Simulation-based risk analysis in production networks

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Abstract

Customer-driven markets, decreasing product life cycles and the demand for innovative custom tailored products are the main reasons for the evolution from single enterprises with a high vertical range of manufacture towards production networks. By utilising the basic experience of each of the involved partners such networks allow the fabrication of products in an individual, efficient and cheap way and therefore increase the competitiveness of the involved enterprises.

Due to the multitude of different entities and their complex interrelations, risk is an omnipresent factor and has to be carefully considered for the planning and operation of production networks which have to be efficient and robust at the same time. In this context robustness means the resistance of networks against unexpected events like suddenly decreasing customer demands, accidents during transportation, breakdown of production or warehousing facilities, natural disasters or wars which can dramatically decrease their overall performance. Thus in addition to efficiency in terms of costs, lead times, etc. the robustness has become a crucial aspect for the configuration of high-performance production networks.

The article describes the application of a simulation environment which is part of the ONE toolset [1] supporting the planning of efficient and robust enterprise networks. Based on the underlying ONE Network Model relevant risk factors related to processes (transportation, production, ordering, etc.) or parts of the network topology (natural disasters, wars, strikes, etc.) can be specified, simulated and analysed. In addition to a basic model assessment, the insights regarding the dynamic model behaviour which can be extracted from the simulation are also used to find better solutions and appropriate model adaptations.

Keywords: risk analysis, simulation, risk modelling, production networks.
1 Introduction

In order to succeed in today’s competitive markets within a global economy companies are forced to improve their quality of service by providing innovative, high-quality products and/or services to the customers faster, cheaper and better than the competitors do. While formerly the paradigm of independency was seen as one of the best ways in order to ensure the economical success it is nowadays the collaboration between enterprises which promises improvements regarding efficiency, excellence, adaptability and flexibility (see Engelbrecht [2]).

While on the one hand such distributed environments offers new opportunities for all of its partners they are usually coming along with a wide variety of risks on different levels which have to be taken into account in order to ensure an economical success. Figure 1 shows an example of a very small production network and the different risk factors which can effect the overall performance.

![Diagram of production network with risk factors](image)

Figure 1: Risk factor within production networks.

Basically such distributed environments contain specific risk factors which are related to different types of facilities (plants, production lines, distributions centres, warehouses, terminals, etc.) as well as links (for transportation or information) where these risks are associated to processes (production of scrap, warehouse damage, wrong dispatching, information loss, or accidents during transportation). Whenever such a risk factor becomes reality it will result in
delays (e.g. after an accident happened during the delivery of an order) and/or additional costs (e.g. organisation of a new carrier, reloading, etc.). In contrast to these internal risk factors there are also external (global and regional) ones affecting one or more network objects (facilities or links) at the same time. Examples for such risk factors comprises strikes or natural disasters usually influences all of the objects within a certain region.

Under consideration of the significant number of potential risk factors which has to be considered within production networks, risk analysis is a crucial point in order to ensure the performance of a given network configuration and thus the economical success for the involved companies.

In general risk analysis is broadly defined to include risk assessment, risk characterization, risk communication, risk management and policies relating to risk. In this context the main objective covers the evaluation of risks resulting from past, current, or anticipated, future activities within the sector which is currently addressed, whereas risk analysis focuses on providing relevant information and determining possible measurements to identify and finally avoid or reduce risks.

For all of the tasks mentioned above simulation is a well suited approach because it allows the evaluation of the dynamic behaviour of a given system represented by the model. If the underlying model reflects relevant risk factors their impact can be evaluated. Furthermore possible network adaptations or measurements can be verified and tested before implementing them in reality.

2 Why simulation?

In general simulation can be considered as a suitable and broadly accepted approach in order to deal with the planning problems coming along with complex systems as production networks usually are (Chang and Makatsoris [3]) whereas the advantages can be summarised as follows:

- Simulation helps to understand the dynamic of systems
- 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.

Beside the fact that there are nearly no limitations regarding the complexity of the system to be treated it is mainly the integration of stochastic elements which makes the simulation unique against other approaches for system evaluation and planning. This variability of certain model elements which can be achieved by stochastic elements explicitly supports the evaluation regarding the effects of risk factors. In combination with the execution of what-if scenarios of virtual as well as real systems simulation further supports their planning and optimisation
under consideration of uncertainties and risks. Thus simulation can be seen as a perfect tool in the field of risk analysis.

