SIMULATION-BASED RISK MEASUREMENT IN SUPPLY CHAINS

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ABSTRACT

Because of modern supply chains complexity, supply chain managers are presently making decisions which are associated with some risk. This paper discusses risk problem in supply chains and presents a supply chain risk assessment approach. The Beer Game model, which is a simplified example of a supply chain, is used to demonstrate application of the suggested risk assessment approach. Two risk events are taken into account: inventory excessive accumulation and backordering. Simulation experiments with the computerised version of the Beer Game show that the approach presented can be used for assessing supply chain risk; at the same time, it is possible to illustrate risk occurrence using the Beer Game model.

INTRODUCTION

It is self-evident that modern supply chains are becoming very complex. Managers have to organise numerous parallel physical and information flows with the purpose to access the main logistic goals such as right production quantity, right production delivery place, right production delivery time etc. Technology development provides supply chain specialists with more efficient management approaches, which help them minimise inventories, define customer demand more accurately and count other values that considerably reduce logistic costs. As a result of such accurate management, these supply networks become very vulnerable to disruptions and unexpected situations. It is easier to create quite an effective management approach for the case of deterministic systems, where all the input data are known to managers, whereas most of the real-world supply chains systems can only be represented with the help of stochastic models with strongly expressed influence of uncertainty. Unfortunately the uncertainty factor generates risks. Besides, many of the key risk factors in supply network have developed from such pressures as productivity enhancing, waste eliminating, supply chain duplication removing, cost improvement driving etc (Strauffer 2003). But actually, taking decisions aimed to decrease risks event probability, supply chain managers may increase total yields. Still, manager has to use techniques for measuring risk probability.

Due to modern supply networks complexity, it is difficult to get precise values of such risk event probabilities using analytical modelling only. Here, simulation approaches prove to be effective for obtaining adequate information about risks in supply chains. This paper describes the simulation-based approach to assessing risks in the concretised supply chain, which is the Beer Game network. The Beer Game is a widely-known simplified supply chain simulation model, which is used for studying (usually for students) features of information and physical flows distribution in supply networks (Simchi – Levi D. et al. 2003). The main idea of the present paper is to describe supply chain risk assessment approach and its application to the Beer Game model. It should be noted that the work presented is exploratory and the approach described should not be seen as a definite solution for calculating risk values.

BACKGROUND

Before representing the Beer Game model and describing the approach to calculating risk values in it, it is necessary to outline common risks in supply chains. Besides, the following paragraph provides some information about existing researches in the sphere of simulation-based risk management.

Risk Management

According to common definition, risk is the potential harm that may arise from some present process or from some future event. Still, in some cases (spheres) a definition of that kind may not fully represent meaning of risk. Thus, for successful risk management in the determined sphere, it is necessary to specify these meanings: meaning of risk, types of risk and risk measurement approaches (Giniyatov).

Let us present the following supply chain risk definition (according to Assistant Professor of Supply Chain Management at Michigan State University, George Zsidisin): the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety (Clouse and Busch 2003).

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Risk types can be easily described in the form of classification. Still, taking into account the multi-shaped features of risks, it is self-evident that classification performance strongly depends on the decision maker's subjective opinion. Thus, different criteria should be used for different classification situations. Classification criteria could be business activity type, risk degree, risk origin reason etc. For example, Mark Clouse and Jason Busch suggest to group supply risk into 5 major categories based upon companies sourcing and supply management projects and examine the drivers behind each. Those categories are: strategy risk, demand risk, market risk, implementation risk and performance risk (Clouse and Busch 2003). The LFA methodology suggests a more detailed supply chain risk classification that is given bellow (Logistic Field Audit TM 2004):

- foreign risk;
- supply chain common elements risks:
  - purchasing risk;
  - production risk;
  - realisation risk;
  - production return management risk.
- logistic management risk:
  - structural risk;
  - financial risk;
  - information technologies risk;
  - operation risk:
    - ✓ transportation risk;
    - ✓ customs risk.

