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Model-Based Decision Support in Supply Chains – Requirements for Monetary Supply Risk Quantification

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Abstract

Optimization of the total risk level by economically feasible risk mitigation can only be achieved through a well-grounded monetary evaluation of the current risk situation. In the field of material supply and procurement directly affecting production and distribution processes a lack of such quantitative simulation model has been identified. Efficient modeling and simulation of monetary supply risk quantification in manufacturing enterprises requires target oriented simplification of the quantification model. Thereby requirements from three different disciplines need to be considered: (1) procurement in supply chains, (2) supply risks, and (3) monetary risk quantification. In this paper we propose a target oriented approach to deviate and discuss requirements for an applicable monetary supply risk quantification model particularly focusing on supply risks providing meaningful results to derive reasonable risk mitigation measures. Hence, a requirement checklist will be provided to be considered in development of monetary supply risk quantification models.

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Keywords: risk quantification; monetary assessment; supply chain risk management; modeling requirements

1. Introduction

Today's manufacturers encounter challenges of global markets. Limited differentiation potentials of products by functionality, quality or price elevate the importance of logistics performance in their supply chain as a major factor of competitiveness [1]. Logistics in general include all tasks of planning, realizing or controlling the spatial transformation of goods and related transformations of goods in terms of quantity, types, handling characteristics as well as logistic determination. [2] Key performance indicators (KPI) are defined to support and facilitate these task by transforming rather abstract objectives into specific and measurable quantitative information and hence making process performances transparent and comparable [3,4]. Usually KPIs are designed to support enterprise's monetary based decision making process. However, enterprises are continuously challenged in meeting their set cost-based targets. Supply risks corrupt supply chains resulting in deviation of the set targets forcing enterprises into decision problems, such as: What is the best inventory policy to compensate for supply disruption? What is the optimal supplier base? To solve such economic problems a transformation of the decision situation into a symbolic-mathematical decision model properly describing existing economic relations is required [5]. Decision models comprise a sound cost target function and a decision base consisting of action alternatives (scenarios), environmental conditions, and resulting consequences [6]. Considering the expected monetary impact of risk in the target function for the decision-making process increases the decision-base and hence results in a more comprehensive and realistic estimation of the expected outcome [7]. This allows balancing costs related with possible action alternatives and expected benefits and hence ensures reasonable decision making in accordance with corporate targets. Quantifying supply risk monetarily, however, is a challenging task that requires a suitable model accounting for the complex dependencies in supply chains.

Thus, the objective of this paper is to identify basic requirements models for monetary supply risk quantification

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need to meet as decision model to generate adequate and meaningful results supporting the decision making process. Models are applied to represent real systems to gain insight about their behavior and in turn, use this knowledge in reality [8]. Hence a model needs to be limited to the aspects that affect the problem under investigation to be utilizable and manageable, while being sufficiently detailed to permit drawing valid conclusions about reality. Therefore, in this paper we systematically analyze which capabilities of solution procedures, model elements, dependencies, inputs, and outputs need to be considered by discussing:

- Procurement in supply chain structures, its relevant activities, and objectives
- Supply risks
- The basics of risk quantification

The paper is structured into 5 sections. After having introduced the purpose of this paper, section 2 provides an overview about the field of supply chain management (SCM) and identifies procurement as the main activity determining supply risk exposure. Subsequently, in section 3 the understanding of supply risk is discussed to identify relevant risk categories and potential consequences that need to be quantified. The basics of risk quantification and implications on proper risk models are visualized in section 4, before in section 5 the identified requirements are summed up and discussed to conclude the paper.

2. Logistics in Supply Chains and Procurement

2.1. Supply Chain Management

The overall goal of all logistics activities is to increase enterprises' competitive capability by improving delivery capability and reliability while minimizing logistics costs [9]. To achieve high logistics efficiency, material and information flows throughout the entire supply chain need to be optimized. Supply chains ideally incorporate all companies involved in value adding activities required for the production of a final product, from raw materials production to the final product's delivery to the end customer [10,11]. Consequently, supply chains include both, cross-company relationships between separate legal entities, and intra-company relations between different departments or sites. Fig. 1 illustrates the basic structure of a supply chain. Even though in literature on SCM some confusion exists in terms of what SCM really is, some commonalities can be identified [12, 13]:

- Intra- and inter-organizational integration and coordination of bidirectional flows of products (services and material) and information, managerial and operational activities from the initial source to ultimate consumer involving many independent organizations and departments
- Providing high customer value with appropriate use of resources to build chain advantages
- Focus on business processes
- Strategic relevance of SCM activities

Consequently SCM sets the overall framework for all logistics activities along the supply chain.

