Global Production Networks – An approach to find the optimal operating point in the conflict between risk- and cost-minimization

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Abstract

The proceeding globalization leads to larger and more complex production networks. Especially the production industry forces companies to distribute their production sites around the globe by high cost pressure. Low labor costs, transport costs, distances to potential markets and productivity influences lead to complex decision situations for managers in charge. Besides the total landed costs to produce the product, portfolio decisions are influenced by external risks, causing fundamental losses like recent past shows. This makes decisions even more complex and leads to the conflict of risk- and cost-minimization. Therefore, an integrated methodology is needed to determine risks and costs of a global production networks. Furthermore, a procedure has to be developed to find the optimal operating point in the area of tension between risk- and cost-minimization. The approach contains the development of a quantitative mathematical risk evaluation for global production networks including differentiated dimension probabilities of occurrence and extent of loss and their combination. For cost calculation the web tool “OptiWo” is used, providing the needed detail level of the production network configuration. Combining the area of tension of risk and cost, the coherence between these two dimensions of global footprint design decisions can be identified. Furthermore, the risk optimized network structure for each level of total landed costs can be identified. Depending on the utility function concerning the risk aversion of the manager in charge or company, an individual network operating point should be detected. To make this approach effectively usable for decision makers, an intuitive and progressively resolving visualization will be developed to obtain a deep understanding of the decision situation. The methodology is supposed to be integrated in a web tool to be adaptable efficiently to every use case. The results of the approach will be validated by industry based use cases.

Keywords: Global Production; Risk Management; Production Networks; Optimization

1. Introduction and motivation

Globalization has resulted in mergers and a dynamic competition in recent years. As a result, companies are urged to unify their activities and distribute their production networks globally. These mechanisms have led to continuously expanding and more and more complex production networks with the aim to tap the full market potential and remain competitive.

Due to the numerous influencing factors, management of global businesses is facing complex decisions [1]. Until now, decision-making processes have been based primarily on the dimension of cost [2]. Accompanied by the global allocation of production sites, companies are subjected to risks that can lead to total site losses. With the distributed value chains over the network, site losses may result in repercussions to the production portfolio. The former potentials can be overcompensated and end in enormous financial losses. In late spring 2014 for example, two major chemical companies, Azot and Stirol, have shut down their production sites in the region affected by the clashes between Russian separatists and Ukrainian military forces [3]. Besides political risks, companies are also facing dangers induced by nature. Catastrophes such as hurricanes, tsunamis or earthquakes can paralyze a production site within short notice. This is aggravated by the fact that the ability of developing countries...
to respond to disruptions is often limited. A fast revival of business activities is therefore impeded. As a consequence of natural catastrophes the global economy has suffered a total loss of about 599.5 billion US Dollars within the last 10 years [4]. A very prominent example to be named in this context is the tsunami catastrophe in Japan in 2011. Toyota and Nissans production had to be paused and machinery, equipment and infrastructure was severely damaged.

In a recent article from October 2014 KUMAR stresses that “there seems to be little evidence that the risks associated with the globalization of manufacturing are systematically managed, even though an ill-advised internationalization project can jeopardize a company’s future” [5]. He identified the lack of rigorous management, identification, monitoring and assessment of risk in production companies [5].

From an operational perspective, companies optimize their network progressively following lean management objectives such as eliminating waste. As a result, redundancy is reduced [6]. However, redundancy is vital to buffer disruptions along the production chain. The financial advantage through optimization becomes a disadvantage as soon as negative external influences occur. Therefore, the network has to be adjusted so that supply can be maintained even in the case of a site loss. But nevertheless, it needs to remain a cost structure that is efficient enough to be competitive [7].

In this paper, an overall approach to find the optimum operating point of a network regarding cost and risk is introduced in chapter 3 after an analysis of the state of the art. As the first results the first step of the overall approach, the assessment risk in a global production network, is presented in details in chapter 4. Finally, the aim is the integration of risk analysis in the design process of global production networks. The paper ends up with a summary and an outlook on future research in chapter 5.

