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Risk Management in Production Networks – A Simulation-based Approach

Carl Hans
Bremen Institute for Industrial Technology and Applied Work Science, University of Bremen
28359 Bremen, Germany

Jens Schumacher
Bremen Institute for Industrial Technology and Applied Work Science, University of Bremen
28359 Bremen, Germany

Boris Bemeleit
Bremen Institute for Industrial Technology and Applied Work Science, University of Bremen
28359 Bremen, Germany

ABSTRACT

Customer-driven markets, decreasing product life-cycle times in combination with the demand for customer-tailored products for minimum prices has triggered new organisational concepts. In contrast to single enterprises with a high vertical range of manufacture nowadays companies aims to join in networks where each of the involved partners contributes its core competencies. These networks can then provide products and services in a more efficient and flexible way than the partners could on their own and thus helps them all to become better and more competitive in a global market.

In the field of production these structures are called value added production networks. Dependant upon the production period of the products which are manufactured within such a network its lifetime may be shorter or longer whereas all of the phases within the life cycle of a production network (comprising establishment, operation and decomposition [1]) requires a careful planning. This is necessary in order to establish structures fulfilling the requirements of all the involved partners regarding efficiency and profitability. Due to the complexity of such networks and the time restrictions for the planning process (in order to be responsive to the market) the planning task becomes even more difficult. One of the most important aspects to be considered here covers the risks coming along with such production networks. Basically distributed environments like these ones contain various risk factors. In the context of production networks they are related to the different kinds of facilities (plants, production lines, distribution centres, terminals etc.) as well as links (mainly for transportation and information flow). Thus they represent an omnipresent factor within production networks and appear in form of unexpected events with considerable effects on the efficiency of production networks. Therefore the insensibility against such events (e.g. the breakdown of a certain production line or logistics link) - which is called robustness - is an important requirement towards network structures which are not only efficient under certain conditions but also stable in unexpected situations which usually cannot be predicted in real life.

There are different concepts and tools available that can be used in order to conduct risk management in production networks. One of these approaches is simulation. The paper describes production networks, the problems related to robustness and why simulation is very well suited for this purpose. In addition an appropriate, user-friendly simulation tool is presented.

KEYWORDS

Risk Management, Production Networks, Network Modelling, Simulation

PRODUCTION IN NETWORKS

In order to rest in today's highly dynamic, customer-driven markets new requirements regarding flexibility and adaptability has to be fulfilled by enterprises in production area. During the past decade it became clear that traditional strategies which were mostly focussed on being independent from others ("my factory is my castle") are not longer valid. In contrast new organisational concepts were discussed which aims to exploit the core competencies of several partners for the production of a certain product or service in order to improve the efficiency and competitiveness of all of the partners and become better as a whole [2]. Although this approach really promises potential for significant improvement it implies a significant increase of the complexity of organisational structures and therefore a higher potential of risk.

In this context it is necessary to have a closer look on what production networks really are. In literature several definitions for this term can be found. They all have in common that production networks are composed of several (more than two) companies which are independent and therefore following their own strategies. Within the value creation chain for the product or service each of the partners take over specific tasks. Usually these tasks are complementary to each other so that that there are no tasks which are conducted by several partners in parallel. This kind of cooperation is called vertical (in contrast to a horizontal cooperation). Thus a production network can be considered as presented below (Figure 1):

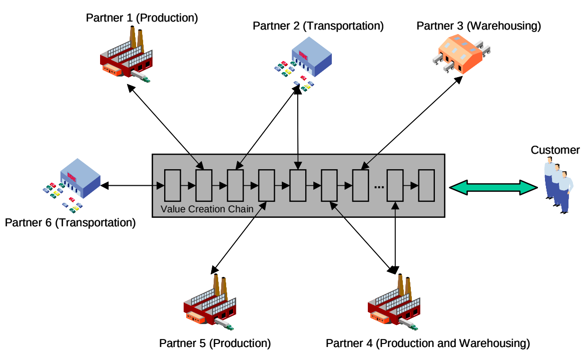

Figure 1: Structure of Production Networks

The example shown here hides some of the complexity which is coming along with production networks. Even if the network comprises only a small number of partners their interaction is affected by various side effects coming along with different kinds of risks. These risks – they are considered as unexpected events which occurs randomly – can have significant impacts on the overall efficiency of such networks - they can even paralyse it if core resources are struck by such events.

