Research on Supply Chain Disruption Risk and Its Hedge Based on Reliability Theory

Fu Shaochuan and Han Qingming

Abstract This article analyses the disruption risk of the supply chain. By introducing the supply chain reliability theory, it establishes a supply chain model with reliability constraints based on the reliability theory. The article simplified the model and is proposed to use *Microsoft Excel* Solver to solve the 0–1 integer programming problem. This method is simple and convenient, laying the foundation for the application of this theory in practice.

Keywords Reliability • Supply chain disruption risk • 0–1 integer programming

1 Introduction

Supply chain disruptions are unanticipated events that disrupt the normal flow of goods and materials within a supply chain [1]. Supply chain disruptions could lead to many problems, such as extending the lead time, out of stock, not satisfactory customers. Such as "9 • 11" terrorist attacks, which led to the closure of U.S. airspace, earthquakes in Japan and the SARS outbreak in 2003, all of them have paralyzed the supply chain.

These pressures are driving intense effort and initiatives to reduce exposure to risk. So it is important to have insight into network construction to avoid disruptions in the supply chain. Therefore, to prevent the supply chain disruption risk and improve the reliability of the supply chain has theoretical and practical significance.

F. Shaochuan • H. Qingming (✉)
School of Economics and Management, Beijing Jiaotong University,
Beijing, Haidian District, People's Republic of China
e-mail: hanqingming@foxmail.com

Z. Zhang et al. (eds.), *LISS 2012: Proceedings of 2nd International Conference on Logistics, Informatics and Service Science*, DOI 10.1007/978-3-642-32054-5_21,
© Springer-Verlag Berlin Heidelberg 2013

2 Literature Review

2.1 Supply Chain Disruptions Management

Snyder and Shen [2] develop simulation models for several networks comparing stochastic demand and supply disruptions. They conclude the two different sources of stochasticity have very different impacts on optimal supply chain design. Hopp and Yin [3] examine an assembly system with the potential for disruptions in capacity.

While among the research, sophisticated quantitative analysis continues to appear, but in general it is not extensive. In view of this, this article analyses the disruption risk of the supply chain by introducing supply chain reliability theory.

2.2 Classification of Risks in a Supply Chain

Classification of risks in a supply chain is also a growing research trend. For example, Deleris and Erhun [4] present a Monte Carlo simulation that they use to evaluate risk levels in the supply chain. According to the risk source, supply chain disruption risk fall into three broad categories [5]: External risks can be driven by events either upstream or downstream in the supply chain. Internal risks provide better opportunities for mitigation because they are within your business's control. Risks between enterprises in the supply chain make influences on all of the members in the supply chain.

2.3 Supply Chain Reliability

The concept of supply chain reliability is related to network reliability theory [6], which is concerned with calculating or maximizing the probability that a graph remains connected after random failures due to congestion, disruptions, or blockages.

There are three structural models of supply chain, the series connection structure, parallel structure and series–parallel structure.

Series structure is a system constructed in series, in which with the increase of nodes, the reliability of supply chain will gradually decline. Parallel structure is a system constructed in parallel, in which the entire system can run as long as a node is in the normal operation. Series–parallel structure is a system constructed both in series and parallel. The reliability of the system depends on not only the series structure but also the parallel structure, and its reliability analysis is more difficult, but it can be a better solution to the practical problem.

3 Modeling the Supply Chain Structure Network

According to the above analysis, a network model of series–parallel structure of supply chain will be made and optimized, building a reliable supply chain model.

3.1 *Analysis Reliability Function of Network Structure of Supply Chain*

Supply chain network model is constructed in a series–parallel structure in reliability analysis, whose reliability block diagram is shown as following Fig. 1. The reliability of the j node of the subsystem is $R_{ij}(t)$, whose operational lifetime is T_{ij}. And the operational life of the system is set as t.

$$\begin{aligned} R_i(t) &= P(T_i > t) \\ &= P\{\max[T_{i1},\ T_{i2}, \ldots,\ T_{im}] > t\} \\ &= 1 - P\{T_{i1} \le t,\ T_{i2} \le t, \ldots,\ T_{im} \le t\} \\ &= 1 - \prod_{j=1}^{m} [1 - R_{ij}(t)] \end{aligned} \tag{1}$$

Assume that the distribution of the operational life of each node within each subsystem is independent of each other. $R_i(t)$ is strictly increasing which means that with m increased, the reliability of node i , $R_i(t)$, will increase.

$$\begin{aligned} R(t) &= P(T > t) = P\{\min[T_1,\ T_2, \ldots,\ T_n] > t\} \\ &= P\{T_1 > t,\ T_2 > t, \ldots,\ T_n > t\} \\ &= \prod_{i=1}^{n} R_i(t) \end{aligned} \tag{2}$$

Assume that the distribution of the operational life of each node is independent of each other. $R(t)$ is strictly decreasing which means that with n increased, the

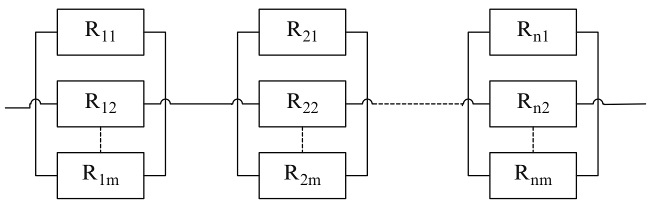

Fig. 1 Reliability diagram of the supply chain network model

reliability of system $R(t)$ will decrease. In summary for the whole supply chain, with the increase of subsystem the system reliability will gradually decline.

