Abstract Number: 015-0668

A Comparison of Quantitative Methods in Supply Chain Risk Management – Benefits and Drawbacks

Dipl.-Wi.-Ing. Gandolf R. Finke[a], Dipl.-Wi.-Ing. Alexander Sproedt[a] and Dipl.-Wi.-Ing. Johannes F. Plehn [a]

[a] *ETH Zürich, BWI Center for Enterprise Science, Kreuzplatz 5, Zürich, 8032, Switzerland,*
Email: {gfinke@ethz.ch, asproedt@ethz.ch, jplehn@ethz.ch }

POMS 21st Annual Conference

Vancouver, Canada

May 7 to May 10, 2010

Abstract

Supply chain risk management (SCRM) is gaining increasing attention. In practical, industrial application of SCRM, qualitative techniques strongly dominate. To support decision making related to SCRs and to include all available information, the paper argues for the additional use of quantitative methods as a logical continuation of qualitative approaches. However, acceptance of quantitative methods by practitioners is relatively low. This paper aims at exploring possible underlying reasons by analyzing the benefits and drawbacks of quantitative methods, and making suggestions as to how their acceptance in industry might be increased. Besides other methods, the authors focus in particular on different simulation techniques currently available as one way of including quantitative data in SCRM. Furthermore, the different simulation techniques are described, and aspects of implementation such as the different barriers of introduction or underlying assumptions are outlined. The paper ultimately concludes with an overall evaluation of the concept of simulation in SCRM.

Keywords: Quantitative Supply Chain Risk Management, Risk Assessment, Acceptance, Simulation, Discrete Event Simulation

1. Introduction and Background

This paper is intended to introduce the reader into the subject of quantitative Supply Chain Risk Management (SCRM). Although much progress in both research and practical implementation of SCRM techniques was achieved within the last decade, it still constitutes a comparatively young field. The paper starts with providing background information on the research field and necessary qualitative aspects. Following this, the paper outlines reasons for the use of quantitative methods before presenting and evaluating a selection of these methods. The paper concludes in the fourth and fifth section with a discussion of the acceptance of these tools and an outlook respectively.

Qualitative Background

Clearly, the focus of past research was on the qualitative aspects of SCRM. There are a number of tools, methods and process models developed of which just a few shall be named in this section. Jüttner, Peck et. al. (2003) have outlined an agenda for research topics to be addressed in this field and provided definitions and structural background for this area. They also included four risk mitigation strategies: avoidance, control, co-operation and flexibility as a means of managing the identified risks.

Further research with more focus on practical risk assessment can be found in e.g. Zsidisin, Ellram et al. (2004) with a more qualitative approach. Zsidisin's et al.'s research also shows the importance of risk assessment as an integral part of risk management. We strongly agree with this viewpoint and are therefore in the course of this paper more concerned with the risk assessment side rather than mitigation strategies when mentioning SCRM.

Oehmen et al. (2009) introduce two interrelated qualitative modeling approaches to identify, assess and model dynamics of supply chain risk factors. The quantitative aspects and methods that will be introduced in later sections generally have to be based on such or similar models in order to identify the appropriate risks to be included in the quantitative tools. Qualitative tools and methods therefore constitute the necessary basis for a quantitative analysis.

Why use quantitative approaches?

As Tayur et. Al. (1999) already stated, "*there is no doubt of the importance of quantitative models and computer based tools in decision making in today's business environment*". As his work further states, this holds especially true for today's increasingly complex and global supply chains.

There are several advantages that accompany the use of general quantitative methods in SCRM. First of all, these techniques represent a way to support managerial decision making. Relevant data that is available in a quantitative format can be included in the management process and therefore improve decision making. This of course also holds true, even if not used in a holistic approach but rather for specific detailed questions in risk management. The quantitative analysis furthermore enhances the transparency of management decisions and provides traceability and objectivity for the policies of those in charge of SCRM.

Additionally, the use of quantitative methods on a broader scale allows for quantitatively grounded comparisons. These comparisons could for example consist of different locations and their risk exposure, different business units of the same company, as a benchmark between business units of different companies or comparing different technologies, methods or techniques to be implemented.