Going into more detail concerning these risks they can be distinguished into two main categories, namely internal risks associated to certain processes within the value creation chain as well as external ones which represents external events like strikes or natural disasters. While internal risks influence certain parts or processes of the value chain external risks affects the resources available. Both have in common that they come along with specific delays and costs. Furthermore each of them has a certain probability of occurrence. In contrast to internal risks it is important to know how long external ones are active– e.g. how long a strike continues. Having these issues in mind Figure 1 has to be enhanced as following:

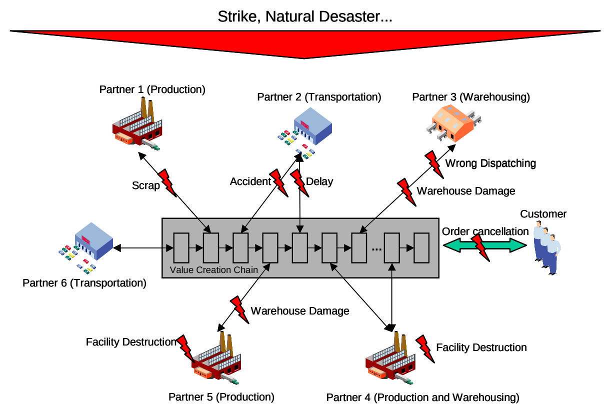

Figure 2: Risk Factors in Production Networks

Now the complexity of production networks becomes obvious. This complexity in addition to the need of short response times to market requirements needs efficient planning and continuous monitoring of production networks in order to ensure their profitability for all of the involved partners. Due to the complexity of production networks the planning and monitoring processes requires appropriate decision support tools which help to find the right partners for production, transportation, warehousing etc. under consideration of risks. In this context a certain configuration which seems to be an optimal one (under consideration of only monetary issues) can be completely inefficient if certain risk events occur. Therefore a proper estimation and management of risks are an important part of network planning and monitoring in order to come to reliable and robust network structures.

WHY SIMULATION?

Today simulation represents a broadly accepted approach in order to deal with complex systems. Thus simulation is also a good candidate for dealing with production networks [3]. In this context the advantages of simulation can be summarized as follows:

- Simulation helps to understand the dynamic of systems
- Nearly no limitation regarding the complexity of the systems to be analysed
- Representation of risks and uncertainties by stochastic parameters allows their consideration within simulation studies
- Systems can be evaluated without the need to make them real
- Evaluation of what-if scenarios with or without risk of accidents, destruction, financial disasters etc.
- Decisions can be verified before implementing them in reality.

Concerning the consideration of production networks the most important advantages covers the allowed complexity of the systems to be investigated as well as the integration of stochastic elements. Especially the latter aspect makes simulation unique against other approaches for system evaluation and planning and supports the investigation of risks related to production networks whereas the execution of what-if scenarios supports the understanding of potential risk factors as well as their impact on networks and how to mitigate them in order to come to systems which are efficient and robust at the same time. Thus simulation represents a perfect base for the realisation of tools for risk management in production networks.

Today a wide variety of different simulation environments is available. The range starts with libraries offering functionality for the realisation of systems on the level of programming languages and ends with general purpose simulation environments supporting the modelling, simulation execution and analysis of simulation data for arbitrary systems by offering a user friendly platform. In between there are simulation environments covering a specific type of system. These environments focuses on specific kinds of systems. Therefore they are not that flexible - instead they usually offer the highest degree of user-friendliness and enable even domain experts to make use of simulation which is often reserved to simulation experts. As a consequence systems like this cannot be enhanced regarding issues which are not supported without significant additional development efforts. Thus the treatment of risk has to be smoothly integrated into such systems which is not the case for existing simulation environments addressing the field of production networks. This shortcoming has been addressed in the ONE toolbox. The toolbox supports the modelling and simulation of production networks under consideration of risk and will be presented later.

