Research on Supply Chain Risks Management by Simulation Analysis

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Abstract Today's supply chains characterize as high uncertainty, high customer expectations, and high vulnerability. Supply chain risk management (SCRM) has been an important area of supply chain management. Internal risks resulted from the interaction among supply chain members act as the major impact on supply chain coordination, but they are difficult to be modeled and analyzed if using traditional mathematical methods. Simulation is a valuable tool for modeling and analyzing the members' behaviors from strategic level decisions to individual production processes. After reviewing the application of simulation on supply chain management, this paper proposes an excel-based supply chain simulation model, which provides a useful tool to model supply chain risk factors and to simulate the interactions among members' production strategies.
Key words Supply chain risk management; Simulation; Modeling; Spreadsheet-based simulation

1 Introduction

Supply chain is a normal phenomenon in manufacturing industry. It is a geographically distributed manufacturing system actually. Suppliers and distributors related to the manufacturers cooperate with each other, forming a virtual manufacturing system which is far more complex. In fact, a supply chain should be treated not just as a chain but also as a complex adaptive supply network.

Supply chains in today's business climate characterize as high uncertainty, high customer expectations, and high vulnerability. Managing risk in supply chains is an important topic in supply chain management. The topic's importance is due to several industry trends currently in place: increase in strategic outsourcing by firms, globalizations of markets, increasing reliance on suppliers for specialized capabilities and innovation, reliance on supply networks for competitive advantage, and emergence of information technologies that make it possible to control and coordinate extended supply chains[1].

Supply chain risk management is defined as "the identification and management of risks within the supply network and externally through a coordinated approach amongst supply chain members to reduce supply chain vulnerability as a whole" [2]. Generally, there are two types of supply chain risks: endogenous risks and exogenous risks. The former results from the interactions among member firms across the entire supply chain network, thus controllable to managers. On the other side, exogenous risks arise from the interactions between the supply chain network and its environment, which is usually out of supply chain managers' control. So, it is reasonable that the major impact to system performances comes from internal risks, such as supply risk, demand risk, and trade credit risk, resulted from members' behaviours [3], which, unfortunately, are difficult to be modelled and analyzed using traditional mathematical methods.

Simulation is ideal to deal with stochastic natures existing in the supply chain. It is especially helpful to *visualize* the supply chain risks. Over the past ten years, supply chain risk management using simulation maintains an increasing trend, mainly because it is regarded as the main technique for supporting decision-making in supply chain systems, owing to its inherent modelling flexibility [4].

In the next section, we will review the application of supply chain simulation briefly since supply chain simulation is an important approach to supply chain risk analysis. Then in section 3, a supply chain simulation model is proposed, followed by its application on risk controlling in a manufacturing supply chain with 5 members in section 4. Finally, in section 5, results and discussions are taken out and the future trends of supply chain risk simulation are pointed out.

2 Recent Development of Supply Chain Simulation

Simulation has long been a significant and powerful force for the improvement of system operations. Advanced computer simulation modelling is the economical decision-making tool that allows us to understand and visualize the effects of change and the resulting costs prior to implementation. Well-designed simulation, including methodology and applications, can help managers studies.

2.1 Contents of supply chain simulations

As a useful modelling and analysis tool, simulation has been widely used for supply network analysis, planning, optimization, evaluation, risk management, and even pre-scheduling of the production throughout the chain. It is a valuable tool for supply chain management from strategic decisions such as system structure design and global resource allotting, to individual member's everyday operational decisions such as production plan and inventory controlling. It is widely used to test the impact of decisions at all levels in the chain, from overall system controlling and optimizing to individual manufacturing system monitoring. Many simulation models have been developed for supply chains designing, evaluating, and optimizing [5], which all contribute to supply chain risk management.

Supply chain coordination and optimization are core operations in supply chain management. Coordination and optimization of a supply chain are the result of all members' interaction, which is the main risk source. It is natural and easy-to-understand that it is the most efficient way to study supply chains by simulating members' behaviours. The famous beer game is one of the earliest such simulation. In recent years, members' behaviour is considered by more and more researchers as one of the most important content to be simulated [6], and a lot of behaviour simulation models are developed [7]. However, to clarify and quantify members' behaviour have been challenging problems, not to mention devising manufacturing/distribution strategies and determining their parameter values. As object-oriented simulation techniques getting better use, there will be a surge in supply chain behaviour simulating in near future.