Other positive aspects of using quantified data are the possibilities that have arisen with the advancement of computer technology. Data processing, combination, complex modeling and calculations can be done within seconds and even the less proficient user is enabled to conduct sophisticated analyses with today's available software. Qualitative data is as such and with the present state of computer technology much harder to process automatically to enable its use in automated risk management decisions support systems.

2. A selection of quantitative methods

The following selection of quantitative methods by no means claims to be complete nor is it intended to cover all different classes of such methods. The interested reader shall be introduced to the selected methods and be provided with a basic understanding of functionality and use of each method in SCRM.

Decision Tree Analysis

A very basic entrance to the enchanting world of quantitative SCRM tools is the Decision Tree Analysis as introduced by Waters (2007). Through quantified probabilities and losses, the different effects of a given number of a decision lead to a certain outcome for each decision taken. Of course, this tool does not provide any real supply chain risk assessment but brings the reader closer to the basic factors of risk: frequency and severity.

The tool is overall highly inaccurate and originally designed for a different purpose, i.e. to evaluate between different options with regards to risk and not to assess the risk itself. In fact, it requires the risk exposure as an input in quantitative form limiting its use for our purposes. Furthermore, only a fixed number of decisions can be included in the analysis which brings it close to our next method, scenario analysis and stress testing.

Scenario Analysis and Stress Testing

The following section on scenario analysis and stress testing is adapted from Finke and Nägele (2009): Scenario analysis and stress testing are methods with the purpose of identifying effects and the impact that changes in certain parameters have on a firm's or supply chain's operational performance. Both focus mainly on less frequent but high impact incidences (LFHI), such as catastrophic events. They do not include any mechanism to estimate frequency but instead only use severity as a risk "indicator" which makes them therefore only one-dimensional in terms of risk assessment (Marshall 2001).

The basic idea of scenario analysis used in SCRM is to quantify the loss or effect of certain situations or events. By applying scenario analysis, a specific future situation for a company or supply chain is modeled with all the factors that have influence on the supply chain's business environment. Normally, this includes identifying and incorporating all consequences.

The assessment starts with the identification of a potential set of events which can affect operational performance. Subsequently, consequences of these events are estimated by analyzing how the firm would react in certain situations. This can include, among others, an investigation of recovery and back-up options or supply chain flexibility. Following this, the overall loss caused by the identified events is derived to indicate how heavily the firm would be impacted. In stress testing, only one parameter or a small number of closely related parameters is changed in order to analyze its effect on the company's returns. Stress testing is therefore less related to an actual future situation but can be used to analyze the dependency of performance on a specific parameter and related changes. Stress testing can also be used as a means to validate models by showing dependencies and performing sensitivity analysis.

A clear advantage of both, scenario analysis and stress testing over other techniques is the fact that scenarios that have not yet been observed or that are highly unlikely to happen can be incorporated. The effect of a LFHI event on the company can be simulated and consequences for the supply chain can be demonstrated. Also, external and internal events can be used as an input for the model. This exercise can thus serve as an inspiration to design mitigation strategies and contingency plans for unlikely, severe events. Obviously, any expert opinion based estimation relies on subjective assessment. Whether a certain event is considered in the analysis or not can be of arbitrary nature. This includes the estimation of its probability, severity and its relevance for the company's performance.

This leads to the conclusion that scenario analysis and stress testing represent a rather incomprehensive, subjective assessment due to their ability to only incorporate a limited loss horizon in terms of the variety of events that are included and due to uncertainty involved in the analysis process itself. All of which restricts the use of such concepts with regard to comprehensively assess supply chain risk in a quantitative way. Furthermore, the challenge when using these tools consists of first, objectively assessing also events that have not been considered before and second, picking the right events, showing relevance to the actual risk environment of the company in terms of probability and impact.

Overall, scenario analysis represents a tool that can be suitable to assess the behavior and consequences of a supply chain, given certain events but does not provide a tool to quantify supply chain risk exposure comprehensively. It can rather be regarded as a method that could be used within a certain tool such as simulation.

Fuzzy Logic

Fuzzy Logic is a form of multi value logic originally developed to model inexact linguistic descriptions. As opposite to Boolean Logic, Fuzzy Logic allows not only true and false as values, but different degrees of truth. It has emerged from the idea of emulating human thought and reasoning processes, which makes it applicable especially when dealing with qualitative, inexact and uncertain problems (Ko, Tiwari et al. 2009).