2.2. Procurement

Procurement includes all material planning and disposition activities [14]. Hence, procurement comprises all strategic sourcing decisions and operative purchasing activities, as well as activities related to goods arrivals. The overall goal is to provide supply of proper goods, of proper quality and quantity, at the exact time and location at minimum costs [15]. It aims to define appropriate and cost-optimal sourcing strategies, inventory and safety stock levels, as well as reordering points, and quality assurance programs. As part of the corporate policy the exact set of procurement goals has to be aligned with superior business objectives, hence general definition of procurement objectives need to be specified further [16,4]. According to ARNOLD procurement objectives can thus be classified into cost-reduction-objectives, quality objectives, security objectives, and flexibility objectives [17]. Basically, procured goods are classified into four article types [18]: raw materials, utilities, trade goods and miscellaneous. As this paper focuses on supply risks directly affecting a company's performance due to faulty supplies of components, modules, systems or other auxiliaries needed for production, the relevant scope of procurement objects is limited to materials being supposed to be assembled to final products. Particularly, relevant procurement objects are production materials in form of raw materials and auxiliaries.

Concluding, procurement is the enabler for subsequent manufacturing and sales processes and ensures a continuous supply of proper raw materials and auxiliaries to the demanded quality in sufficient quantity, at due time, and to the lowest possible costs. Procurement thus is the interface connecting business internal processes with external suppliers and is exposed to the area of conflict between the logistics targets of efficiency and security.

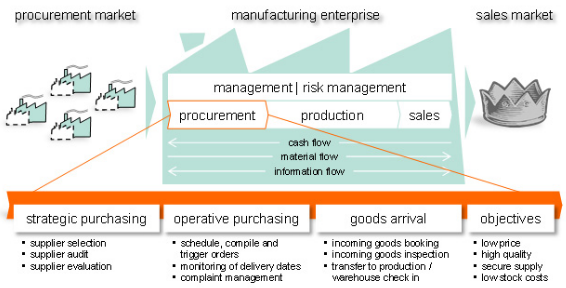

Fig. 1: Procurement in the context of supply chains

2.3. Derivation of Requirements

Based on the insights gained above, some requirements for models for monetary supply risk quantification can already be derived. To be able to accurately represent supply chain processes intra- and inter-organizational relations need to be representable through model elements accounting for sourcing, manufacturing, and sales processes (R1). Sourcing elements should represent the supplier base based on the respective sourcing strategy (e.g. global / local sourcing or single / multiple sourcing) delivering the ordered lots of materials under consideration of varying order and inventory policies ranging from periodic supplies on stock to demand triggered order releases. Sales elements determine the demand and should provide insight about the amount of shipped products, the shipping date, and the respective condition in terms of quality. Procurement objects that need to be considered are raw materials and auxiliaries being assembled into final products (R2). The degree to which the single elements and supply chain processes are modeled (level of model detail) depend on the analysis purpose and cannot be generalized. Analysis of a the effects of supply risk on specific manufacturing processes assumingly require a higher level of detail than analyses in terms of the global supply risk situation of an enterprise. Further requirements regarding the actual functionalities and information that need to be considered are derived in the following sections.

Table 1: Requirements related to the structure of supply chains

Requirements	Description
R 1	Intra- and inter-organizational relations need to be representable through model elements accounting for bidirectional flows of products and information, managerial and operational activities from the initial source to ultimate consumer
R 2	Relevant procurement objects are raw materials and auxiliaries being assembled into final products

3. Risk and Supply Risk

3.1. Risk

Most commonly risk definitions are distinguished between cause-oriented and effect-oriented perspectives [19,20,21]. Cause-oriented definitions consider uncertainty of information validity as the root-cause of risk and define risk as measurable uncertainty [22]. On the contrary, effect-oriented conceptions deal with risk consequences [21]. Effect-oriented understandings of risk generally consider risk as the chance of missing targets [23,10]. To properly manage risk a combination of both understandings is required. Hence, risk in the present context is defined as the chance of missing targets due to uncertainty regarding occurrence probabilities of future events.