SIMULATION-BASED RISK ANALYSIS

While applying simulation for risk management of production networks main focus is put on the identification of potential risks and their impacts in case of their occurrence. For this purpose three phases will be passed each of which contains the following steps (Figure 3). Phase 1 covers the identification of the problem. Here all of the different risks in combination with to be investigated within the simulation study has to be specified together with relevant performance indicators for the evaluation of the quality of a certain model.. Afterwards the underlying scenario is defined. This step mainly covers the conceptual design of the network in terms of nodes (plants, distribution centres, terminals, etc.) as well as links (information and transportation links).

Afterwards – within phase 2 - the system to be considered has to be specified within the simulation environment. In this context the so-called conceptual model will be built by combining and specialising the objects offered by the system. In order to make models more realistic, some systems offers data mining functionalities which can be applied e.g. for identifying distribution functions representing certain aspects within the model which fits best related to available real life data. Usually the modelling process is supported by user friendly graphical interfaces targeting in particular the requirements of domain experts for network modelling. Hereafter the model is ready for execution within the simulation module. While executing the model within the simulator most systems comprises special animation features in order to allow a first overview of model dynamic and furthermore the identification of modelling errors.

Now phase 3 is following where the simulation data gained during model execution are used for the assessment of the underlying model in order to get insights into the relevance of certain model parameters regarding the overall performance. Further insights regarding model behaviour and potential improvements can be extracted here by comparing the results achieved with the other system configurations. All of the conclusions drawn during the analysis phase will be applied later, in order to develop further adaptations of the network model which will be assessed by re-starting the process with model execution.

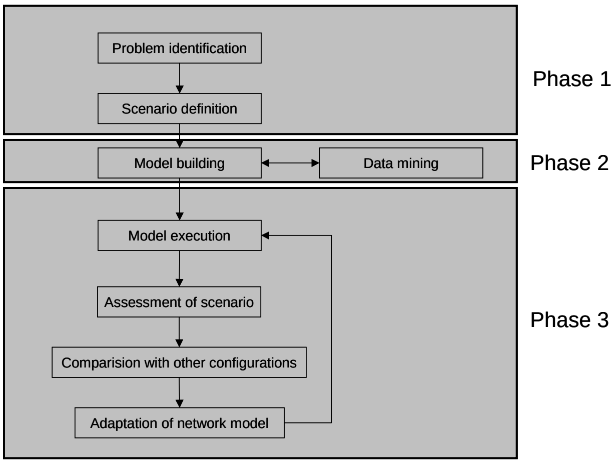

Figure 3: Main steps for simulation-based risk analysis

While following this evolutionary approach the user gets a better understanding regarding the relevance of model parameters and the impact of changes. Based on this knowledge the simulation user develops new, better models which are also verified regarding their effect. The idea is that the models becomes better and better until no further improvement is possible. The result in this context would be an efficient and robust production network which can be established in reality with minimal risks. By playing around with the model parameters representing the different kinds of risk the user can get a deeper understanding regarding the impacts of risk events and whether model adaptations are really necessary in order to ensure the robustness of the network configuration. Furthermore simulation can be applied in order to ensure the effect of such adaptations before implementing them in reality. In the following the ONE tool will be presented. This simulation environment offers several different functional modules supporting all of the steps comprised by phase 2 and 3.

