COHERENCE OF RISK AND COST IN GLOBAL PRODUCTION NETWORKS

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Abstract- Globalization forces companies in the manufacturing industry to allocate their global production sites dependent on cost factors. These cost factors such as low labor costs, transport costs, and productivity effects are leading to complex decision situations for managers in charge of the production. Besides the cost factors also risk factors as another influence must be considered in this context. Like recent events in the past showed, risks are causing fundamental losses if not addressed sufficiently. Including the risk factor makes decisions even more complex and leads to the conflict of risk and cost minimization. A quantitative determination of risk could not be found in literature. Therefore, an integrated methodology has been developed to determine risks and costs of a global production network (GPN). It can be applied to investigate the coherence of risk and cost in global production networks. Furthermore, optimization limits within the given boundaries are identified and an optimal configuration within the area of tension between risk and cost minimization is identified. This methodology has been validated via an industrial based use case.

Index Terms- Management, Production, Networks, Risk, Cost

I. INTRODUCTION

In recent years, globalization resulted in highly dynamic market competition. Consequently, companies are forced to reduce their production costs, by unlocking the potentials of global production. These potentials are mainly based on better cost structures especially concerning labor cost within the supply chain. In addition to higher market dynamics the product life cycles are constantly decreasing whilst product differentiation is increasing, and hence the design of production networks becomes a more complex task for managers in charge [1]. Until now, decision-making processes are mainly considered on the dimension of cost [2].

Accompanied by the potentials of global production networks (GPN), companies are subject to new risks such as political and geographical risks which can cause site losses in the production network. For distributed value chains over the network, site losses may cause fundamental damage to the whole network. This implies that the former newly gained potentials of global production could turn quickly into enormous financial losses. For example, in year 2013 the production sites of BASF and Toyota in Egypt needed to be shut down due to politically motivated riots [3]. Besides political risks, geographical risks such as earthquakes, hurricanes or tsunamis can also trigger production shut downs within short notice. As a consequence of natural catastrophes for instance the global economy has suffered a total loss of about 599.5 billion US Dollars within the last 10 years [4]. One of the best known examples of 2011 to be named in this context is the tsunami in Japan. Production at Toyota and Nissan broke down and machinery, equipment as well as infrastructure were damaged. Due to this parts for final assemblies were missing and consequently down times in other global sites occurred. Toyota lost the production of about 370,000 vehicles and with it the top positon as world's car manufacturer. [5]

These events bring back the issue of risk considerations in global manufacturing as a recent article from KUMAR stresses: "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" [6]. He identified the lack of rigorous management, identification, monitoring and assessment of risk in production companies [6].

In this paper a methodology for quantifying risk and cost of different global production network structures on production data level is illustrated. Furthermore, the coherence between risk and cost in production networks is shown and validated by an industrial based use case. Finally, the given boundaries in risk and cost minimization within the production system and the optimal operating point will be identified.

II. STATE OF THE ART

A production network is defined by RUDBERG as "(…) a factory network with matrix connections, where each node (i.e. factory) affects the other nodes and hence cannot be managed in isolation." [7]. In contrast to a supply chain a production network is limited to company-wide main factories, while supply chain and supply chain management extends over the company borders as well.

The framework of the system is set with a company's business model and production. This framework limits the field of actions for network management. For example, production network management is not able to change sales, core market or production processes. These should be seen as fixed for the network design. Inside this framework a plethora of complex network configurations can still be designed by product allocation, machines, and factories on a global scale. The count of different configurations reaches a number of 10 by the power 4,700 which exceeds the number of atoms in universe by far [8]. In a decision situation like that it is necessary for the responsible manager to be sufficiently supported.

The main motive of production network design is the minimization of operative costs to maintain competitiveness in the market. As shown in part I., optimizing costs alone might not be sufficient to find the optimal network configuration for a company. Cost savings are prone to be neutralized by the occurrence of external risks [9].

With the need of the two dimensions risk and cost in the framework of network management the tension field is set. According to the portfolio theory by MARKOWITZ risk and cost cannot be eliminated completely and the reduction of one may cause the increase of the other, however an efficient frontier of dominating configurations is possible to find. [10]

This implies that an integrated risk and cost decision basis is needed to provide the managers in charge with both dimensions. Furthermore, the limitations of production network designs in both dimensions need to be quantified as well as the optimal configuration in the tension field of risk and cost need to be found.