After different classifications are reviewed, proper risk classification for a simplified supply network, which is similar to the Beer Game, can be shown in this paper. This classification contains only three main points and takes into account only those problems, which can slow down production moving over the supply chain. They are:

- purchasing risk (the supplier doesn't have enough inventory to satisfy current supply chain member's replenishment order, payment transfer delay etc.);
- delivery risk (risk that the supplier will not provide ordered goods in time; such risks include transportation risk, attendant documentation failures, recipient warehouse repletion etc.);
- warehousing risk (damages during warehousing, stealing, attendant documentation failures etc);

Two main methods of risk measurement can be distinguished: expert opinion based method and statistical method. For a long time companies were defining, prioritizing, mitigating and auditing risk with the help of subjective measurement approaches (Agarwal 2005). There are many approaches to modern expert based measurement, which take into account experience and intuition of many people with the purpose to reduce possible decision mistakes. However, the use of expert method is usually connected with the time losses, and it cannot be performed without necessary expert help (for example, making decisions in a new sphere). At the same time, the result of such measurement still remains subjective. Thus, statistical method proves to be more effective for measuring risk within the framework of simulation. Taking into account that risk event occurrence probability and precise risk consequences are unknown variables, probable outcomes are usually assumed to be random variables. Let us distinguish some basic approaches to statistical measurement of risk that are based on (Pettere and Voronova 2003):

- arithmetic mean;
- average absolute deviation;
- average square deviation;
- risk probability;
- coefficient;
- risk scales.

In many cases the value of arithmetic mean for losses, which already happened, can be useful enough for risk assessing. In other cases average absolute deviation of those losses can expand efficiency for risk measurement. The risk assessment based on calculating average absolute deviation is very popular in the sphere of finance. The Value at Risk (VaR) measurement is a classical example of the mentioned approach. In the sphere of logistics, Inventory at Risk (IaR) and Demand at Risk (DaR) are similar approaches to such risk assessment (Sodhi 2005). Another approach defines risk value as the probability that risk event will occur. When it is necessary to take into consideration risk event probability and risk event severity values, the risk coefficient can be used to compare different risk situations. The last approach to risk measurement is based on risk scales application. Unfortunately, researches in that area do not provide a standartised approach to risk scale creation, which is the main disadvantage of this approach.

Simulation-Based Risk Measurement

Today, simulation is widely accepted for predicting, explaining, training and identifying optimal solutions. Simulation is used extensively in sphere of logistic systems to model production and assembly operations, develop realistic production schedules, study inventory policies, analyze reliability, quality and equipment replacement problems and design material handling systems. There are many well-known benefits of simulation. For example, simulation allows one to evaluate outcomes of any decisions before implementing them into real systems; simulation models are easier to understand than many analytical approaches; simulation allows one to create models, whose analytical realization is impossible or complicated (Evans and Olson 1998). It can be assumed, that such abilities make simulation very useful for risk analysis. It should be noted that the idea to assess risk using simulation, is not new. For example, Monte Carlo simulation can be used for supply chain risk analysis which is associated with hazards (Elkins et al. 2004). Another example discusses the possibility of making wrong decisions in the sphere of inventory management (Deleris and Erhun 2005).

This paper describes an approach to risk analysis in the simplified supply chain, which is represented by the Beer Game. The Beer Game is the training program, which illustrates the dynamics of supply chains and teaches principles for effective inventory replenishment management. The goal of this game is to minimise the total inventory holding and unmet demand (backorder) cost. At the same time, the modelling with the Beer Game can illustrate risk influence in supply chain and simulation-based risk measurement approaches.

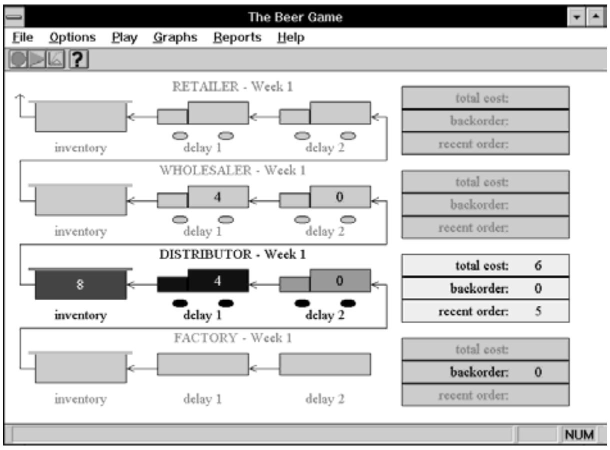
SUPPLY CHAIN: BEER GAME BASED MODEL

As was mentioned previously, this paper discusses risk assessment in simple supply chain system, which is used in the Beer Game. This section describes the above-mentioned model and also gives information about risk calculation within the framework of this supply chain model. It is necessary to notice, that classic Beer Game is typically played on a large board. In our case the computerised version of the game is used instead. Actually, the computerised game can fully represent the classic onboard game. At the same time, the strong advantage of the computerised model is built-in inventory replenishment policies which can be used for automated supply chain component management.

