007-0010

A Simulation Model for Calculating the Response Time of a Supply Chain Network

Dr. Ding, Yizhong, Professor

Economics and Management School

Shanghai Maritime University

Address: 1550 Pudong Dadao/Shanghai 200135/P.R.China

Email: yzding@shmtu.edu.cn; josiews@hotmail.com

Phone: 86-21-58854470

POMS 18th Annual Conference

Dallas, Texas, U.S.A.

May 4 to May 7, 2007

A Simulation Model for Calculating the Response Time of a Supply Chain Network

Abstract: The response characteristic of a supply chain network is an important criterion for supply chain assessment. However, the existing approaches to describe the response characteristics can hardly reflect the behavior of the whole network. A practical simulation model of the response time of a supply chain network is established in this paper. This model is used to calculate the response time, which can describe the integral response behavior as well as the stochastic variability in a supply chain network.

Keywords: supply chain network, response time, simulation model, stochastic characteristics

1. Introduction

The response time of a supply chain network is an important criterion for supply chain assessment. It reflects the quality of a supply chain network, such as the service level, the operation efficiency, timeliness, etc. PRTM (2000) presented eleven criteria to measure the quality of a supply chain, in which the response time is an important criterion.

The main existing methods for describing the response level of a supply chain are as follows.

(1) The rate of delivery in time, which is equal to the proportion of the number of delivery in time to the total delivery number.

(2) The period of the fulfillment of an order in a supply chain, which is the total time from order acceptance, through material purchasing, production and delivery, till the reception of the product by the consumer.

(3) The response time of a supply chain, which can be calculated by the following formula (Ma Shihua et al, 2000).

Response time = (the demand-forecasting time) + (the transmission time of the forecasting message from the information nodes to the manufacture nodes) + (purchasing time and production time)+(the delivery time from the manufacture nodes to the users) (1)

The methods above have some difficulties in measuring the stochastic characteristics of the supply chain networks. They either suppose that the response time of a network is a constant, or only consider the maximum or average value of the response time. In fact, for two supply chain networks, even if they have a same maximum time and average response time, a same rate of delivery in time, and a same period of the fulfillment of an order, their response levels are unlikely to be the same. It is because their response times and the rates of delivery in time usually change randomly and have different deviations.

Besides, the methods above have some difficulties in measuring the integral response characteristics of the whole network. They often evaluate a supply chain network in terms of the response time on some special routes, such as the route that have the maximum value of the response time, instead of all routes. It can hardly reflect the response characteristics of the whole network.

This paper introduces a simulation-based model for calculating the response time of a supply chain, which can reflect the stochastic and integral characteristics of a supply chain network.