2.2 Frequently used approaches, technologies, and tools of supply chain simulations

Except for various SCM information systems widely used by all kinds of manufacturing companies, many simulation tools have been developed for supply chain research and/or real-practice. Theory researching and algorithms studying are the basis for simulations. The widely used supply chain simulation methodologies and approaches include visual interactive simulation, parallel simulation, distributed simulation, spreadsheet-based simulation, simulation games, analytical models, bespoke programming, and process mapping, and so on.

The most frequently used techniques for supply chain simulation include discrete event simulation (DES), system dynamics (SD), agent based simulation (ABS), Monte Carlo simulation, Petri-nets, intelligence simulation, and so on. Among these techniques, DES is the most frequently used one, followed by SD [8]. Agent based simulation (ABS) is a traditional approach to model supply chain behaviour, using object-oriented techniques. Monte Carlo techniques have long been used to analyze operation level problems such as order scheduling and multi-echelon inventory management. Petri-nets are suitable for strategic decision simulation like system structure designing and business process optimizing. Intelligent simulation is developing quickly in recent years and has been applied on nearly all aspect of supply chain simulation [9].

There has been a lot of commercial software for supply chain simulation such as Supply Chain Guru, IBM Supply Chain Analyzer (IBM SCA), Acorn SCA, and IBM Supply-chain Network Optimization Workbench (SNOW), to name a few. However, most of supply chain modelling and simulation tools were developed by researchers. Visual, interactive, and simple to use become three basic requirements to simulators. To be a truly useful decision making tool, a simulation model also needs to be accurate, which is attained through rightly-chosen simulation techniques.

2.3 The application of spreadsheet based simulation on supply chain context

Spreadsheet based simulation is a convenient and efficient approach which is welcomed by supply chain managers (especially those in SMEs) but has not got enough attention from researchers.

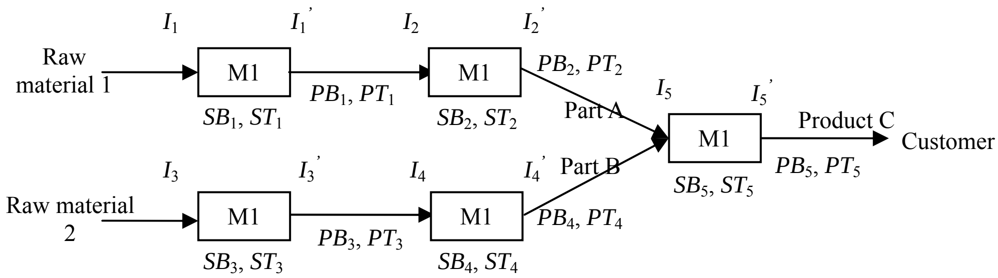
The spreadsheet offers numerous merits in terms of easy data manipulation, rapid calculation, instant visual feedback and analytical as well as graphical capabilities. Moreover, given its numerous menu-driven, built-in functions, there are many types of tasks a user can utilize the spreadsheet to perform, from strategic decision supporting to everyday management behaviour suggestion [10]. It is also a good tool to introduce supply chain operations for the teaching purposes.

The most popular spreadsheet tool is Microsoft Excel, which is usually employed by spreadsheet-based simulations, under the help of some other tools. ActiveX Automation, VBA technology and Excel Link are usually used to implement the communication between Excel and host simulators.

3 Simulation Model for Supply Chain Risk Management

Nowadays supply chains are usually on the base of make-to-order, trying to be "lean, agile, and responsive". To simultaneously realize the two contradictory objections, managers have to make decisions hastily in relatively short time and take self-benefit as the core focus, thus resulting to the risk propagation and amplification throughout the whole chain.

A typical manufacturing supply chain with a dominant manufacturer is described in figure 1. The dominant manufacturer (M5) receives customer orders for product C, and then creates its orders for necessary parts (i.e., part A and part B) and sends them to upper stream members, M2 and M4. Every member has its own operation scheme, including the inventory strategy, the business process configuration, and the transport mode, etc. To every manufacturer, the manufacturing process includes setup (technology preparing, materials preparing, equipments setting up, etc), material processing, and finally, finished items transport. Generally, each of these activities takes time and has a reasonable batch size.