2. State of the art

After a brief introduction to the theory of risk management in production networks, a literature review of approaches for network design is given. Due to the tension field of risk and cost approaches for cost orientated network design are presented followed by risk orientated approaches. Finally, the results of the literature review are summarized.

2.1. Risk

According to NEUER predictions are made for decisions that go beyond an observed period [8]. There exist so called “not-suggestible factors”. These factors are the reason for the unpredictability of forecasts. Decision theory differentiates three states of distinctness of not-suggestible factors: security, when there is predictability, risk, when the probability of occurrence is known, uncertainty, when no probability can be determined [9].

Risks have a great effect on economic systems and play a vital role in the design of production networks. Based on the impairing effect of risk on the businesses performance, risk can be observed as the hazard of a loss or damage. Risk can not only be caused by business decisions and activities, but also through unswayable incidents [10]. These risks, which are not directly linked to unswayable events are called “pure risks”. For reasons of clarity and comprehensibility, these pure risks are called “risks”, in the course of this paper. One of these unregularly occurring hazards is, for instance, heavy damage to the facilities due natural catastrophes [11]. To sum it up, the term “risk” is used for the occurrence of undesirable events, which are not certain, but likely to occur [12]. The theory of business studies has identified, that the degree of risk can be quantified by the product of probability of occurrence and impact. The probability of occurrence can only be estimated for repeating events. For rare events, the probability has to be set subjectively [11]. On the other hand, the impact, or extend of loss, describes the damage done by the arising risk. This damage is generally of materialistic nature, but can also occur in the shape of know-how losses or damage done to the company’s image.

2.2. Approaches for a cost-orientated design of global production networks

In this section approaches, available in the literature, for a cost-orientated design of global production networks are presented. However, the majority of authors descend from the field of supply chain management. Methodologies tailored especially for production networks are less frequent to find in the literature.

Already in 1991 COHEN and MOON discovered the need for optimization of production networks. The author’s aim is to develop a model which enables the cost-efficient design of a network. Annual costs, which are composed of fix costs and variable costs, are consulted as optimization criterions. The authors conclusively identify two distinct types of factories in the trade-off between synergy effects and minimization of transport costs: focused plants and regional multiproduct plants [13].

SCHELLBERG’s approach serves as the basis for the efficient design of global production networks. The focus of the author’s approaches lies on the capacity and investment planning of distributed serial production of complex products within a production network. Also, SCHELLBERG presents a software implementation with PRONEG, a global footprint design software tool. His method is based on the MOTION approach (Model for Transforming, Identifying and Optimizing Core Processes) [14], which was developed earlier to aid reorganization of processes [15].

Gathering the costs of a production network based on JACOB’s quantitative optimization procedure, [16] the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University published an approach, which refers to a web tool called OptiWo. This tool enables the calculation of a cost reduced network design with regard to the specific production and network variables by using an evolutionary algorithm, a method that also finds application in the field of Operations Research. The software optimizes the global production network by calculating the total landed costs for different configuration scenarios. This approach enables the comparison of several scenarios with regard to the specific costs of each network configuration [17] [18].
2.3. Approaches for a risk-orientated design of global production networks

Risk due to force majeure such as earthquakes and floods that effect production systems are identified by KÖNIG. For the control of such risks, KÖNIG suggests emergency procedures and insurances as suitable means of control for risk management. Since these risks “do not influence the production system directly, nor can be influenced via technical measures”, KÖNIG does not develop proactive measures [19].

In his study from 2012, TANG observes that risk management of supply chains in the literature generally focuses on the description of risk and the conceptual model advancement, instead of the development of quantitative models. These theoretical models may raise attention for risk management in the industry, but leave a substantial gap and potential. According to TANG, this gap can be filled by the development of a quantitative method. As a foundation for the conception of a quantitative risk management model, TANG identifies the following methods: Robust Planning, Revenue Management, Agency Theory, Option Theory, System Dynamics and Reverse Logistics [20].