ONE – A SIMULATION TOOL FOR PRODUCTION NETWORKS

In contrast to other tools in the field of production network assessment, design and optimisation the ONE tool [4] addresses risk analysis from the beginning in an integrated way. It aims to offer a holistic and user-friendly approach supporting decision making at the strategic and tactical level with a continuous view on the whole network. In order to fulfil the different requirements coming along with the planning and optimisation of production networks the tool was designed based on several core components interlinked to each other by open and flexible interfaces. The main functionality which is provided by each of these components covers network modelling, simulation and optimisation and is reflected by the system architecture (Figure 4) .

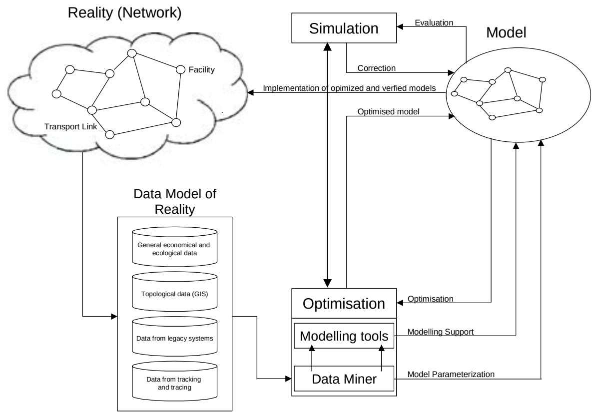

Figure 4: ONE system architecture [5]

It comprises the following modules:

1. The network module aims to provide an user-friendly, interactive approach for the specification of network models. Based on an object-oriented concept a predefined set of parameters is provided covering all relevant aspects of real production networks. These can be specified via a graphical user interface. Relevant risk factors has been smoothly integrated into the object hierarchy offered by this module.
2. The simulation module allows the execution of network models (which has been built using the network module) following the discrete, event-based approach. In order to make the simulation environment as user-friendly as possible this component offers further functionality supporting the simulation control, visualisation and simulation data analysis. By offering graphical control panels as well as predefined charts in combination with user-friendly concepts for data selection and analysis the ONE tool enables domain experts to make use of simulation.
3. The optimisation module provides a set of optimisation methods (including mathematical as well as genetic algorithms) in order to support the user identifying most

efficient network configurations. While formal approaches are difficult to apply due to the mathematical models they are based on the focus is put on evolutionary approaches here. After applying this genetic, evolutionary approach to some existing problems (e.g. the supplier selection problem, which can be formulated in a single as well as multi-objective way by addressing not only costs but also quality of service) it seems to be quite promising.

4. Finally the statistical data miner offers a set of methods in order to enrich network models with real-life data for making them more realistic. Basic functionality here is the derivation of appropriate distribution functions based on existing data.

All of the modules depicted above aims to provide a user-friendly approach supporting a continuous simulation-based planning and optimisation of production networks. In order to give an impression of how the tool can be used for simulation-based risk management its application will be presented with some screenshots in the following section.

APPLYING ONE FOR RISK MANAGEMENT IN PRODUCTION NETWORKS

In this context the first step covers the specification of a model of the network to be investigated regarding certain problems e.g. the supplier selection problem under consideration of specific risks.

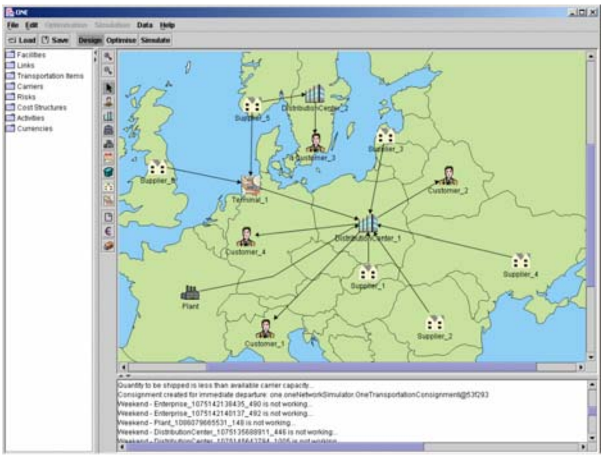

Figure 5: Model of a production network [5]

Figure 5 shows the modelling panel where such a model was already specified. Here we find several different facilities (or nodes) representing customers, plants, suppliers, distributions centres and terminals. All of them are interconnected by several links representing transportation links. All of these visible parts comprises further information to be specified within specific dialogs which are opened after double-clicking on them. In addition the model comprises various non-visible parts as – among other things – detailed information about the products to be moved through the network.