Fuzzy Logic provides a mathematical framework to represent uncertainty in decision making processes with underlying imprecise or lack of information. In a mathematical programming model, fuzzy numbers are introduced to reflect uncertainty, while constraints associated with these are further treated as fuzzy sets. A membership function defines the degree of satisfaction of a constraint, therefore allowing a small extent of constraint violation represented by its value. The advantage of modeling uncertainty using the Fuzzy Logic approach rather than other methods lies in the fact that Fuzzy Logic does not assume any statistical distribution for the uncertainty parameters and a model's complexity is relatively low even when introducing a large amount of uncertain parameters (Mitra, Gudi et al. 2009).

Through Fuzzy Logic it is possible to translate an inexact, non-deterministic input into a deterministic output. This is the reason for it being widely spread, i.e. for the control of air conditioners, elevators or a car's ABS. Within the area of Supply Chain Management, there are various applications for Fuzzy Logic as well. Over the last years, many mathematical models have been developed for supply chain design, supplier selection, capacity planning, warehouse location problems and others (i.e. (Wang and Shu 2005; Lee 2009; Mitra, Gudi et al. 2009; Peidro, Mula et al. 2010; Wu, Zhang et al. 2010)). In these models, fuzzy numbers are used to represent uncertainty in parameters like product demands, machine uptimes, safety targets, delivery times or capacity. Fuzzy Logic thus represents a tool that may well be used within the risk assessment process but does not assess the supply chain risk's exposure as a whole.

Artificial Neural Networks

Artificial Neural Networks (ANNs) are information processing systems inspired by the behavior and architecture of biological nervous systems such as the human or animal brain. ANNs consist of a number of strongly interconnected non-linear processing units, the neurons, acting as mathematical operators performing specific operations (Ko, Tiwari et al. 2009). The network is designed in a way to match the problem to be solved. The most distinctive feature of ANNs is their ability to "learn". After its construction, the ANN can be trained to solve a specific problem by feeding it with examples. The ANN will learn how to treat any input data to generate the desired output, even when the dataset is complex or imprecise (Luo, Wu et al. 2009). With their ability to learn, ANNs are often considered as a basic element for artificial intelligence (Ko, Tiwari et al. 2009).

ANNs have been proven to be very effective especially for solving complex classification and regression problems. They handle non-linearity between input and output variables and are proven to be able to approximate any mathematical function under certain conditions (Aburto and Weber 2007). As such, they can be trained to recognize non-trivial patterns in complex datasets (Ko, Tiwari et al. 2009). Based on these capacities, ANNs are particularly useful for time series predictions, such as stock exchange indexes or exchange rates (Aburto and Weber 2007).

Within the area of Supply Chain Management, ANNs have been used to design intelligent supplier relationship management systems, sales and material demand forecasting, particularly aiming at reducing the bullwhip effect, supplier selection and to support the supply chain planning process e.g. (Aburto and Weber 2007; Gumus, Guneri et al. 2009; Ko, Tiwari et al. 2009; Luo, Wu et al. 2009). Within the domain of Supply Chain Risk Management, ANNs are particularly useful for the development of early warning systems. Again, ANNs also represent a tool that could be an integrated part of an overall supply chain's risk assessment.

Simulation

The popularity of the concept of simulation has experienced an enormous boost in recent years. This is, among other factors, due to the advancement of computer technology and the availability and ease of use of the corresponding software and programs. However, there are very different kinds of simulations, some of which we will introduce in this part of the paper.

The first type of simulation is Monte Carlo simulation. Used in SCRM, this simulation combines values chosen from two probability functions and provides one resulting probability function. Miller and Engemann (2008) show how this method can be used to model and simulate natural disaster risk across a whole supply chain. The clear advantage of this method is its ease of use and implementation. However, also the use of the tool is limited as the analysis carried out only focuses on disruption risk. The assumptions such as independence of disruptions are strong. Transferring this method to include all relevant risk factors and to overcome the underlying limiting assumptions seems difficult and would make the method very intransparent for users.