For HALLIKAS a division of the production into several sites already represents a practice to share risk. According to him, risk influences parts of the network differently, as each subpart of the network has other structures or focuses. Within this focus there is supposed to be a part of the structure that can carry risk in a better manner than other parts. Consequently, risks can be beared better by a network than by each individual part. Especially financial repercussions can be absorbed better through the higher volume of a collective network. Although HALLIKAS refers to inter-organizational networks with his proposition, the idea can be transferred to intra-organizational networks as well [21].

SCHUH presented an approach on risk analyze in production networks in 2014 with a risk calculation on know how and resource distribution basis [22]. With further research it became clear that the calculation has to be deepen on process level to calculate the financial impact of site losses and the approach has to be extended and combined with the cost dimension to increase the companies’ benefit.

2.4. Result of literature review

The literature review shows that risk management in the field of production networks has mainly been examined within the research of supply chain management. The consideration of risk is generally based on qualitative examination. Network structures of companies from the production industry and their unique characteristics are not discussed in detail.

The cost dimension is well presented in literature. The approach from WZL could be utilized to add the risk dimension.

In summary, there does not exist an approach to find the optimum operating point for a global production network in the tension field of cost and risk.

3. Overall approach to find the optimal operating point of a production network with respect to cost and risk

The research approach to determine optimal operating points of a production network and to give a decision basis for the management, can be structured in four major steps. An operating point is determined by the complete network configuration on production process level. This configuration includes the whole production activities on all sites from sourcing to the customer like product distribution, machine parks, used area, transport connections, duties, etc.

First of all, a brief overview about the approach is given followed by a more detailed description of the individual steps.

3.1. Overview

The approach can be divided into four major steps as shown by figure 1.

![Fig 1. Overview on identification of optimum operating point](image)

To be able to find the optimal operating point within the tension field of cost and risk, cost and risk have to be calculated for a specific operating point. For an approach on process level there does not exist a sufficient calculation for the risk in global production networks as chapter 2.4 shows. Thus, a calculation following the classical risk management is needed to be developed. Within step two, the two dimensions risk and total landed cost for the unharmed network clamp the tension field of interest. The cost calculation is provided by the tool OptiWo [17][18]. The risk is calculated via the combination of probability of a site loss and the impact of the site loss over all sites. Finally, we achieve the transparency of the assessment of an operating point concerning cost and risk. By using determining structures for cost optimization and risk optimization such as redundancies and complementary, as well as their combination, a multitude of operating points can be generated and strategies verified. As soon as both dimensions can be assessed as bad goods in terms of the portfolio theory of MARKOWITZ [22], a hyperbolic relation is expected. In step three, the efficient boundary of potential operating points and the core structures will be identified. In the fourth step, there will only be efficient operating points left to consider, but the manager in charge has to identify one of the operating points suiting the utility function of his company.
3.2. Calculation of probability and impact of site loss risk

The first step is divided into two dimensions of the classic risk management: the determination of the probability of occurrence and the impact of a site loss. To determine the probability of occurrence influential risks have to be identified. The next step includes the gathering of information of global risk data, through the consultation of databases from risk analysis companies. Based on the identified risk dimensions and the provided global risk data, an assessment has to be conducted in order to yield a key figure to denote the probability of occurrence of a site loss of the production network. Furthermore, an industry and situation-specific adaption needs to be undertaken to enhance the validity of the key figure based on different branches. Following the definition of risk, the network structure ought to be analyzed regarding the impact of an occurred event.

3.3. Matching cost and risk for an operating point

To consolidate the information to a risk key figure for step two, a multiplication of risk in percent and impact in cost, would be eligible. With the used data, the financial impact of a site loss can be determined. Combining the input from the impact determination and the probability of occurrence any potential operating point can be classified in the tension field of risk and cost. The detailed approach can be found as the first results of the overall approach in chapter four.

3.4. Identification of the efficient boundary of potential operation points

In this step of the approach, the target is to define the influence of redundant and complementary structures of global production networks (figure 2). As complementary structures optimize cost by scale effects, redundancies reduce risk by adding options for compensation. The alteration on process level will empower the management to generate various operating points in the spanned tension field focusing on risk and cost optimization. This is illustrated in step 3 of figure 1.