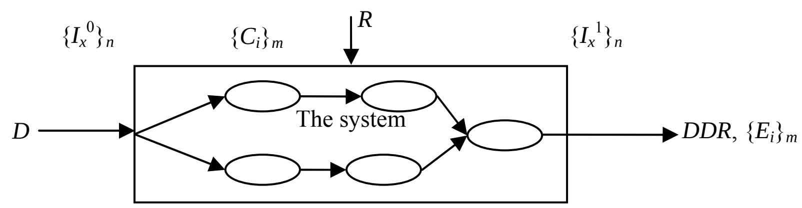
SB_i – setup batch size for member i　　ST_i – setup time for member i
PB_i – process batch size on member i　　PT_i – unit process time for member i
TB_i –transport batch size after member i　　TT_i – transport time after member i
I_i – inventory before member i　　I_i' – inventory after member i

Figure 1　A Typical Supply Chain with a Dominant Manufacturer

The main risks that supply chain managers try their best to avoid are customer dissatisfaction and supply chain disruption. Except for quality and cost, the most important factor for customer dissatisfaction is "not in time", or delivery delay. Similarly, supply chain disruption is usually resulted from interior delivery delay, which is affected by material availabilities and members' production strategy configurations. Another important risk source is the uncertainty of ultimate market, which refers to the stochastic customer demands/orders which obey to certain distributions. Then, as to the supply chain system with m members and n materials (raw materials, parts, and products) described in figure 2, we can formulate its risks as

$$Risks = f(p(CDS), p(SD)) = g(D, \{C_i\}_m, \{I_x^0\}_n, R). \tag{1}$$

Here, $p(CDS)$ represents the probability of customer dissatisfaction, $p(SD)$ the probability of system disruption, D the stochastic market demands, $\{C_i\}_m$ members' production strategy configurations, $\{I_x^0\}_n$ initial inventory state of the materials, and R the system level coordination rules.



I_x^0 – initial inventory for material X,　　I_x^1 – final inventory for material X
D – arrived customer demands　　DDR – delivery delay rate for customer orders
E_i – efficiency of member i　　C_i – production strategy of member i

Figure 2　The Risk Analysis Model of the Supply Chain with Members and Materials

To analyze and manage supply chain risks, we developed a MS Excel-based simulation model which aims to simulate the work process of the manufacturing & service systems. Customer demands are simulated as a serial of randomly-arrived orders to the system, requiring random amounts of products. Member manufacturers can adjust production strategies by configuring their process parameters and inventory policies. After simulation, the performance of the system is appraised and reported, which acts as the input of the system risk assessment.

Except for risk predicting and controlling, the simulation model can also realize at least 4 functions: to investigate the resource utilization and diagnose the bottleneck in the system, to control WIP and improve lead time by testing different parameter configurations, to improve customer satisfaction by previewing the handling process of customer demands, and finally, to make comparisons between supply chain systems.

4 Predict and Control Supply Chain Risk by Simulation

Customer dissatisfaction and supply chain disruption are fatal risks that managers try to evade and evaluate. As we discussed, these risks both result from delivery delay (interior or/and exterior), which is traced further down to member operation behaviours. In this section, we will simulate the risk predicting and controlling process of supply chains facing stochastic market demands, which are simulated as randomly arrived customer orders. Through analyzing customer orders' lead times and supply chain members' waiting times, the risks of customer dissatisfaction and supply chain disruption are studied.

Take the supply chain system described in figure 1 as an instance. Suppose the dominant manufacturer (M5) faces stochastic market demand for product C, which is composite by 1 item of part A and 4 items of part B, as shown in figure 3. The market demand distribution for product C is known. We further suppose the members are all taking make-to-order strategy, with no ready inventory for their products, just as in ideal agile supply chains based on lean manufacturing. Members have basic production parameters as listed in table 1. These assumptions are normal in discrete manufacturing supply chains in auto, machinery, and electrics industries.

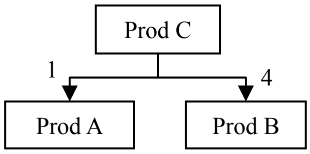


Figure 3 The BOM of Product C

Figure 4 demonstrates the handling process of the system to a customer order requiring 50 items of product C. It is clear that members respond to the customer order and start working sequentially, but some members have to pause occasionally because of interior delivery delay.

Table 1 Production Parameters of Materials

material	manufacturer	SB_i	ST_i	PB_i	PT_i	TB_i	TT_i
Part A	m1	1000	100	1	10	50	40
	m2	1000	50	1	25	100	20
Part B	m3	1000	200	1	30	100	60
	m4	1000	100	1	20	50	40
Product C	m5	1000	200	1	100	20	50

Suppose the arriving of customer orders obeys the Poisson distribution, with λ=10; and the required amount of customer orders obeys to Normal distribution, N(50,10). In a simulation, during a period, the supply chain received 11 customer orders, whose detail information is displayed in table 2. Simulation result shows that, under the basic configurations above, nearly all of these orders are delayed. In most of the time, the manufacturer of the product, M5, is waiting for the necessary parts, which are not delivered on time