Kleijnen (2005) names four other simulation techniques. First he mentions spreadsheet simulation. Commonly used, spreadsheet simulation describes a fairly simple yet effective simulation tool. However, as before, the simplicity comes along with a limited use.

In his paper, Kleijnen (2005) next mentions System Dynamics as a simulation technique. Originally developed by Jay Forrester to be used in engineering sciences it is gaining increasing popularity in other fields too (Shah 2001).

“System dynamics is [not only] a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems [but it] is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations”(Sterman 2000).

System dynamics is a method to evaluate the interrelation between different factors and influences on an overall system. A major role is played by feedback loops which determine how factors are in turn affected by the system state. Models can be highly complex but the use seems inappropriate due to the structure of inputting data and the overall transparency of the tool.

Third, the simulation concept of business games is mentioned. Due to the obvious imperfection of the method it shall only be referred to here for the sake of completion. By no means can the results of a business game, though otherwise maybe valuable information, be used to achieve an accurate supply chain risk assessment. It may well be used for parts of the assessment but does not constitute a holistic approach.

Last, Kleijnen (2005) names the concept of Discrete-Event (DE) simulation. Zsidisin and Ritchie (2008) show how DE-simulation can be used for risk assessment of supply chain disruptions. The model of Zsidisin and Ritchie (the book chapter is actually written by Melnyk, Rodrigues and Ragatz) is a very useful and appropriate use of DE-simulation. However, in their model certain aspects of supply chain risks have not been accounted for such as buffers, variations in lead times or a shift in demand. This is only consequent when trying to analyze the risk exposure from disruptions of the supply chain.

A more advanced model and its practical implementation are discussed by Schmitt and Singh (2009) in their paper on supply chain disruptions. The underlying network of the DE simulation model is given below.

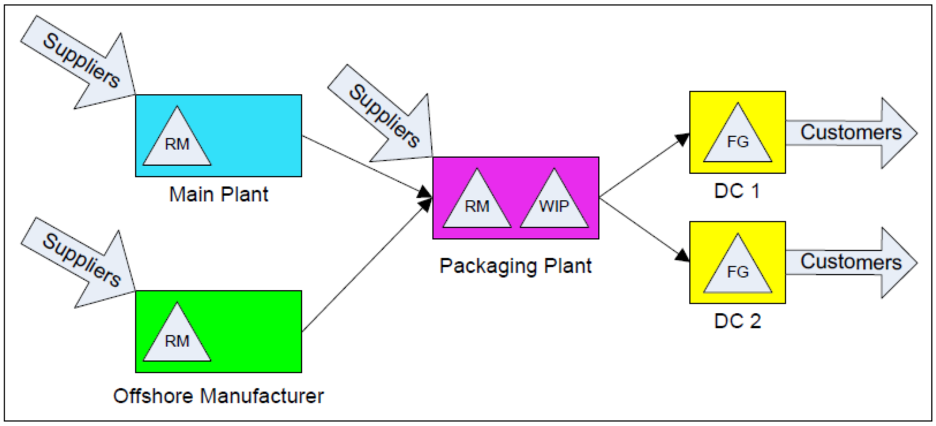

Fig. 1: Underlying network for Discrete-Event simulation model.

Source: Schmitt and Singh (2009)

The model proposed here is able to cope with different types of disruptions, randomly occurring and even covers the aspect of demand variations. The overall measured unit is the fill-rate of orders, i.e. the service level. The model also allows for an analysis of the effect of additional inventory, capacity etc. Thus it is of great value even in the decision-making process and strategic risk mitigation as the consequences of concrete measures can be analyzed, i.e. scenario analysis can be implemented with this method.

3. Evaluation

This section is intended to outline the drawbacks and benefits of the above mentioned SCRM methods with regards to the overall goal of supporting decision making related to supply chain risks. As in the previous section, this evaluation has a special focus on computer simulation techniques, in particular Discrete Event simulation. Initially, the drawbacks are discussed, followed by benefits and an overall summary of the evaluation

Drawbacks

As one of the most important drawbacks of quantitative methods, and simulation in particular, is the necessity for data availability. Depending on the effort to collect the relevant parameters' data and the complexity and number of parameters used in each method, this effort will constitute a significant workload for the company and thus related costs. This investment decision should of course always consider the relation to the use of the results in decision making. We will return to this topic in a later section on the acceptance and spread of these systems.