![Fig. 2 – Redundancy strategies influencing cost and risk](image)

To analyze the coherence of cost and risk, repercussions due to the variation of risk drivers and changes of the network configuration have to be examined. For this purpose, calculations for numerous network configurations using real set of data are going to be conducted by varying redundancy strategies like figure 2 illustrates.

On the basis of previous theoretical and empirical research, a coherence similar to the one depicted in the figure 1 can be expected. The particular operating points represent a cost-risk-bundle, which itself represents an individual network configuration. Following the theory of microeconomics, costs, as well as risk, can be interpreted as “bads” (bad goods) [22]. According to this feature and the inherited direction of displacement of the company-specific indifference curves to higher utility levels, it is obvious that solely the bundle with the least cost at the same level of risk are interesting for further discussion. These identified points can be connected to form an efficient frontier. It is rather clear that both “bads", risk and cost, can not be avoided entirely while production even with a full focus on one or another, but it will both decrease with the focus as the expected extremes in figure 1 illustrates. Finally, a hyperbolic relation is expected for the efficient boundaries [23].

Based on the methodology from the previous sections, redundancy strategies can be identified that enable a cost and risk minimization to the point where the frontier function is reached. The goal is to generate an assertion how to design the network, so that it is situated on the frontier function. As a consequence, it is possible to determine a risk-minimizing configuration for a certain cost level of the global production network.

3.5. Finding the optimum operating point

The results reached in the course of the methodology enable us to design production networks within the area of tension of risk and cost as well as redundancy and complementarity. To finalize the picture of the configuration, results have to be harmonized with the company’s individual strategy. The marginal costs of the risk minimization procedure will be determined through the individual aversion of risk of the company, respectively the management.

4. Detailing the first step of the overall approach – Risk assessment of global production networks

A quantitative method focusing on the determination of a risk key figure for risk \( r \) of a global production network operating point consisting of the extent of loss \( \sigma \) and probability of occurrence \( \rho \) has been developed. This method establishes the first step of the methodology described in chapter 5.

4.1. Determination of the probability of occurrence of a site loss

Since the probability of a site loss is difficult to quantify, as it underlies a huge amount of influencing factors, a qualitative approach is inevitable to yield a representative figure. The basic data is generated by professional data bases, concerning political risks and geographical risks. While there is no data available of a final percentage, different scales used by the data bases are combined to fit the use case and scaled to a system illustrated in figure 3 to the probability of occurrence \( \rho_i \) of site \( i \).
measures is needed to be calculated. A site loss affects, due to all, even indirectly affected chains, to collapse.

the dependencies, other locations and process steps of the impact. One can identify three steps when determining the consideration of the mechanisms that arise in the event of an occurring risk, process chains have to be restructured, often making the network structure less vulnerable. In the case of an outage, sites are also affected indirectly by the outage.

finishes. In the event of a site loss along the value chain, other networks and usually pass several different locations before production network. The loss of profit is computed for each site of the production network. Products are moved along the value chain in production networks and usually pass several different locations before finish. In the event of a site loss along the value chain, other sites are also affected indirectly by the outage.

On the other hand, other sites can, as long as know-how and the necessary equipment is present, substitute affected process steps. Redundant design of processes at multiple locations can help to compensate damage significantly and make the network structure less vulnerable. In the case of an occurring risk, process chains have to be restructured, often leading to higher specific process, transport and administrative costs. As a matter of fact, this influences the profit, which acts as value to determine the impact. According to the consideration of the mechanisms that arise in the event of risk, one can identify three steps when determining the impact.

First, the profit of the initial, unharmed network \( P_0 \) is going to be evaluated. In this initial situation the profit over all products is being determined through the consideration of the given input data. These are information about the value chain’s process- and product structures, shift information, sales information, financial statements about resources and equipment, logistics and transportation data, as well as operative key figures and investment data, sells prices, etc.

Secondly, the profit of a site loss without restructuring measures is needed to be calculated. A site loss affects, due to the dependencies, other locations and process steps of the production network, too. Therefore, the second step assumes all, even indirectly affected chains, to collapse.