Risk factors belongs to these invisible parts. They are associated to various aspects of the system whereas (as already mentioned) internal risks are distinguished from external ones. While external risk factors represents events affecting a region and therefore several facilities like strikes or natural disasters internal risk factors covers uncertainties related to processes. Therefore they can occur within transportation (accidents, traffic jams, etc.) production, warehousing and many other places. However all of the different kinds of risks have two things in common:

1. A certain probability for their occurrence.
2. A consequence which is expressed as a penalty regarding time (delay) and money (costs).

How to specify this for an internal risk factor within ONE is shown below (Figure 6) for the specification of the risk of an order cancellation for a product ordered by a certain customer.

Figure 6: Specification of internal risks

Here the probability is specified in the range between 0.0 and 100.0 percent whereas the consequence is specified in a delay and additional costs representing the costs for transportation and warehousing of the product until it can be sold to somebody else.

In addition to these aspects external risk factors comprises the duration they are active (e.g. the time a strike holds on). These risk factors are not associated to a certain facility or process and will be therefore specified globally for the whole network. Figure 7 shows the specification for this kind of risk within the ONE network module.

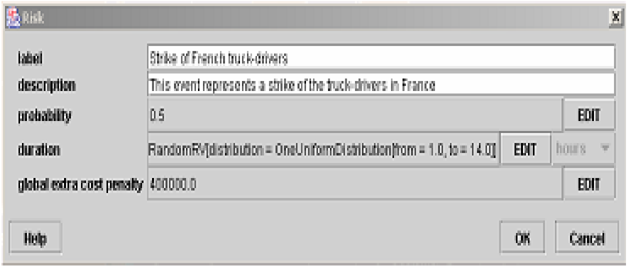

Figure 7: Specification of external risks [5]

The dialog on the left top of the modelling surface contains all of the external risk factors within the given model. The other dialogs around allows the specification of probability, duration and penalty.

After the network modelling phase is finished the model can be executed within the simulator whereas a given model will be usually executed several times in order to get deeper insights regarding the impact of variable parameters (the stochastic elements). Afterwards the data gained through simulation will be analysed using the graphical components offered by the system. Now the impacts and effects of the different kinds of risks can be estimated and decisions related to acceptance of further optimisation can take place.

OUTLOOK AND CONCLUSION

While looking for tools supporting risk management simulation generally is a good choice. Especially due to the opportunity of investigating even complex structures as well as for the possibility to consider stochastic aspects simulation offers certain advantages to other approaches (e.g. mathematical programming, FMEA etc.). Most of these approaches cannot deal with the complexity of production networks while others does not consider the variability of risk factors in a sufficient manner. However most of the simulation environments which are available today are not user-friendly enough in order to enable domain experts to apply simulation for their planning processes. Others do not support risk related to production networks properly. ONE combines both of these requirements and offers a user-friendly simulation environment which explicitly addresses risk management for production networks. In this context the paper gave an overview about the problems and risks as well as their impacts coming along with production networks, the advantages of simulation and how simulation can be applied in order to support risk analysis.

Due to the demand for highly adaptive, flexible and – at the same time - efficient network structures new and innovative concepts are under discussion especially in the field of transportation. In this context a promising approach is currently under research in the Collaborative Research Centre 637 [6]. Here the concept of autonomous cooperating logistics process are investigated regarding its feasibility and limitations. Due to the autonomy of the entities within such structures risk becomes an important aspect in order to foster the confidence in such self-controlled environments. Therefore appropriate ways for risk management has to be explored and adapted whereas simulation can again be good candidate to support this task.

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