Another aspect related to the data issue is the fact that it is possible that certain required data might not even be existent or possible to collect. It might also be that data format or granularity is inappropriate for the use in a SCRM method. This drawback should be accounted for by selecting only those parameters that are known to be available and accessible in the right format with an effort that corresponds to the use of the tool.

Consistent collecting and monitoring requires a formalized process in order to ensure comparability of the collected data. The use of inconsistently collected data is strongly limited. Accuracy, units and measurement or collection process should be documented and well communicated to align all involved people. This is especially important the more comprehensive and outreaching the data collection efforts are, e.g. the more tiers of a supply chain are covered or the larger the company covering many different locations. To conclude the subject of data collection and availability one should be reminded that the results of every model can only be as exact as its input parameters.

Additionally, there is another effort which must not be neglected for a useful quantitative SCRM tool to be in place. Particularly for simulation models – of course, depending on the complexity of the model – the modeling effort will as well depict a significant workload. However, one should consider that once a model has been created, it will usually only require minor reconfiguration and therefore little modeling effort in the long term. The authors believe it to be advisable to not change the existing tools constantly as management processes and decision makers need to adapt and get used to the respective tool. Also, tools are embedded in a risk management process that needs to be consistent in itself – changes to the tool may require changes to the whole process and vice-versa.

Last, due to the complexity and number of influencing parameters in some simulation models, a loss of transparency becomes apparent. Since this complicates the traceability or detection of errors in the model, special emphasis on model validation shall be exerted. Again, also this topic will be discussed in the section on acceptance of quantitative methods in SCRM.

Benefits

Having mentioned the downside of quantitative risk management tools and methods in Supply Chain Management, the authors will now introduce the interested reader to the advantages and positive aspects of the above mentioned tools.

First and foremost, quantitative methods enable decision makers to base their management policies on reliable results and data analysis. Supported by computer technology and the technological advancement of the last decades enable the highly complex calculations and combinations of input parameters to be carried out in seconds. Making use of these possibilities is highly advised by the authors.

The second benefit is more focused on the concept of simulation models and here particularly the Discrete Event simulation technique: Discrete Event simulation provides a basis to simulate many different indicators or units of measurement such as Key Performance Indicators KPIs, inventory levels, machine and resource utilization, down-time and service level measurements all at the same time. This allows a view of the overall picture and gives the user an overview of and a feeling for the interrelations between these aspects. The technique further allows for monitoring and extensive data collection of system parameters over the simulation time and therefore enables decision making not only based on expected values but on whole probability distributions. Additionally, DE simulation is able to incorporate information on different levels for decision support – making its use even more flexible.

Furthermore, a formalized process of data collection, processing and analysis ensures everything that is necessary has been included and sufficient analysis has been carried out to make decision regarding a certain topic. Using purely qualitative risk management tools, it is easier to work without having included all available information, as the decision maker might feel confident about a specific topic and therefore not collect, potentially important, further data.

Simulation also enables the user to test the supply chain’s behavior in certain situations that have not yet occurred, i.e. to carry out scenario analysis using the model. The authors believe that the hereby mentioned benefits of quantitative methods in SCRM outweigh the drawbacks and therefore strongly recommend the use and further development of these tools in practical industrial implementation.

4. Acceptance of quantitative SCRM methods

The acceptance of quantitative SCRM methods by industry is another related issue to be emphasized in this research. This section is split into two parts: First, describing the reasons for the limited dissemination and second, strategies to increase this acceptance.

Reasons for the limited spread

Despite all above stated benefits and advantages of implementation of quantitative methods in SCRM, these methods are not yet experiencing much popularity in industrial application. As briefly mentioned in the first part of this paper, qualitative techniques still dominate and provide the basis for most decisions regarding SCRM. The authors strongly agree that the qualitative aspect of risk management in supply chains is an important basis that must not be neglected. However including quantified data in the analysis allows for several improvements in risk management as outlined in section one.