3.2. Supply Risks – Root-Cause and Effect-Oriented Perspective

First of all, there are purchaser-related supply risks. *Supply risks* directly affect the availability of supplies at the manufacturer’s facility. Yet, supply risks originate from poor supplier and logistics performance. Therefore, another group of risks is supplier risks. *Supplier risks* include all risks related to the supplier’s strategic orientation and operational processes that can cause poor supplier performance. Additionally, there are uncontrollable *market and field risks* emerging from region- and market specific conditions, as well as from external or natural events.

Consequently, supply risks are the noticeable consequences of all upstream risk events and express themselves as *deviations from the expected quality* of delivered parts, *deviations from the scheduled date of delivery* of ordered lots, *deviations from the planned quantity* of delivered goods, and *deviations from the planned prices* of procured goods. Those deviations can cause risk costs that need to be determined by transforming expected operational consequences, such as delays or the amount of faulty parts into monetary values. For instance, supply risks can cause a disruption of the manufacturing stream. By consideration of fixed expenses for utilities, and labor costs, as well as the mean output per time unit, expected monetary losses due to a disruption of an expected duration can be derived [24]. Quality deviations of finished and already shipped products result in consequential costs for potential warranty or liability claims or imminent market losses due to a decrease in reputation [25].

Supply risk can thus be defined as the chance that due to uncertainty regarding occurrence probabilities of future events, raw materials and auxiliaries required for the desired final product are provided with negative deviations from the expected type, quality, quantity, due date, location and / or costs. Supply risks can thus basically lead to four major financial risk consequences:

- Stock-out costs,
- Costs for excess inventory
- Failure costs
- Unexpected purchasing costs

Stock-out costs comprise opportunity costs for lost production volumes, hence lost sales, and possible contractual penalties. Costs for excess inventory occur in case of early deliveries. Failure costs comprise costs for potential machine outages caused by faulty parts, costs for potential rework processes, and possible reliability claims. Purchasing prices can be negatively affected by increasing raw material prices or unfavorable exchange rates for instance.

3.3. Derivation of Requirements

Based on the previous sections requirements regarding model inputs and relevant dependencies can be derived. Firstly, supply risks to be considered are of following kind: risk of untimely delivery, quantity risk, quality risk, and financial risk (R3). Whereas the effect of the latter one can directly be computed, computation of the financial impacts of the other risk types requires an analysis of the respective consequences (R4). Therefore, a model for monetary supply risk quantification needs to consider and capture the operational effects of supply risks, which possibly are excess inventory, stock-outs, and material failures, and analyze the respective costs those effects may cause.

Table 2: Requirements related to supply risks and their consequences

Requirements	Description
R 3	Supply risks that should be considered are: risk of untimely delivery, quantity risk, quality risk, and financial risk
R 4	Modeling and analysis of events subsequent to the point of failure occurrence to determine stock-out costs, costs for excess inventory, failure costs, (and unexpected purchasing costs)

4. Risk Quantification

Practitioners most commonly quantify risks in terms of the expected value of occurrence probabilities and severities by directly classifying risks using simple nominal or ordinal scales [26]. According to DAHMEN, the choice of an appropriate scale for risk assessment is dependent on the availability of data. In the absence of data, ordinal scales are to be preferred. Occurrence probabilities can then be assessed by applying categories such as 'unlikely', 'rarely', 'likely', and 'frequently'. The severity of possible risk effects is described by categories such as 'minor', 'noticeable', 'critical', and 'disastrous' [27].

However, allocation of exact, discrete monetary consequences and occurrence probabilities to specific conditions is not possible. A large variety of causes give rise to uncertain system states. This could be uncertain inputs or conditions in industrial processes, metrological errors, operational unknowns, unpredictable environmental influences or model inaccuracy [28]. Therefore, a simplified scaling approach to assess risk does not provide accurate assumptions. In order to properly consider the lack of information, ranges of values have to be defined to represent uncertainty. When occurrence probabilities are linked with possible effects probability distributions can thus be derived (Fig. 2) [27]. The expected value is computed as the product of occurrence probability and impact severity. The expected value E(x) or λ usually equals the resulting mean of an experiment being repeated infinite times and can thus be considered the arithmetic mean of a frequency distribution. [26]