III. LITERATURE REVIEW

Figure 1: Literature Overview

Need for action regarding the configuration of a global production network	SCHUH ET AL	HALLIKAS	TOMLIN	ZÄH	LANZA 10	LANZA 12	CHOPRA
Content-wise criterions							
Consideration of internal corporate networks	●	○	○	●	●	●	○
Consideration of configuration possibilities of global production networks	●	○	○	◑	●	●	○
Cost consideration and analysis	●	◑	◑	◑	●	●	◑
Consideration of salary costs	●	○	○	◑	●	●	○
Consideration of costs regarding material, energy and raw materials	●	○	○	○	●	●	○
Consideration of logistics costs	●	○	○	○	●	●	○
Model of Total Landed Cost (TLC)	●	○	○	○	○	○	○
Risk consideration and analysis	○	◑	●	◑	●	◑	●
Risk = Probability * extent of damage	○	●	●	○	○	○	◑
Risk factor: Political system (war/terrorism)	○	○	●	○	○	○	●
Risk factor: Natural catastrophes	○	○	●	○	○	○	●
Classification into the area of tension between costs and risks	○	○	○	○	●	○	●
Consideration of risk preferences of decision maker	○	○	●	○	●	○	●
Formal criterions							
Comprehensibility	●	●	○	●	◑	●	●
Universal application	●	◑	○	◑	●	●	●
No realistic assumptions	●	◑	○	◑	●	●	●
Utilizing relational data structures/ quantitative investigation	●	○	●	○	●	●	○

● = comprehensive consideration ◑ = partial consideration
○ = no consideration

Table 3.7: Deficits of existing approaches.

The literature review constitutes the actual situation in theory of approaches to deliver a solution to provide a decision basis for global manufacturing footprint design in the tension field of cost and risk.

Configuring global production networks is scientifically examined from different perspectives. In the following the main approaches are analyzed. Within the scope of an IT-supported approach

SCHUH et al developed the tool OptiWo which utilizes a genetic algorithm to approximate and visualize various scenarios such that costs and delivery times are optimized. [11] HALLIKAS' concept combines network configuration with risk management from a supplier's angle. Based on personal interviews conducted from practice four company-wide risk groups are identified. The arrangement of these risks with regard to their likelihood and extent of damage is condensed into a risk portfolio. [12,13] TOMLIN develops a mathematical model that evaluates the entrepreneurial resilience regarding supply-chain disruptions. The model focalizes three possibilities to react to supply-chain disruption. Depending on supplier performance and the decision-maker's own risk preference a reaction plan is selected. [14] The stage model of ZÄH determines the appropriate commitment into foreign activities. The stage model sub-divides the degree of foreign activities into five stages. At each of these stages a qualitative evaluation regarding the risks and opportunities is conducted which supports the inclusion of risk during the planning process. [15] LANZA's approach is based on a simulation with the software Plant Simulation which evaluates total expected costs of different varieties of a production network. [16] Another approach by LANZA is a three step model for analyzing and monetarily evaluating different production network configurations for deriving cost optimal guidance for the decision making process. [17] CHOPRA highlights externally induced supply-chain disruptions and the resulting expected damages. For an optimal reaction towards these disruptions a four-step process for identifying risk categories and drivers is introduced which are then matched with appropriate measurements. [18]

Essentially all approaches incorporate risks within the configuration of GPNs however seldom a combination between the priorities of cost and risks is considered. An overview of the deficits of the approaches regarding a cost-risk consideration is depicted in

Figure 1. A consideration of costs in internal corporate networks takes place in SCHUH et al, ZÄH and LANZA. In TOMLIN and CHOPRA company-wide networks such as supply-chains are considered which, nonetheless, can be partially transferred to an internal corporate network view. The consideration of configuration possibilities of global production networks in a systematic way is included in approaches from SCHUH et al, ZÄH and LANZA. Whereas SCHUH et al and LANZA analyze and optimize different configuration scenarios, LANZA defines different stages of foreign activities. A cost consideration and analysis is only ensued in SCHUH et al by the Total Landed Cost model which allows for a systematic view in terms of cost types. LANZA also considers costs by utilizing real data structures however different cost types are not distinguished which hampers systematic analyses. Risk consideration and analysis is addressed in all approaches except for REUTER. However only in HALLIKAS, TOMLIN and CHOPRA a systematic assessment on the basis of likelihood and extent of damages is considered. In addition to that only TOMLIN and CHOPRA consider damages by force majeure. The classification into the area of tension between costs and risks is conditional on a sound cost and risk consideration which is only ensued in LANZA and CHOPRA. The decision-maker's risk preference is considered in TOMLIN, CHOPRA and LANZA's first approach. Formal criterions are mostly considered in all approaches. The universal application of the approach of TOMLIN is restricted due to the high degree of abstraction and regarding the concepts from HALLIKAS, ZÄH and CHOPRA the nonexistent quantitative evaluation and thus high dependence on expert knowledge restricts universal application.