Since the advantages of its use have been clearly stated the reader may rightly ask what the reasons for the less common implementation of these concepts are. This issue is discussed in this section of the paper. We will initially name reasons for the lacking popularity and subsequently derive strategies for researchers and industry to circumvent these barriers in order to be able to use the above stated advantages of quantitative methods. The authors have identified five main causes for the less wide spread of quantitative methods:

First, as already mentioned in preceding chapters, there is a critical amount of data necessary in order to support higher level decisions in SCRM. For more important decisions, data collection efforts might be more justifiable but it still poses an additional challenge to collect the information in a quantified format. Additionally it is of utmost importance to know which kind of information should be collected and monitored on a constant basis in order for the appropriate and most effective method to be implemented and used. A database of events, effects and according losses would be an example which would have to be constantly updated and maintained.

Yet another reason for the small spread of quantitative SCRM tools is the lack of integration of the above mentioned techniques into decision making and management processes in general. There appears to be a significant gap consisting in the lack of defined management processes including qualitative and quantitative SCRM tools. Without such defined processes or process models, the application of quantitative methods is likely to be only selective and less constant. This in turn also has a consequence on the continuative development of tools and methods as a constant and widespread use would lead to more attention of this field from all sides.

Third, the authors would like to mention a psychological reason. Although context, results and methodological procedure of quantitative methods such as simulation might seem clear and evident to those who designed the model or method, the transparency is not necessarily shared by all users. This implies a certain lack of trust and degree of skepticism on the management side towards methods that are not entirely comprehendible or transparent to them which might be particularly true for the more complex models. This apparent lack of transparency of the method itself is not to be confused with the transparency and traceability of management decision making mentioned as an advantage in previous sections.

Next, the authors believe that the size of a company plays a significant role for the implementation of quantitative methods. Large corporations are more likely to invest into more sophisticated tools for SCRM and thus be able to leverage their advantage. Small companies, on the other hand, might possess more flexibility to adapt to sudden changes and thus not rely as much on extensive risk management approaches or at least believe to possess this flexibility. The authors however believe that the need for active SCRM arises with the complexity, global interdependence and structure of the supply chain rather than the size of an organization.

Last, another factor negatively affecting the spreading of quantitative SCRM methods deals with the comprehensiveness of the analysis. The more tiers and supply chain partners that are willing to actively engage in a holistic approach for SCRM, the more useful the results are. This means that quantitative analysis is better the more it covers of the supply chain in detail. Although companies are growing closer together and starting to share data for collective Supply Chain Management, a critical level is still not met where companies are usually cooperating intensively enough. Risk data may contain highly sensitive information and are therefore only shared with hesitation if at all. We believe that all the above mentioned factors have and still are contributing to barriers of implementing and spreading for quantitative SCRM.

How can acceptance be increased?

Having described different quantitative methods and outlined the predominant positive attributes of quantitative methods in this field we are now discussing ways to increase the popularity of such methods in industrial application.

One way of making these methods more popular is certainly a step-wise approach. The risk manager should be able to work his way from less to more complex models and thus understanding the mechanism and different aspects that can be covered. A step-wise approach where several smaller systems are consecutively combined to more complex models combining all features seems reasonable for this learning. This way, the decision maker can relate better to the tools at hand and thus overcomes the otherwise apparent lack of transparency. At the same time, the analyzed scenarios and used variables should also increase in complexity and number over time in order to further improve the learning process. This introduction step by step is not meant to contradict the aforementioned and propagated continuous use one model in order to get used to it but rather to see as a way of leading the user to one tool to be used on a constant basis.

Another solution might be the use of overall less complex systems in general to portray the different aspects covered by a more complex model. In this case, either a quantitative or qualitative way will have to be found to combine the different results to one recommendation or decision support process. Within all these processes, there should always be a single, appropriate and understandable measure to express the outcome of risk analyses. Being able to communicate the results also plays a key role in spreading the popularity of such methods.

Finally, we believe that the model, tool or method development should not be carried out by researchers alone but with constant feedback from industry. This input guarantees and enhances the use, implementation and transparency of the method from industry perspective. In order to gain further trust, much focus should lie on the validation of these models and the adjustment and 'fine-tuning' of the model's parameters.

5. Conclusion and Outlook

The paper has initially introduced the reader briefly to the background and the more qualitative side of SCRM arguing for the necessity of qualitative methods for the introduction of quantitative ones. This was followed by a set of reasons for the introduction of quantitative tools in general.