2. A Simulation Model of the Response Time of a Supply Chain Network

The activities in formula (1) can be described in a network shown in Fig.1

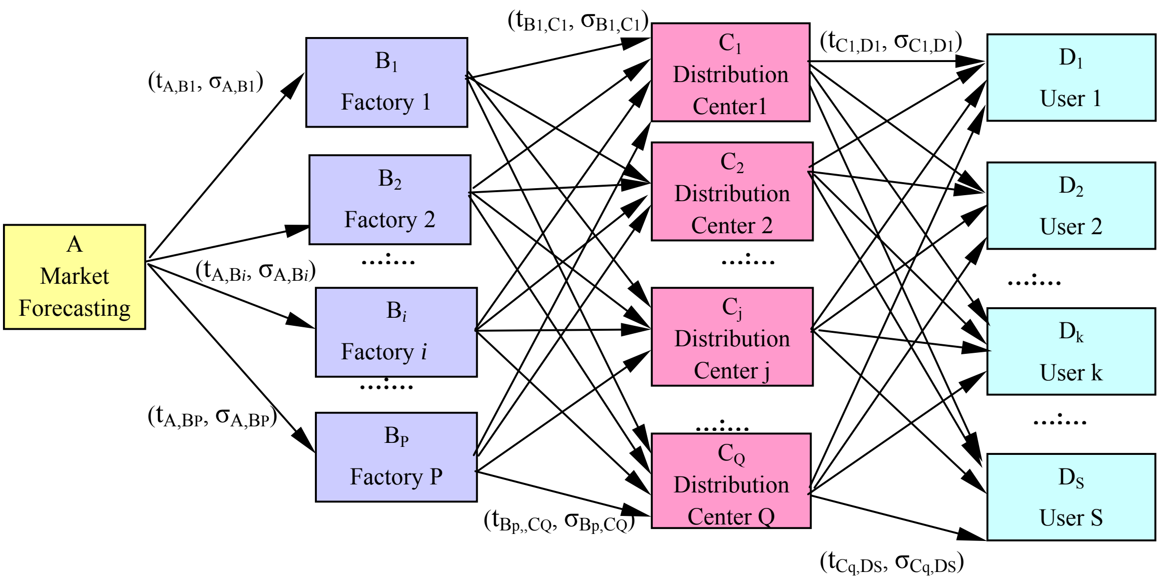

Fig.1 The Activities in a Supply Chain Network

The network in Fig.1 describes the process of forecasting, manufacturing, and distributing in a supply chain. An edge between two nodes denotes an activity in a supply chain. The two numbers written on an edge denote the time needed by the activity and its standard deviation. The activity between node A and node B_i （i=1,2,…,P）is forecasting and material purchasing. The number written on the edge between node A and node B_i is the time needed from market forecasting and material purchasing to the beginning of the manufacturing in factory *i*. The activities between node B_i（i=1,2,…,P）and node C_j（j=1,2,…,Q）are manufacturing and transporting activities. The number written on the edge between node B_i and node C_j is the time needed from manufacturing the products in factory *i* to transporting them to distribution center *j*. The activity between node C_j（j=1,2,…,Q）and node D_k（k=1,2,…,S）is distributing activity. The number written on the edge between node C_j and node D_k is the time needed from the distribution center *j* to consumer *k*. The numbers written on the edge between node A and node B_i denote that the average time needed from market forecasting to the beginning of the manufacturing in factory *i* is $t_{A,Bi}$ and its standard deviation is $\sigma_{A,Bi}$. The numbers written on the edge between node B_i and node C_j denote that the average time needed from manufacturing the products in factory *i* to transporting them to distribution center *j* is $t_{Bi,Cj}$ and its standard deviation is $\sigma_{Bi,Cj}$. The numbers written on the edge between node C_j and node D_k denote that the average time needed from the distribution center *j* to consumer *k is* $t_{Cj,Dk}$ and its standard deviation is

$\sigma_{Cj,Dk}$.

A simulation model is established in this section to calculate the response time of a supply chain network. First, a series of random variables are produced according to the distribution of the historic data to obtain the required times needed for the activities. Then, the average value and the deviation of the response time on each route are calculated. Finally, the average response time and its deviation of the whole network are calculated. The procedure of calculating the response time is shown in Fig.2.

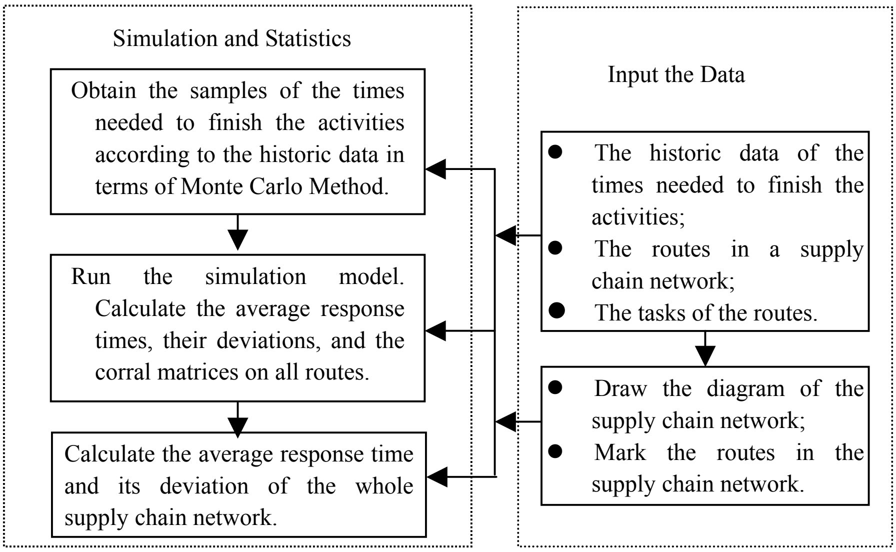

Fig.2 The procedure of calculating the response time in terms of the simulation model

The steps in detail are as follows.

Step 1: Draw the diagram of the supply chain network. Find out the routes from forecasting to the final consumers. Suppose that there are n routes in the network, and K_i arcs in the *i-th* route (i=1,2,…,n), in which K_i is the number of the arcs in the *i-th* route. Each arc presents an activity.

Step 2: Determine the number of the tasks for the *i-th* route V_i (i=1,2,…,n). Calculate the proportion of the tasks of the *i-th* route to the total tasks by formula (2).

$$r_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \qquad (i=1,2,\ldots,n) \qquad (2)$$

In which, V_i is the tasks (the production, the volume of transportation, the service, etc.) of the *i-th* route; r_i is the proportion of the tasks of the *i-th* route to the total tasks; n is the number of the routes.

Step 3: Establish a simulation model, by running which the response times of all the routes are obtained. Calculate the average response time of the *i*th route $\overline{T_i}$ (i=1,2,…,n), its deviation $\sigma_i{}^2$ and standard deviation σ_i, and the corral coefficient matrix $\rho = \{\rho_{ij}\}$ (i,j=1,2,…,n). The detailed procedure is as follows.

(1) Produce a series of random variables according to the distribution of the historic data, by which the sample of t_{ij} is obtained. t_{ij} is the required time for finishing the *j-th* activity in the *i-th* route (i=1,2,…,n; j= 1, 2, …, $K_{i,}$). K_i is the number of the activities in the *i-th* route.

(2)Calculate response time T_i of the *i-th* route (i=1,2,…,n) by summing up the times for all activities in each route.

$$T_i = \sum_{j=1}^{k_i} t_{ij} \qquad (i=1,2,\ldots,n) \qquad (3)$$

In which, T_i is the response time of the *i-th* route.