IV. APPROACH

The overall approach has been developed and published in the year 2014/2015 [19,20]. In this paper the risk determination could be finalized and the approach could be validated.

Operational costs are calculated by the IT-Tool OptiWo [21]. Risk calculation is separated in the two steps: (1) probability and (2) impact of a site loss. The calculation of the probability of occurrence for a site loss is calculated based on corresponding data bases including political and geographical risks. These two potential risks are aggregated to a site loss risk. Depending on the granularity level of the data bases, a risk scoring for each site is the result. The impact of a site loss is calculated by the profit loss of the network due to a site loss for each site. The calculation will be shown in detail in part V. As a result of the calculation a point in the tension field of risk and cost is identified. For given company frameworks, basic network structures are used to develop a multitude of potential configurations. It is not possible to calculate all possible solutions due to the high solution space. The result is optimized with towards a decrease of risk and cost collaboration of man and machine based on the model in cyber-physical systems [22]. Experience and knowledge of managers in charge are used to develop an optimal configuration for the company.

V. RISK CALCULATION

Figure 2 depicts the risk calculation of global production networks in a flow chart. The overall risk is calculated as the sum over all potential location losses. These are quantified by the probability of occurrence multiplied with the direct loss for the percentage of lost CapEx due to the occurring risk and the operational damage due to the impact of a potential downtime of the specific site to the network profit as:

$$
\begin{aligned}
Risk[€] &= \sum_{l^{down}} \Big(\big(DirectLoss_{l^{down}}[€] \\
&* LossPercentage_{l^{down}}[\%]\big) \\
&+ \big(ProfitLoss,withComp_{l^{down}}[€/month] \\
&* DowntimeLoc_{l^{down}}[months]\big)\Big) \\
&* Probability_{l^{down}}[\#]
\end{aligned}
\tag{1}
$$

To determine the potential direct loss per harmed site l is calculated as:

$$
\begin{aligned}
DirectLoss_{l^{down}}[€] &= \sum_{j} \big(InvestCost_{j,l^{down}}[€] \\
&- DepreciationRate_{j,l^{down}}[€/year] \\
&* AverageAgeofMachines_{j,l^{down}}[years]\big) \\
&* NbrResources_{j,l^{down}}
\end{aligned}
\tag{2}
$$

With $InvestCost_{j,ldown}$ as the invest cost of machine type j at site l, the $DepreciationRate_{j,ldown}$ as the depreciation per year for machine type j at site l, the $AverageAgeofMachines_{j,ldown}$ as the average life time of machine type j at location l and $NbrRessources_{j,ldown}$ as the amount of machines of type j at site l.