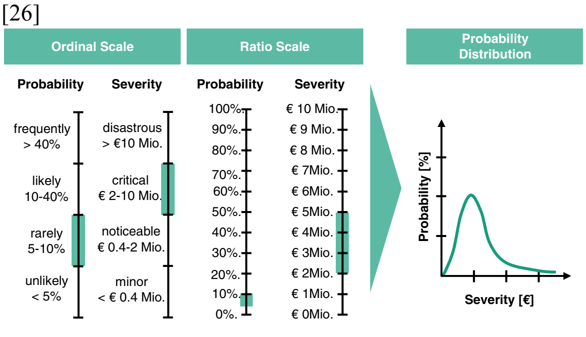

Fig. 2: Assessment alternatives in risk quantification under uncertainty

Literature dealing with quantitative risk assessment postulates that risk should be specified through a suitable probability distribution. As risk is defined as the deviation from a planned value, statistical measures can be applied to operationalize and compare the possible magnitude of such deviations. [7] There are basically two ways to determine probability distributions: direct estimation of a distribution assigning occurrence probabilities to respective levels of severity, and determination of the probability distribution through aggregation of two separate distributions for occurrence probability and severity [7,29,30].

As for direct distribution estimation, relevant literature sources propose various different types of continuous distributions. As the mass of damage distributions is usually concentrated on rather moderate impacts, right-skewed distributions are mostly applied, such as the log-normal distribution, Weibull distribution, gamma distribution and Pareto distribution. [3,26] However, direct estimation of loss distributions in case of supply risks is hardly possible as financial impacts are predominantly determined by internal conditions [30] and the availability of historic data is restricted [31]. Therefore monetary supply risk assessment requires identification of likely operational effects and their evaluation based on appropriate dimensions that can be associated with respective costs (see section 3). [24] Hence, occurrence probability distributions for supply risks need to be defined as model inputs based on which the resulting financial impact is computed. Occurrence probability distributions can be obtained by generating a frequency distribution based on available data or by expert estimation. Applicable probability distributions can be the Poisson distribution, the binomial and negative-binomial distribution. [3] The above mentioned distributions for modeling occurrence probabilities, however, refer to a specific point of time or a time period and are therefore static. If dynamic risk evolutions over time need to be considered, stochastic processes have to be modeled [7,32]. A stochastic process is a mathematical model describing random developments over time (e.g. Marcov chains). Examples for such processes are: radioactive decay, movement of molecular particles, stock prices, insurance risk development and waiting queues. However, to model those stochastic processes a detailed understanding of system behavior is required. [33] In the context of complex global supply chains accurate predictions are considered extremely complicated and not possible with reasonable effort.

4.1. Risk Aggregation

In order to determine the total risk situation of an organization or department, the entirety of individual risks needs to be aggregated [26]. Risk aggregation is subject to the problem of interdependencies and correlations of risks, which need to be taken into account [31]. Generally, there are analytical and simulation approaches applicable for risk aggregation. Analytical methods usually require a simplified model, which is considered the major drawback of such methods. [34]

Hence simulation is a common method for stochastic models. One simulative way to aggregate multiple risks is the so called Monte Carlo simulation (MCS). Instead of elaborating analytically, this approach uses numeric approximation [34]. The accuracy of the result depends on the quality of the defined input distributions and, just as for traditional methods, on the sample size, hence the amount of simulation runs. [35,36] The advantage of the MCS lies in its simplicity and the convenient fact that respective software tools allow a quick creation of representative samples. Meaningful risk aggregation of interrelated risks with adequate effort is only possible via MCS. The definition respectively estimation of input risk distributions and underlying correlations, however, is considered difficult. [37]

4.2. Risk Measure and Level

If risk is defined as a loss distribution, risk measures characterizing the risk level are required in order to make different risk levels comparable and thus to provide a suitable decision criterion [26]. Different decision makers have different attitudes towards risk and may be risk neutral, risk affine, or risk-averse. To account for this rather subjective sense of risk and readiness to assume risk, a risk quantification model should provide adequate risk measures.