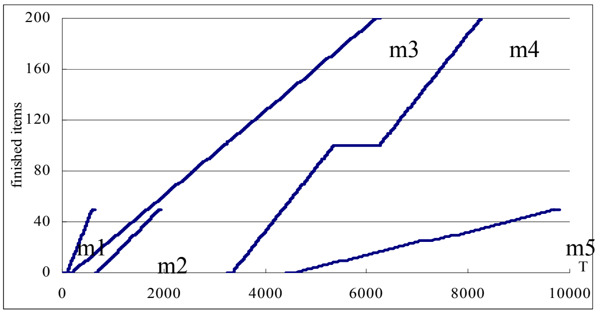


Figure 4 Members' Response and Working States after Receiving a Customer Order

Table 2 Information of Arrived Customer Orders during a Period

Order No.	Required amount	Arriving time	Required delivery time	Actual start time	Actual delivery time
1	45	0	468	7150	9150
2	39	5023	12193	12250	13650
3	44	6936	10380	43910	46060
4	54	9881	18892	16930	20710
5	55	14665	18334	23910	27290
6	56	23196	23478	30390	35750
7	60	27483	32897	61770	66370
8	58	35259	43784	38250	41550
9	45	42356	48482	49410	51760
10	55	48516	57446	55070	57870
11	39	52388	57930	68870	70270

Because of restriction in technology and facility capacities, members' production parameters (i.e., setup batch sizes and times, processing times) are fixed. Moreover, as the distances between members are also unchangeable, it is out of their control to adjust transport time for finished products (assume the transport net has been optimized). However, members *can* adjust their logistics strategies to alleviate delivery delay: transport batch sizes are in their control. To analyze the impact of the transport policy, we ignore members' setup processes (i.e., $ST_i = 0$, $i = 1$ to 5). Suppose the unit transport cost is C_T, and if the customer order is not fulfilled on time, there will be a delay penalty, C_D, for every time unit exceeding the required delivery time T_R. As to a customer order requiring 100 items of product C, the lead time and supply chain members' waiting time rates under different transport batch sizes is displayed in figure 5.

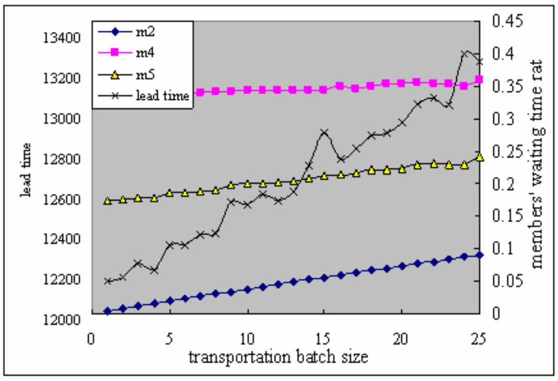


Figure 5 Decrease Transport Batch Size to Improve the Timeliness

The bigger the batch size is, the more the downstream members will wait, resulting longer lead time for customer orders. When C_T = 10, C_D = 5, and T_R = 12500, the potential costs for different transport policies are listed in figure 6. It is easy to find that the best strategy is to set the transport batch size as 8, with minimal cost 135.

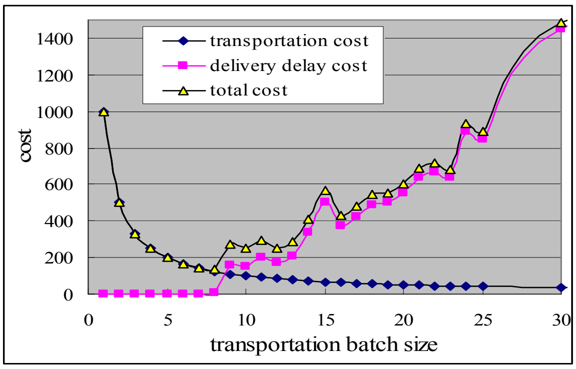


Figure 6 Find the Optimal Transport Policy by Simulation

5 Conclusions and Discussions

Simulation is ideal to *visualize* the supply chain risks. Spreadsheet-based simulation is a convenient and efficient approach which is welcomed by supply chain managers. We proposed an Excel-based supply chain simulation model. It is useful to coordinate the system operation, predict the system performance, and then act as a real-time risk monitoring and controlling tool for manufacturing supply chains.

However, the model is still to be improved in the future. Because it is focusing on manufacturing process, members' mental behaviours, or the process of subjective decision making, still cannot be simulated efficiently. Moreover, inventory factors are usually important to supply chain risk management, but are not fully simulated in this model. To support distributing decision-making simulation is another improving direction.

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