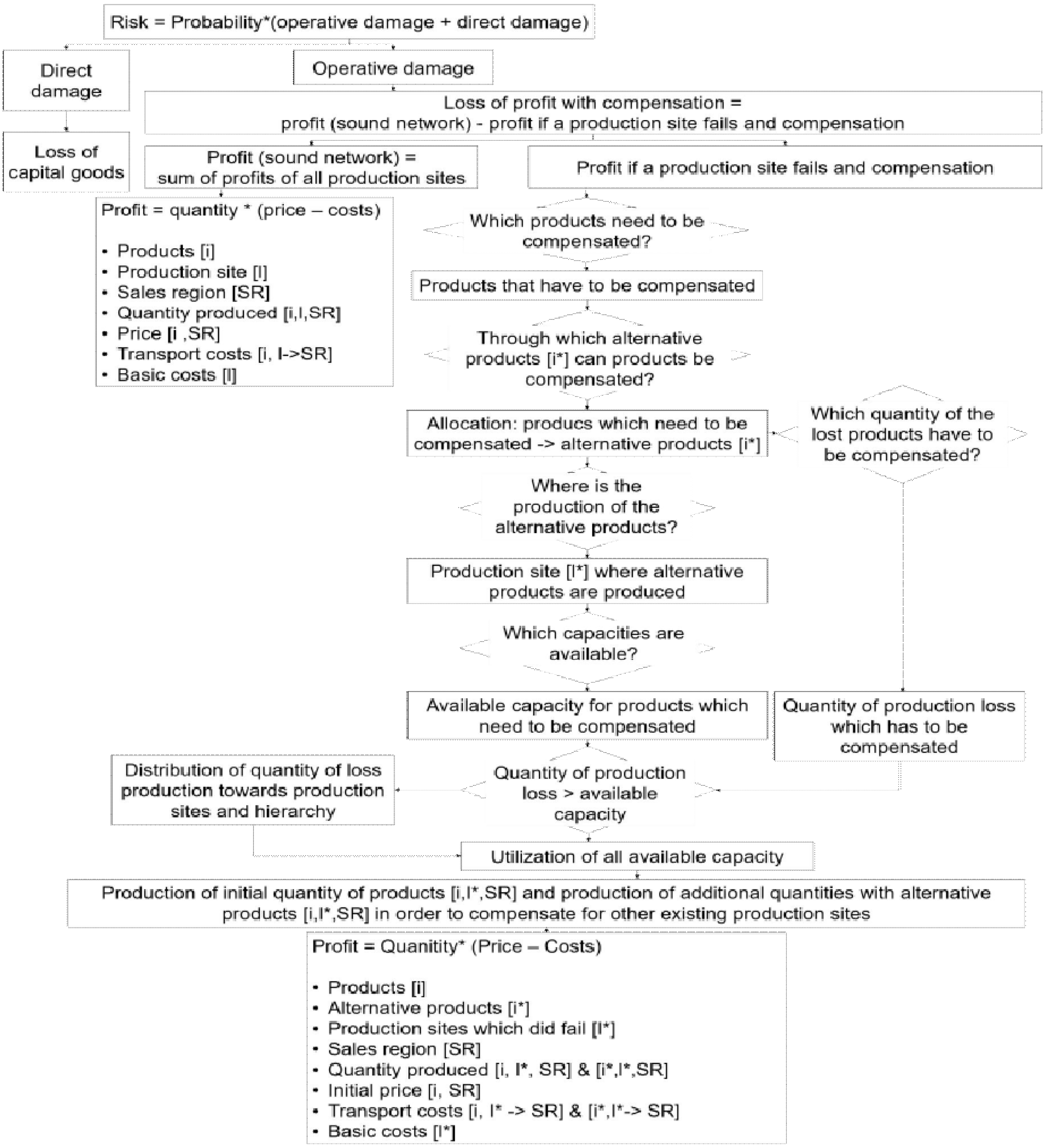

Figure 2: Work flow of Risk calculation

The operative damage is calculated as the profit loss with compensation for a harmed site by the difference of the unharmed Network $Profit_{ges}$ and the profit of the network with a collapse of site l and the use of compensatio $Profit, withComp_{l_{down}}$. Compensation means the use of other sites to compensate the production losses in the network due to the collapse of site l:

$$ProfitLoss, withComp_{l_{down}}[€/month] = Profit_{ges}[€/month] - Profit, withComp_{l_{down}}[€/month] \quad (3)$$

With a profit of the unharmed network as the sum over all location profits:

$$Profit_{ges}[€/month] = \sum_{l} Profit_{perLoc_l}[€/month] \quad (4)$$

Where a location profit is calculated as the amount of coverage per product produced in the network minus the total landed cost for the internal value creation over every product i for every sales region sr including the value creation in the factory $CostPerPiece_{i,l}$ which includes all costs the value creation generates, the transport costs $TranspCostPerPiece_{i,l \rightarrow SR}$ and basic cost, which are fixed costs that are needed to have a factory running.

$$\begin{aligned} Profit_{perLoc_l}[€/month] &= \sum_{i} \sum_{SR} Quantity_{i,l}[piece/month] \\ &* \Big(Price_i[€/piece] \\ &- \big(CostPerPiece_{i,l}[€/piece] \\ &+ TranspCostPerPiece_{i,l \rightarrow SR}[€/piece]\big)\Big) \\ &- BasicCost_l[€/month] \end{aligned} \quad (5)$$

The profit for a harmed network by a loss of site l $Profit, withComp_{l_{down}}$ is further calculated after the compensation logic in Figure 2 with the new product quantities, transport connection and factory data to:

$$\begin{aligned} Profit, withComp_{l_{down}}[€/month] &= \sum_{l^*} \Bigg(\sum_{i} \Big(Quantity_{i,l^*}[piece/month] \\ &* \Big(Price_i[€/month] \\ &- \big(CostPerPiece_{i,l^*}[€/piece] \\ &+ TranspCostPerPiece_{i,l^* \rightarrow SR}[€/piece]\big)\Big)\Big) \\ &+ \sum_{i^*} \Big(Quantity_{i^*,l^*}[piece/month] \\ &* \Big(Price_i[€/piece] \\ &- \big(CostPerPiece_{i^*,l^*}[€/piece] \\ &+ TranspCostPerPiece_{i^*,l^* \rightarrow SR}[€/piece]\big)\Big)\Big) \\ &- BasicCost_{l^*}[€/mont] \Bigg) \\ &- BasicCost_{l_{down}}[€/month] \end{aligned} \quad (6)$$

Finally, it is possible to quantify the risk of an individual network configuration. As soon as data for probability of occurrence of a site loss can be determined in a percentage with an estimation of the downtime the risk can be quantified in a hard financial indicator.