The μ decision criterion is one of the most popular rules in decision making processes. Hereby the expected value indicates the risk level. It is a widely spread criterion, especially in the field of business economics, but its major weakness it that standard deviation is not considered. The μ,σ decision criterion is an easy way and often applied criterion to analyze decision problems under risk. However, there are decision situations, where the criterion does not meet the "dominance principle" as long as the decision maker is risk neutral. [6] Besides the mean value and the standard deviation, the VaR is a common risk measure especially applied in the insurance and financial sector. It is defined as the amount of loss not being exceeded with a certain probability during a defined period. The VaR does explicitly not display the maximum amount of loss, but is an estimation of the expected maximal loss under expected market conditions. Even though VaR is a popular and easy to understand risk measure, there are some drawbacks. First of all, VaR is an incoherent risk measure as there may be situations where VaR of two or more portfolios is higher as the sum of the VaR of the individual assets. This is contradictory to the concept of risk diversification. Furthermore, extreme events are not considered as the tail of the distribution is "cut off", which might result in an underestimation of the actual risk potential. Instead of assessing the risk position on the basis of financial assets, measures for assessing risks based on flow values have been developed to meet the requirements of the operational day to day business. Likewise the VaR those measures indicate maximum negative deviations not being exceeded with a certain probability during a defined period. Examples are the Cash Flow at Risk (CaR), EBIT at Risk and Budget at Risk. A risk measure considering extreme events is the Conditional Value at Risk (CVaR, respectively Expected Shortfall). It equals the expected value of loss under the condition that the VaR is exceeded. It thus equals the mean of the "cut-off" tail of the distribution. Fundamental for the accuracy of all risk measures is the underlying set of data. Especially extreme events are oftentimes over- or underestimated. It thus has to be deliberated whether or to which extend the tail of a distribution is taken into account. [26]

4.3. Derivation of Requirements

After having discussed the basics of risk quantification some more requirements can be derived. To adequately account for uncertainty regarding the likelihood of risk occurrence and the expected severity, risk is to be quantified using probability distributions. Input probabilities and effects (e.g. delay in days) need to be defined for each supply risk (R5), which are aggregated to a total loss distribution considering financial risk effects (R6). The actual risk level eventually needs to be quantified using appropriate risk measures (R7). Such measures should consider different attitudes towards risk and indicate the possible range of monetary effects. Hence, rather than the mean value, the VaR in combination with the CVaR could be adequate measures. However, which measures to choose depends on the preferable decision criteria of the respective user of the model influenced by the user's risk attitude.

Table 3: Requirements related to risk quantification

Requirements	Description
R5	Risk needs to be quantified using probability distributions to adequately account for uncertainty regarding the likelihood of risk occurrence and the expected severity
R6	A total risk distribution needs to be generated by aggregating the expected losses due to the different supply risks (simulation recommended)
R7	Adequate risk measures need to be defined considering different attitudes towards risk and indicate the possible range of monetary effects (e.g. VaR)

5. Conclusion

In order to facilitate a more reasonable decision making process in the field of procurement and logistics, target costs functions should be extended by adding risk induced costs to the decision base. This requires a model allowing monetary supply risk quantification. In this paper we identified basic requirements for such a model which have been derived from the basic supply chain structure and procurement, the nature of supply risks, and the basics of risk quantification. Requirements R1 and R2 set the overall model framework and are already implemented in existing approaches dealing with SCM. Further requirements specify which risks to be considered and indicate which dependencies and risk consequences generally need to be considered in order to be able to monetarily quantify supply risks. Requirements R5-R7 specifically define how the uncertain nature of risk should be considered and illustrated. Table 4 summarizes the requirements to be considered. However, those requirements do not specify the appropriate level of model detail, as this depends on the specific analysis purpose. Thus, the identified requirements set the basic framework for models for supply risk quantification of arbitrary level of abstraction and detail.

Table 4: Summary of requirements

Requirements	Description
R1	Intra- and inter-organizational relations need to be representable through model elements accounting for bidirectional flows of products and information, managerial and operational activities from the initial source to ultimate consumer
R2	Relevant procurement objects are raw materials and auxiliaries being assembled into final products
R3	Supply risks that should be considered are: risk of untimely delivery, quantity risk, quality risk, and financial risk
R4	Modeling and analysis of events subsequent to the point of failure occurrence to determine stock-out costs, costs for excess inventory, failure costs, (and unexpected purchasing costs)
R5	Risk needs to be quantified using probability distributions to adequately account for uncertainty regarding the likelihood of risk occurrence and the expected severity
R6	A total risk distribution needs to be generated by aggregating the expected losses due to the different supply risks (simulation recommended)
R7	Adequate risk measures need to be defined considering different attitudes towards risk and indicate the possible range of monetary effects (e.g. VaR)

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