Beer Game Model

The Beer Game simulates the following scenarios. First, consider a simplified beer supply chain consisting of a single retailer, a single wholesaler who supplies the retailer, a single distributor who supplies the wholesaler, and a single factory with unlimited raw materials which makes (brews) the beer and supplies the distributor. Each component in the supply chain has unlimited storage capacity, and there is a fixed supply lead time and order delay time between each component.

Every week, each component in the supply chain tries to meet the demand of the downstream component. Any orders which cannot be met are recorded as backorders, and met as soon as possible. No orders will be ignored, and all orders must eventually be met. At each period, each component in the supply chain is charged a $1.00 shortage cost per backordered item. Also, at each period, each component owns the inventory at that facility. In addition, the wholesaler owns inventory in transit to the retailer, the distributor owns inventory in transit to the wholesaler, and the factory owns both items being manufactured and items in transit to the distributor. Each location is charged $0.50 inventory holding cost per inventory item that it owns. Also, each supply chain member orders some amount from its upstream supplier. It takes one week for this order to arrive at the supplier. Once the order arrives, the supplier attempts to fill it with available inventory, and there is an additional two week transportation delay before the material being shipped by the supplier arrives at the customer who placed the order. Each supply chain member has no knowledge of the external demand (except, of course, the retailer), or the orders and inventory of the other members. The schema of the described system and its simulation environment are shown in Figure 1.



Figures 1: Computerised Beer Game Model

The goal of the retailer, wholesaler, distributor, and factory, is to minimize total cost, either individually, or for the system (Kaminsky and Simchi – Levi 2003).

Risk Measurement

This paper does not describe mathematically how supply chain parameters affect the risk probability. Thus, only local risk (inventory risk at each warehouse) calculation is described. Still, four risk events can be distinguished for the above-mentioned model:

- current warehouse inventory level cannot be replenished due to out of stock at the previous supply chain member warehouse;
- demand increasing causes inventory devastation, so the current demand cannot be satisfied;
- demand decreasing causes inventory level excessive increasing, which will accordingly raise inventory costs;
- chosen inventory replenishment policy leads to unplanned total costs.

From the above it follows that two model output variables can be used for making risk assessment: inventory level and unsatisfied orders quantity (backordering) at each warehouse. As was mentioned before, there are different types of risk assessment approaches. This paper introduces the idea that risk calculation approaches can be used to compare the efficiency of chosen inventory replenishment policies.

Risk assessment is carried out in three ways. The first one represents risk assessment due to risk probability. The next one describes risk assessment due to risk coefficient calculation for each of output variables which are inventory level and backordering. At the final step, both risk coefficients summation is described, which gives a more effective opportunity for supply chain management decision making.

Probability as a Measure of Risk

Usually, for adequate risk assessment, risk event probability calculation is necessary. Still, the probability itself can be a good enough measure for risk estimation. The probability can be measured in subjective and objective ways. For the described Beer Game model, objective measurement is used that is based on simulation output statistics. In such a way, a probability can be measured, which describes inventory and backordering levels values for the next time. Thus, the probability that inventory level (backordering level) will be equal to *i*, is two values relation (1): the number of simulated weeks, in which such inventory level (backordering level) has been registered; and the number of simulated weeks. Inventory and backordering probabilities can be calculated as follows:

$$p^I(i) = \frac{x_i^I}{L} \quad (1)$$

$p^I(i)$: probability that inventory level will be equal to number *i*.

x_i^I: number of simulated weeks, in which inventory level was equal to number *i*.

L: number of simulated weeks.

$$p^O(i) = \frac{x_i^O}{L} \quad (2)$$

$p^O(i)$: probability that backordering level will be equal to number *i*.

x_i^O: number of simulated weeks, in which backordering level was equal to number *i*.

Still, a calculation of that kind does not provide effective risk assessment. A more useful form is calculated probabilities accumulation, which gives us risk measurement approach similar to Value at Risk. Thus it is possible to calculate the probabilities that inventory level (or backordering level) will not exceed the chosen value:

$$P^I(i) = \sum_{j=1}^{i} p^I(j) \quad (3)$$

$P^I(i)$: probability that inventory level will not exceed value *i*.

$$P^O(i) = \sum_{j=1}^{i} p^O(j) \quad (4)$$

$P^O(i)$: probability that backordering level will not exceed value *i*.