VI. CASE STUDY

The methodology was validated in an industrial based use case, which is presented in the following. First of all, the case is explained. Afterwards the implementation of the approach is shown briefly and results are given. To handle the amount of data efficiently the risk calculation was programmed in an IT-Tool. Based on the OptiWo data base the IT-Tool calculates the risk. Further input data is data concerning the probability of occurrence. In this case a downtime of six months, a direct loss of 60% and probability of occurrence for a site loss of 1% for Germany, 1,1% for USA, 1,2% for Poland and 1,5% for India and China was used.

The company belongs to the automation industry. Any final product contains company specific metal conductor parts which are not available from third-parties. These 23 conductor types are the considered products in this case. To ensure the supply safety for all five assembly sites Germany, Poland, China, India and USA, the company needed to figure out which configuration of the global production network is able to provide the best results in terms of cost and risk reduction. Without these conductors, the company will not be able to sell about 90% of their final products, which might be critical for the whole company. The production processes and the 23 different machine types were fixed on the status quo. All data had been collected concerning the Total Landed Cost approach. With the strategic decision, that no further sites will be opened for the metal conductor production, the already existing five sites are setting the strategic framework, as mentioned in

part II. Still the number of possible configurations is larger than 10 by the power of 273 within this framework. To overview the tension field of risk and cost, ideal-typical network structures from literature are used. Based on ABELE the extreme network structures global factory and local-for-local where used to initialize the analysis [1]. The results are depicted in Figure 3. Following the idea of collaboration of man and machine the results are analyzed by experienced managers which resulted in new configurations. An iterative process was used to generate different new scenarios, which could be evaluated and quantified efficiently.
By analyzing the ideal-typical structures it became obvious that local-for-local minimizes risks and a global factory in a site with an inexpensive cost structure like China minimizes costs. To find a configuration in between these extremes, characteristics of both were used to generate mixed configurations. These where generated by fixing network structures, which made up good results in one or the other dimension and using the OptiWo optimizer to minimize the cost within the open range. Finally, an optimized scenario could be developed, which faced the needs of the company best by a useful compromise between risk and operational cost.

The results show that the portfolio theory by MARKOWITZ is explicatable. The expected efficient frontier of dominating configurations is sketched in Figure 3. To proof the theory and the existence of the frontier, all 10 by the power of 273 results in the framework should be calculated and endorsed in the portfolio. Nevertheless, the limitations of the framework can be estimated already.

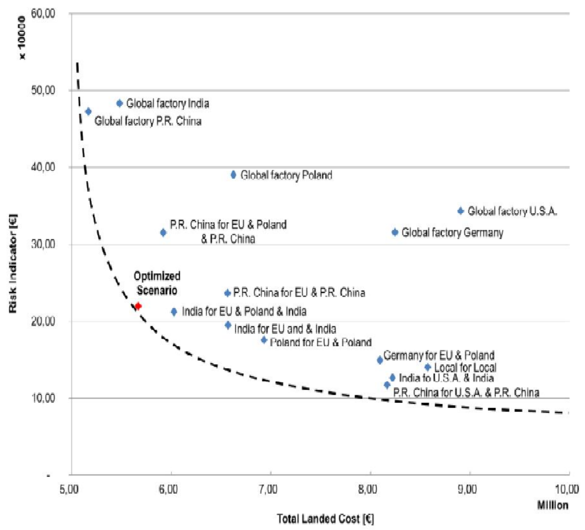

Figure 3: Results of the case study

CONCLUSION

The presented work showed that the integration of risk management in the design of global production networks is needed for a reliable global production. The gap in literature could be revealed. Finally, the developed methodology allows managers in charge to overview the dimensions of risk and cost in their production network efficiently. Beside the improved decision overview, improved configurations could be developed in an iterative process and the limitations of global production network design in these dimensions can be estimated. A case study was conducted to validate the approach.

Further research will be needed to show the general validity of the methodology with application on other use cases. The methodology for the estimation of the probability of occurrence needs to be detailed. For further improvement of the decision making process additional dimensions should be integrated to get an overview over all potential company goals, which could be reached with the design of the global production network.

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