In section two, the authors describe a selection of methods and tools to be used in SCRM ranging from Decision Tree Analysis to Discrete-Event simulation. This incomplete overview includes discussions on the practical use and barriers to introduction before evaluating the described approaches in section three. Overall the authors believe that the concept of simulation in SCRM and here particularly the DE-simulation marks a very promising and useful approach to support decision making in SCRM.

The paper concludes with section four focusing on the acceptance of quantitative methods. Reasons for the less wide spread of these tools as well as possible strategies to enhance their implementation in industry are part of this section. Overall the authors believe that simulation promises to be a useful concept in SCRM decision-making. However, there is still a gap existing in the area of integrating methods in management processes and proving the use in industry. Further research is thus necessary to continue developing this important and industry-relevant field.

6. Bibliography

Aburto, L. and R. Weber (2007). "Improved supply chain management based on hybrid demand forecasts." Applied Soft Computing **7**(1): 136-144.

Finke, G. and F. Nägele (2009). Designing an applicable framework to quantify operational risk. CTL, Massachusetts Institute of Technology. Cambridge, Karlsruhe Institute of Technology, KIT.

Gumus, A. T., A. F. Guneri, et al. (2009). "Supply chain network design using an integrated neuro-fuzzy and MILP approach: A comparative design study." Expert Systems with Applications **36**(10): 12570-12577.

Jüttner, U., H. Peck, et al. (2003). "Supply chain risk management: outlining an agenda for future research." International Journal of Logistics: Research & Applications **6**(4): 197-210.

Kleijnen, J. P. C. (2005). "Supply chain simulation tools and techniques: a survey." International Journal of Simulation and Process Modelling **1**: 82-89.

Ko, M., A. Tiwari, et al. (2009). "A review of soft computing applications in supply chain management." Applied Soft Computing **In Press, Corrected Proof**.

Lee, A. H. I. (2009). "A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks." Expert Systems with Applications **36**(2, Part 2): 2879-2893.

Luo, X., C. Wu, et al. (2009). "Supplier selection in agile supply chains: An information-processing model and an illustration." Journal of Purchasing and Supply Management **15**(4): 249-262.

Marshall, C. L. (2001). Measuring and managing operational risks in financial institutions : tools, techniques, and other resources. Singapore.

Miller, H. E. and K. J. Engemann (2008). "A Monte Carlo simulation model of supply chain risk due to natural disasters." International Journal of Technology, Policy and Management **8**: 460-480.

Mitra, K., R. D. Gudi, et al. (2009). "Towards resilient supply chains: Uncertainty analysis using fuzzy mathematical programming." Chemical Engineering Research and Design **87**(7): 967-981.

Oehmen, J., A. Ziegenbein, et al. (2009). "System-oriented supply chain risk management." Production Planning & Control: The Management of Operations **20**(4): 343 - 361.

Peidro, D., J. Mula, et al. (2010). "A fuzzy linear programming based approach for tactical supply chain planning in an uncertainty environment." European Journal of Operational Research **205**(1): 65-80.

Schmitt, A. J. and M. Singh (2009). "A Quantitative Analysis of Disruption Risk in a Multi-Echelon Supply Chain." SSRN eLibrary.

Shah, S. (2001). Operational Risk Management. Casualty Actuarial Society 2001 Seminar on Understanding the Enterprise Risk Management Process, San Francisco.

Sterman, J. (2000). Business dynamics: systems thinking and modeling for a complex world. Boston, Irwin/McGraw-Hill.

Tayur, S. (1999). Quantitative models for supply chain management, Kluwer Academic.

Wang, J. and Y.-F. Shu (2005). "Fuzzy decision modeling for supply chain management." Fuzzy Sets and Systems **150**(1): 107-127.

Waters, D. (2007). Supply chain risk management, Kogan Page.

Wu, D. D., Y. Zhang, et al. (2010). "Fuzzy multi-objective programming for supplier selection and risk modeling: A possibility approach." European Journal of Operational Research **200**(3): 774-787.

Zsidisin, G. A. (2008). Supply chain risk, Springer.

Zsidisin, G. A., L. M. Ellram, et al. (2004). "An analysis of supply risk assessment techniques." International Journal of Physical Distribution & Logistics Management **34**: 397-413.