ability to overcome unexpected changes are: supply chain structure, bill of material, product portfolio, demand pattern, market power, production technology, product design, and product lifecycle. Each element has an effect on the extent of supply chain risk so have they interactions and has to be carefully determined for each supply chain prior to the installation of mitigation strategies. For instance, supply chains that process products, which consists of substitutable pre-products or which are offered by different suppliers may be less vulnerable to factor modifications. Non-substitutable products are quite often produced or manufactured by highly complex production technologies. In particular, the chemical processing industry, whose production is characterized by physically and temporally complex processes, has highly individualistic production facilities. Special chemical processors, like reactors or homogenizers,

are difficult to obtain. When these components are damaged by water or fire, it often takes several month up to years to replace them [11]. Consider the example of a Swiss chemical producer trying to limit the loss evoked by a breakdown of its production process. Typically, companies strive to limit the loss they might encounter by closing insurance contracts. However, the considered major re-insurer refused to insure the production breakdown, because the replacement time of the batch reactor was estimated to be over one year [11]. Such situations demand for special modeling perspectives in order to derive more resilient supply chains that overcome such disruptions. More resilient, i.e. less vulnerable, supply chains positively affect the level of risk. Whenever the constitution of a supply chain is capable to absorb changes, the risk – the potential non-achievement of performance objectives – reduces correspondingly.
Consequently, the constitution as well as the environment of a supply chain needs to be carefully examined by the means of supply chain risk analysis in order to determine adequate risk countermeasures.

4 Conclusions and tasks of supply chain risk analysis

Heuristic forms of thinking guided supply chain practitioners and scientists to oversimplifications and misinterpretations of the effects of risk. Hagman concludes that the analysis of risk in general is up for debate [5]. We emphasize that this is especially true for the analysis of supply chain risk. Due to the limits of explanatory power provided by the supply chain risk definition and the methodology deduced from this definition, numerous biases arise. The assessment of risk as a product of event-related probability and impact may lead not only to faulty identifications, but also to deficient conclusions. Statements about the future are difficult and have to be handled with care. Besides prospective developments, it is the understanding of how changes affect the supply chain, that need to be carefully evaluated. We declare the analysis of the underlying supply chain and its dynamics as the major purpose of supply chain risk analysis. In the following we summarize the main conclusions derived in this paper:

- Instead of starting risk analysis with the identification, gathering and assessment of potential events that may serve as a disruptive trigger, we propose that it is the main task of supply chain risk analysis to evaluate the potential effect of modifications of supply chain factors and assess their influence on key performance indicators.
- Risk analysis is conducted not only on different planning levels, but also seeks for an interrelated process between all stages with the objective to identify risk-aware balanced supply chain solutions.
- The development of supply chain factors is captured by uncertainty profiles such as recurring changes, moderate changes, major changes, and level shifts.
- Effectiveness refers to the functional capability of supply chain processes which results in the satisfaction of customer demands. Efficiency refers to the profitable execution of supply chain processes. The functionality and profitability of supply chain processes operationalize both, supply chain effectiveness and efficiency.
- It is the purpose of supply chain risk analysis to support the decision maker in evaluating how his risk attitude affects the potential non-achievement of supply chain objectives.
- The resilience of the underlying supply chain depends on elements as different as the supply chain structure, the bills of material, the product portfolio, the demand pattern, the market power, the production technology, and the product design. The present state of each of these elements needs to be evaluated in order to understand the underlying dynamics.

The identification and assessment of supply chain risk, therefore, should respect the influence of existing potential triggers, PoT, the prevailing portfolio of performance measures, $PPor$, and the actual constitution of the underlying supply chain, SCC, on the possible deterioration of supply chain performance. The extent of supply chain risk, SCR, depends on the status of each of these elements:

$$SCR := f(PoT, PPor, SCC) \tag{1}$$

The status of each of these elements is described by supply chain factors, SCF, that capture current element levels, i.e. $PoT(SCF_1, SCF_2, ..., SCF_n)$, $PPor(SCF_1, SCF_2, ..., SCF_n)$, and $SCC(SCF_1, SCF_2, ..., SCF_n)$.

$$SCR := f(SCF_1, SCF_2, ..., SCF_n) \tag{2}$$

If these dynamics are understood, mathematical approaches can formalize these dynamics and develop appropriate model formulations. The solution of those optimization models supports decision makers in implementing reliable risk-aware supply chain designs and/or plans. Then, it is possible to overcome the biased stepwise process of assessing, identifying, and mitigating supply chain risk individually. First approaches that respect the aforementioned elements are available in [6] and [8].

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