So, supply chain manager has to choose the restriction value. This paper describes calculations, which produce the probability that:

- inventory level will not exceed value 10;
- the number of back orders will not exceed value 0.

Risk Coefficient as a Measure of Risk

When risk is calculated as a risk event probability, the risk costs are not taken into account. This is not a problem when risk costs are identical. In the Beer Game case, each event, spare inventories and backordering, has different costs, which depends on the size of spare inventories and number of unsatisfied orders, accordingly. Thus, the simplest way to calculate such risk coefficient is to multiply probability value and costs factor:

$$r^I = \sum_{j=1}^{N} p^I(j) * c_j^I \quad (5)$$

r^I: risk coefficient for the chosen inventory level exceeding.

c_j^I: cost function for the chosen inventory level.

N: maximal inventory level registered during simulation.

$$r^O = \sum_{j=1}^{K} p^O(j) * c_j^O \quad (6)$$

r^O: risk coefficient for the chosen backordering level exceeding.

c_j^O: cost function for the chosen backordering level.

K: maximal backordering level registered during simulation.

Complex Risk Coefficient

Having an approach to inventory risk and backordering risk assessment, one can make decisions intended for their separate management. Nevertheless, as was mentioned previously, there are many cases when one risk event probability decreasing causes other risks event probabilities. For example, it is possible to create inventory replenishment policy, which fully excludes backordering event, but at the same time, such a decision will strongly increase average inventory level at the warehouse. So, it is useful to make all risk criteria summation, which follows from multiple criteria decision theory:

$$R = \sum_{j=1}^{N} p^I(j) * c_j^I + \sum_{j=1}^{K} p^O(j) * c_j^O \quad (7)$$

R: complex risk coefficient.

Thus, according to the above-mentioned formula, the risk management aims for coefficient *R* minimisation. It is also necessary to point out the disadvantage of that approach. It doesn't take into account an income from supply chain operations.

EXPERIMENTS

The simulation illustrates application of the described approaches to risk assessment in the simplified supply chain. This paper discusses three experiments with the Beer Game model. For those experiments, identical client demand distribution generators were used (input data). The main goals of the experiments were to represent risk assessment approach and investigate how different inventory replenishment policies could be compared based on risk measurement criteria.

For each experiment, only one replication was used, whose simulation time was 300 weeks. Besides, risk calculation does not include the first 100 week period data (warm-up period).

For the first experiment, basic inventory replenishment policy (default inventory replenishment policy of the above-mentioned computerised Beer Game) is used for all supply chain members. This policy is called "Updated s". According to that policy, each order has to fill inventory level up to value *s*, which is continuously updated to the following value: the moving average of demand received by current supply chain member over the past 10 weeks times the lead time for an order placed by that member, plus *M* times an estimate of the standard deviation during the lead time.

Table 1 represents risk assessment based on risk event probability calculation.

Table 1: Risk Probabilities in Experiment 1

Retailer	Wholesaler	Distributor	Factory
$P^I(15)$	probability that inventory level will not exceed value of 15		
97,5%	84%	55%	25,5%
$P^O(0)$	probability that backordering level will not exceed value of 0		
89,5%	88%	88%	95,5%

One can see that the probability for warehouse to be over-crammed grows up due to the final supply chain member; thus it evidently shows the presence of the Bull-whip effect.

The next table shows risk assessment based on risk coefficient calculation.

Table 2: Risk Coefficients in Experiment 1

	r^I	r^O	R
Retailer	2,945	0,430	3,375
Wholesaler	4,493	0,685	5,178
Distributor	8,058	0,765	8,823
Factory	13,220	1,250	14,470

In the second experiment, the input parameters contain similar values except for inventory replenishment policy at "Distributor" warehouse, which uses Min-Max inventory replenishment policy. Table 3 and Table 4 represent risk assessment results according to the second simulation experiment.

It seems that risk criterion was improved due to the second experiment. Still, new inventory policy at "Distributor" warehouse badly affects the last member of the supply chain.

Table 3: Risk Probabilities in Experiment 2

Retailer	Wholesaler	Distributor	Factory
$P^I(15)$	probability that inventory level will not exceed value of 15		
98,5%	88,0%	72,5%	11,5%
$P^O(0)$	probability that backordering level will not exceed value of 0		
92,5%	90,5%	90,0%	99,5%

Table 4: Risk Coefficients in Experiment 2

	r^I	r^O	R
Retailer	2,820	0,190	3,008
Wholesaler	3,888	0,375	4,263
Distributor	5,240	0,380	5,620
Factory	13,093	0,020	13,113

The last experiment's input data contain "Distributor" Min-Max policy parameters alteration, which decreases inventory level exceeding and backordering risks.