Today there is a wide variety of different simulation environments available whereas the range starts with libraries offering functionality for the realisation of systems on the level of programming languages. In addition a wide range of general purpose simulation environments are available supporting the modelling, simulation execution and analysis of simulation data for arbitrary systems by offering a user friendly platform. Finally there are simulation environments covering a specific type of system. Although these environments focuses on specific kinds of systems they usually offer the highest degree of user-friendliness and therefore enable even domain experts to make use of simulation which is often reserved to simulation experts. But although simulation generally allows the treatment of risk the available tools are not necessarily suitable for risk analysis. In order to enable simulation for this purpose risk has to be smoothly integrated into the underlying economic models for the simulation. In contrast existing simulation environments addressing the field of production networks usually doesn’t consider risk in a suitable way which allows to support the activities mentioned above for the field of risk analysis.

This shortcoming has been addressed in the ONE toolbox. Main components in the ONE toolbox are a network model and a simulator, both of which explicitly support the modelling and simulation of production networks under consideration of risk.

3 The ONE-toolbox

As depicted before it is not enough just to offer the consideration of stochastic elements or variability of certain model parameters for evaluating systems in the context of risk. In order to be useful for risk analysis appropriate tools has to offer the specification of risks as well as their impacts as part of the underlying model.

In contrast to other tools in the field of production network assessment, design and optimisation the ONE tool addresses the risk analysis from the beginning and in an integrated way. It focuses on decision making at the strategic and tactical level and offers a holistic approach with a continuous view on the whole network. Thus the ONE tool supports the consideration of risk over the whole network on different levels.

In order to meet these objectives the ONE toolbox was designed in an open and component-based way whereas different modules has been developed covering statistical data mining, modelling, simulation and optimisation of enterprise networks. The ONE architecture, shown in Figure 2, reflects these functionalities by comprising the following modules:

1. The network module supports an interactive development of network models following an object-oriented approach. By offering a predefined set of parameters all relevant aspects can be specified in a user-friendly
way whereas 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. In addition to simulation execution this component offers further functionality covering the simulation control, visualisation and simulation data analysis. The simulator has been implemented following the discrete, event-based approach.

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.

4. The statistical data miner offers a set of methods in order to enrich network models with real-life data for making them more realistic.

Due to the central role of the model in the field of simulation this paper focuses on the network module containing all information which is required for simulation-based risk analysis of production networks. The following section aims to give a general overview about the application of simulation and the way it is supported by the ONE toolbox.

4  Approach for simulation-based risk analysis

While using the ONE tool for the simulation-based risk analysis of production networks the following steps has to be performed as shown within Figure 3. The first step addresses the identification of the problem. Here the specific kinds of
risk or performance indicators to be investigated within the simulation study are specified. 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).

While these first two steps will be performed outside of the ONE toolbox the model building which follows, requires the ONE Network Module. Here the conceptual model will be built by combining the appropriate objects offered by the system and specifying the associated parameter sets. In order to make models more realistic, functionalities provided by the data mining module can be applied e.g. for identifying distribution functions representing certain aspects within the model which fits best related to available real life data. The modelling process is supported by an object oriented modelling approach in combination with a graphical user interface targeting in particular the requirements of domain experts for network modelling.

Hereafter the developed model is ready for execution within the simulation module. As for the network module the simulator also offers user-friendly graphical components for simulation control, animation and visualisation of simulation data. After model execution the simulation data is used for the assessment of the given 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 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 restarting 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. This will lead to appropriate model adaptations which can be verified
regarding their effect. An automated way of model optimisation or improvement can be realised by utilising the optimisation module as shown in Figure 2. Here the simulator is directly coupled with a genetic algorithm in order to provide information regarding the network efficiency which is used internally for the evolutionary optimisation process (see Ding et al. [4]). This approach allows the simulation-based optimisation of productions networks under consideration of risk.

Basically by using the object parameters representing risks 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 the tool can be used in order to ensure the effect of such adaptations before implementing them in reality. The case study presented below aims to illustrate the application of the ONE tool focussing on the modelling while conducting a simulation-based risk analysis.