The final step involves the calculation of profits after a restructuring of processes \( P_i \) as it would happen in the case of a disruption. On the basis of the computable free capacities of the process steps at the production sites, one can further regard adjustments to lower the impact of risk and shift process chains in a way to absorb and limit the impact.

To sum it up, the operational loss \( (L_i) \) can be expressed as the difference between the initial profit of the unharmed network \( P_0 \) and the profit after restructuring in the event of a loss of site \( i \) \( (P_i) \).

\[
L_i = P_0 - P_i
\]

4.3. Formation of a site-specific impact key figure

To gain the stated key figure, a normalization of the given values is necessary. Since the loss is a delta of profits, and is compared to the unharmed state of the network, one could mistakenly argue that the initial profit \( (P_0) \) before the occurred risk suits as a normalizing factor. Nevertheless, too often profits are negative or zero, leading to informative results. To eliminate this issue, the initial revenue \( (R_0) \) is utilized as a divisor. Due to the fact that revenue is strictly positive in every thinkable scenario, it serves as a reference point for the analysis. Eventually, the formula for the site specific quotient consist of the delta profit, which is equivalent to the profit loss, and the initial revenue of the whole network.

\[
\sigma_i = \frac{L_i}{R_0} = \frac{P_0 - P_i}{R_0}
\]

An in depth examination of the behavior of the quotient reveals three regions: the quotient is between 0 and 1 for a profit loss between zero and initial revenue, the quotient goes to infinity for an “infinite” profit loss, and last, the quotient is negative for negative profit losses. For a quotient greater than 1, the impact is already in the same order of magnitude as the initial revenue. In this case, immediate improvement of the network structure should be considered since a disruption due to a failure of one site has fatal outcomes. On the other hand, for negative values the “question mark” region is met. In this case, the management ought to scrutinize the existing network structure, because as a matter of fact the company is more profitable without the damaged site. The quotients remaining region between zero and one is of high interest, since the majority of network structures will be within that region.

4.4. Merging impact and probability to form a comparable risk key figure

The impact quotient has to be brought together with the probability of occurrence to build a risk key figure for a specific operating point as step 2 of the overall approach shows. To do so, the quotients for an impact of a site loss \( (\sigma_i) \) are multiplied by the probability of occurrence \( (\rho_i) \) to generate the specific site risk of site \( i \).

\[
r_i = \rho_i \cdot \sigma_i
\]

Now, the networks’ average risk key figure can be identified by calculating the average of all individual site risks. The average is weighted by the total value creation at the specific site \( (\omega_i) \) on a cost basis.
r = \sum_{i=1}^{n} \frac{r(i)}{\sigma(i)^2} + \frac{1}{n} \tag{4}

Following this method, a loss and risk key figure can be calculated which offers comparability for different enterprises and varying network configurations.

5. Summary and Outlook

The presented approach enables the management to assess the risk related to a specific configuration of their global production network. It can be applied to any production network of any size and complexity.

Following the presented approach, the creation of a method to assess the risk of a given global production network is achieved. In respect of the methodology presented in section 3, the next steps will include the determination of the behavior of production networks regarding the variation of redundancy and complementarity in network design, as well as the coherence analysis on cost and risk in production networks. Finally, it will be possible to identify the efficient operating points of a production network with this approach. Companies just need to figure out their preference between cost and risk and the optimum operation point can be found.

Within further research industry based use cases to validate the overall approach are needed. Because of the complexity and the resulting mass of data, further development will focus on intuitively and comprehensively illustrated visualization for the results. The method’s output should be visualized transparent in the different levels of aggregation to get a quick overview about the risks of core products and dangerous sites to make choosing easier [24]. Finally, pattern recognition will developed and implemented to identify network structures and the network configuration data causing a high risk. That will help managers to identify action fields to improve their production network. In the future, it is planned to integrate the Risk Analysis System directly into the OptiWo tool to allow an overview over the dimensions of cost and risk in a single configuration tool and a direct usage of the generated data for calculating the cost of the network.

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