3.2 Mathematical Model and Resolution

Supply chain model consists of n sub-systems. The cost of child nodes in each subsystem is C_{ij}. The sub-system of supply chain is composed of m nodes.

The objective of the supply chain model is the reliability of the series system which consisting of subsystem to meet the condition, $R \geq R_0$. And the reliability of each subsystem meets the condition $R_i \geq R_0(i)$, and spends the minimum total cost of C.

$$\sum C = \min\left\{\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} C_{ij} \cdot X_{ij}\right\} \tag{3}$$

$$R = \prod\nolimits_{i=1}^{n} R_i \cdot X_i \geq R_0 \tag{4}$$

$$R_i \cdot X_i \geq R_0(i) \tag{5}$$

$$R_i = 1 - \prod\nolimits_{j=1}^{m} [1 - X_{ij} \cdot R_{ij}] \tag{6}$$

$X_i = 1$, subsystems i should be included in the supply chain model, or $X_i = 0$
$X_{ij} = 1$, node j should be included in the subsystem i, or $X_{ij} = 0$

According to the definition of the model, we need to determine which subsystem-s should be included in the whole supply chain, and which node enterprises s-should be included within each subsystem in order to find a program with the minimum cost based on the reliability.

3.3 Solving Ideas

This model is an 0–1 integer programming model. Usually the exhaustive method would be used to solve the 0–1 integer programming problem to find the optimal solution. Using Microsoft Office Excel to solve such problems is fast and accurate, and you can get a multiplier effect. In accordance with practical requirements, the solution ideas are given as following:

(1) Entry the known cost, reliability data, increase the variable region; (2) Calculate the cost of each subsystem; (3) Calculate the reliability of each subsystem; (4) Set constraints; (5) Calculate the total cost of the supply chain system.

4 Numerical Studies

4.1 Conditions and Assumptions

To illustrate more convenience, the numerical example was simply adjusted, assuming that there are four alternative subsystems in the supply chain, and each of the subsystem has four alternative nodes. The reliability of the supply chain system requires 0.95. In addition, each subsystem should include at least two nodes to make sure the stability of the system. The cost and reliability of each node in each subsystem are shown in Tables 1 and 2.

4.2 Modeling Resolving

Set the corresponding parameters in the Solver function in Excel and select the target cell, constraints and the variable cell. This results show in a graphical representation of Fig. 2. The supply chain consists of four subsystems, the first subsystem consists of 1,3 node, the second consists of the 1,4 node, the third consists of the 1,2 node, the fourth consists of the 2,3 node. The optimal cost is

Table 1 The cost of each subsystem node units: 10,000 yuan

	Subsystem 1	Subsystem 2	Subsystem 3	Subsystem 4
Node 1	1.90	2.00	1.60	1.90
Node 2	2.00	2.20	2.00	2.30
Node 3	1.80	2.40	1.80	1.80
Node 4	1.50	1.80	2.40	1.50

Table 2 The reliability of each subsystem of each node

	Subsystem 1	Subsystem 2	Subsystem 3	Subsystem 4
Node 1	0.90	0.85	0.80	0.75
Node 2	0.80	0.70	0.80	0.85
Node 3	0.85	0.80	0.90	0.90
Node 4	0.70	0.90	0.70	0.70

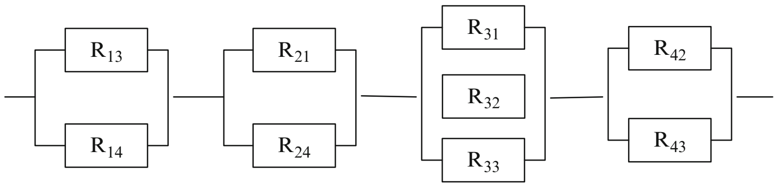

Fig. 2 Solver results

17 million dollars. The reliabilities of the four subsystems are 0.99, 0.99, 1.0 and 0.99. The reliability of the entire supply chain is 0.95 which means that it meets the reliability requirement.

5 Conclusions

This paper analyses the disruption risk of the supply chain. By introduction of supply chain reliability theory, establishing a supply chain model with reliability constraints based on the reliability theory, taking into account the conditions of reliability and resource and the minimization of the cost of the supply chain system. The numerical study show that the use of the model and the algorithm could provide a reference to the supply chain network determination with reliability constraints, which can not only reduce the overall cost of the supply chain to ensure rapid response capability, but also improve the supply chain to resist interruption risks.

References

1. Hendricks KB, Singhal VR (2003) The effect of supply chain glitches on shareholder wealth. J Oper Manag 21:501–523
2. Snyder LV, Shen ZJM (2006) Supply and demand uncertainty in multi-echelon supply chains. Working paper, P.C. Rossin College of Engineering and Applied Sciences, Lehigh University, Bethlehem, PA
3. Hopp WJ, Yin Z (2006) Protecting supply chain networks against catastrophic failures. Working paper, Department of Industrial Engineering and Management Science, Northwestern University, Evanston, IL
4. Deleris LA, Erhun F (2005) Risk management in supply networks using Monte-Carlo simulation. In: Kuhl ME, Steiger NM, Armstrong FB, Joines JA (eds) Proceedings of the 2005 winter simulation conference, Association for Computing Machinery, Piscataway, pp 1643–1649.
5. Oke A, Gopalakrishnana M (2009) Managing disruptions in supply chains: a case study of a retail supply chain. Int J Prod Econ 118(1):168–174
6. Colbourn C (1987) The combinatorics of network reliability. Oxford University Press, New York