5 An example

In the following the interaction with the tool will be demonstrated via several screenshots.

Figure 4 shows the modelling area offered by the ONE Network Module after building the associated network model. The scenario which is presented here represents a very simple model comprising several customer objects reflecting the demand for certain products as well as two distribution centres delivering these orders which will be delivered by several supplier objects as well as a plant which allows a more detailed consideration of production processes within the model. For the delivery of the British and Scandinavian suppliers a multi-modal logistic chain was modelled by adding a terminal object which is coming along with some further risk elements. The problem which can be faced by such a model mainly addresses the identification of the most efficient combination of suppliers under consideration of costs and customer service level considering specific risks resulting from different candidates located in various places. Having in mind the various risk factors which were presented within Figure 1, there is a significant number of factors which can cause the occurrence of different risk events all of which reduces the efficiency of the production network regarding the key performance indicators like costs or customer service level.

After specifying the required objects their parameter sets have to be defined. For this purpose the network module offers object-specific dialogs containing the attribute set for each of the different object types.

For the description of risk the ONE Network Module follows the approach which was depicted before by allowing the specification of predefined internal risks as well as external risks which can be added by the user. An example of an internal risk which is called “uncertainty of order cancellation” can be specified for customer objects.

This risk factor is generally available for all of the customer objects which are used for modelling and it depends on the modeller whether it will be considered
within simulation by setting the probability of occurrence to a value greater than zero whereas this value reflects a percentage and therefore ranges from 0.0 to 100.0. All of these internal risk factors are hard-wired within the underlying object model. While specifying such a risk factor it’s consequence (or impact) will be described in terms of delays and additional costs.

![Modelling surface showing the network topology.](image)

Figure 4: Modelling surface showing the network topology.

In contrast to these pre-defined risks the ONE Network Model supports the specification of user-defined risk factors. Although these are restricted to the category of external risks they allow a sophisticated specification of user-defined risk factors within network models which can be considered during simulation. presents the definition of such an external risk within ONE. As shown here the attributes to be specified for a external risk event comprise it’s probability, it’s duration after it occurs and the direct impact which is described in terms of additional costs caused by the risk.

Other than for internal risks which are more or less independent external risks are usually further coupled to other numerical values. This is realised by specifying the change of values whenever a certain external risk is active whereas this time of activity covers the timespan from it’s beginning up to the time which was specified as duration. The risk of a strike of French truck drivers (as specified within ) can be used now in order model specific changes of the numerical value reflecting additional costs e.g. related to the transportation link between the French plant and the distribution centre located in Poland. The meaning is that whenever the risk “Strike of French truck drivers” is active
during simulation the value for the parameter representing additional costs related to the transportation will change according the value specified before by the user. In addition the value specified as “global extra cost penalty” will be added to the overall costs caused by the model. If the risk is not active while a transportation process will be simulated then the value which has been specified as the normal one will be taken.

Figure 5: Specification of risk events.

After building the model it can be executed within the ONE Network Simulator whereas the system performance can be evaluated regarding different key performance indicators like overall costs or customer service levels. Due to the specification of risk impacts in terms of costs and delays each occurrence of a risk factor directly affects these performance indicators. In addition the simulator allows the monitoring of the occurrence of risk events within the model.

6 Conclusion

It was shown that simulation generally is a good choice while looking for tools supporting risk analysis and management for the development of robust production networks. Unfortunately most of existing simulators in the field of production networks do not consider risk. Therefore they are not suited for risk analysis. In contrast to them the ONE tool explicitly addresses risk. The paper gave an overview of how simulation can be applied supporting risk analysis.
Furthermore the integration of risk within the ONE tool was described in more detail.

Due to the increasing complexity of production networks as well as stronger requirements regarding their adaptivity new innovative solutions are investigated in order to find concepts offering more flexibility and efficiency at the same time. A promising approach in this context is represented by self controlled logistics processes which are currently investigated by the research initiative “Sonderforschungsbereich 637” [5]. Due to the autonomy of the entities within such networks new kinds of risk arises which has to be carefully explored. In order to foster the confidence into such self-controlled environments appropriate concepts and tools for risk analysis have to be investigated and developed whereas the advantages of simulation could be used in order to realise innovative and reliable solutions.

References