Table 5: Risk Probabilities in Experiment 3

Retailer	Wholesaler	Distributor	Factory
$P^I(15)$	probability that inventory level will not exceed value of 15		
97,5%	87,5%	65,5%	42%
$P^O(0)$	probability that backordering level will not exceed value of 0		
90,5%	89,5%	92,5%	96%

Table 6: Risk Coefficients in Experiment 3

	r^I	r^O	R
Retailer	2,803	0,315	3,118
Wholesaler	4,065	0,450	4,515
Distributor	6,238	0,500	6,738
Factory	9,525	0,295	9,820

The table data give an opportunity to ascertain risk dependence on the changes in the supply chain. Making the collected risk measurement values research, one can compare different policies due to collected risk indicators research. It is also possible to observe how policy changes at one member of supply chain affect the risk factor at other members.

It seems that both the risk probability and the risk coefficient calculations are usable enough for risk assessment. Still, it is much easier to make supply chain management decisions using percentage values. On the other hand, such an assessment does not take into account risk costs function.

CONCLUSIONS

This paper introduces a risk measurement approach, which can be applied to supply chain management. The obvious advantage of such risk assessment is calculation-based measurement that means subjectivity dependence reducing. Thus, it is easier to integrate this approach into models to enable automated risk calculation. It should be noted, however, that the described risk event probability and risk coefficients calculation results have to be analysed by experts. Another disadvantage of this risk assessment approach is the necessity for the statistical data. Therefore, it is worthwhile to use such risk assessment in combination with simulation, in order to provide necessary data.

The purpose of the paper was to demonstrate risk assessment possibility using the Beer Game model. The described approaches were applied to the computerised version of the Beer Game. According to simulation results it is possible to draw conclusions about the adequacy of the described risk measurement approach. In particular, the calculated risk values can be used to compare different inventory replenishment policies. Still, the presented paper is only a start for future research, which will be mostly focused on risk studying environment creation. The chosen computerised version of the Beer Game causes some difficulties during experiments implementation. Most likely, it will be necessary to implement a new program that would represent the Beer Game supply chain management model with the integrated risk assessment approach. Future research also has to include risk coefficient rationing and multi criteria optimisation mechanisms to provide a more effective measure for making management decisions. Another task of future research is to modify the Beer Game model to make it more intended for studying risk in supply chains.

REFERENCES

Agarwal, S. 2005. "Managing Risk in Supply Chain". Supply&Demand Chain Executive. August.

Clouse, M. and Busch, J. 2003. "How to Identify and Manage Supply Risk". Supply Chain Planet. October.

Deleris, L., Elkins, D. and Pate-Cornell, E. 2004. "Analyzing Losses from Hazards Exposure: a Conservative Probabilistic Estimate Using Supply Chain Risk Simulation". In *Proceedings of the 2004 Winter Simulation Conference* (Washington Hilton and Towers Washington, Dec. 5-8). U.S.A., 323-330.

Deleris, A. and Erhun, F. 2005. "Risk Management in Supply Networks Using Monte-Carlo Simulation". In *Proceedings of the 2005 Winter Simulation Conference* (Orlando, FL. Dec. 4-7). U.S.A., 1643-1649.

Evans, J. and Olson, D. 1998. *Introduction to Simulation and Risk Analysis*. Prentice-Hall, Englewood Cliffs, 12-13.

Giniyatov, R. "Risk and Management (COSO Model)". *Audit Ware.* 2005. (In Russian)

Simchi-Levi D., Kaminsky, P. and Simchi – Levi, E. 2003. *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*. McGrow-Hill/Irwin. 319-333.

Pettere, G. and Voronova, I. 2003. *Business Risk Management*. Banking Institution of Higher Education. 33-40. (In Latvian)

Sodhi M. 2005. "Managing Demand Risk in Tactical Supply Chain Planning for a Global Consumer Electronics Company". *Production and Operation Management*. Spring.

Strauffer, D. 2003. "Supply Chain Risk: Deal with It". *HBS Working Knowledge*. April.

Logistic Field Audit TM. 2004. "Supply Chain Risk Management Using LFA Technologies". LFA Supply Chain Risk Management: Base Conception. (In Russian)

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