(3)Simulate by repeating step 2~step 4 for Q times. Q groups of the response times of each route are obtained. Suppose $T_i^{(q)}$ is the response time of the *i-th* route in the *q-th* simulation.（i=1,2,…,n; q=1,2,…,Q; Q is the total times of the simulation）

(4) Calculate the average response times, the variances, the standard deviations, and the correlation matrix of the response time among the routes by formula (4)~(7).

$$\overline{T_i} = \frac{\sum_{q=1}^{Q} T_i^{(q)}}{Q} \qquad (i=1,2,\ldots,n) \qquad (4)$$

$$\sigma_i^2 = \frac{\sum_{q=1}^{Q} (T_i^{(q)} - \overline{T_i})^2}{Q} \qquad (i=1,2,\ldots,n) \qquad (5)$$

$$\sigma_i = \sqrt{\frac{\sum_{q=1}^{Q} (T_i^{(q)} - \overline{T_i})^2}{Q}} \qquad (i=1,2,\ldots,n) \qquad (6)$$

$$\rho_{ij} = \frac{E[(T_i - \overline{T_i})(T_j - \overline{T_j})]}{\sigma(T_i)\sigma(T_j)} \qquad (i,j=1,2,\ldots,n) \qquad (7)$$

In which, $\overline{T_i}$ is the average response time of the *i-th* route; σ_i^2 and σ_i are the variance and the standard deviation of the response time of the *i-th* route, respectively; ρ_{ij} is the correlation between the response times of the *i-th* and *j-th* routes. The correlation matrix is $\rho = \{\rho_{ij}\}$.

Step 4:Calculate the average response time of the supply chain network

Actually, not all the routes exert a same influence on the total response time of the network because they may bear different amount of tasks. In order to take the tasks of the routes into consideration, formula (8) is used to calculate the average response time by taking the proportions of the tasks of the routes as the weights. $\overline{T}$ reflects the average response level of the whole supply chain network.

$$\overline{T} = \sum_{i=1}^{n} \overline{T_i}\, r_i \tag{8}$$

In which, $\overline{T}$ is the average response time of the supply chain network; $\overline{T_i}$ is the average response time of the *i-th* route; r_i is the proportion of the task of the *i-th* route to the total task; n is the total number of the routes.

Step 5: Calculate the variance and the standard deviation of the response time in the whole supply chain network by formula (9) and (10).

$$\sigma^2 = \sum_{i=1}^{n} \sigma_i^2 r_i^2 + \sum_{\substack{j \neq i \\ j=1}}^{n} \sum_{i=1}^{n} r_i r_j \sigma_i \sigma_j \rho_{ij} \tag{9}$$

$$\sigma = \sqrt{\sigma^2} \tag{10}$$

In which, σ^2 is the variance of the response time of the whole supply chain network; $\sigma_i{}^2$ and σ_i are the variance and the standard deviation of the response time of the *i-th* route, respectively; r_i is the proportion of the task of the *i-th* route to the total task; ρ_{ij} is the correlation between the response times of the *i-th* and *j-th* routes. ($0 \leqslant \rho_{ij} \leqslant 1$, $\rho_{ij} = \rho_{ji}$, $\rho_{ii} = 1$)

The first item on the right side of formula (9) shows the direct influence on the total deviation by the deviations of the response times on all routes, which depends on the deviations of the response times and the tasks on the routes. The second item on the right side of formula (9) shows the indirect influence on the total deviation by the interaction among different routes, which depends on the deviations of the response times and the tasks on the routes, as well as the correlation among the routes.

3. An Example

A supply chain network is shown in Fig3. Suppose that the rule of the distribution system is JIT (just-in-time). Node A, B, C and D presents market, factories, distribution centers and customers, respectively. Also, they can present the beginning or ending of the activities. The number above a node in Fig.3 presents the number of the products the node takes. For instance, Node B_1 presents factory 1 and the number 1000 above Node B_1 means that factory 1 produces 1000 products (Suppose that 600 products for Customer 1 are provided by factory 1.); Node C_1 presents Distribution Center 1 and the number 1800 above Node C_1 means that 1800 products are transported into and out of Distribution Center 1; Node D_1 presents Customer 1 and the number 600 above Node D_1 means that Customer 1 receives 600 products, etc. An arc between the nodes presents an activity. The number on an arc means the time (days) needed for the activity.

Suppose that the times needed for the activities between Node A and the nodes in level B obey uniform distribution, and the times needed for the activities between the nodes in level B and C, as well as in level C and D, obey normal distribution. For instance, the numbers (2,3) above the arc between Node A and Node B_1 mean that the time needed for the market- forecasting and transferring the forecasting information to the Factory 1 obeys a uniform distribution in region (2,3). The numbers (10,1) above the arc between Node B_3 and Node C_2 mean the time needed for purchasing, manufacturing and transporting from Factory 3 to Distribution 2 obeys a normal distribution with an average value equal to 10 and a standard deviation equal to 1.

Determine the response time of the network.

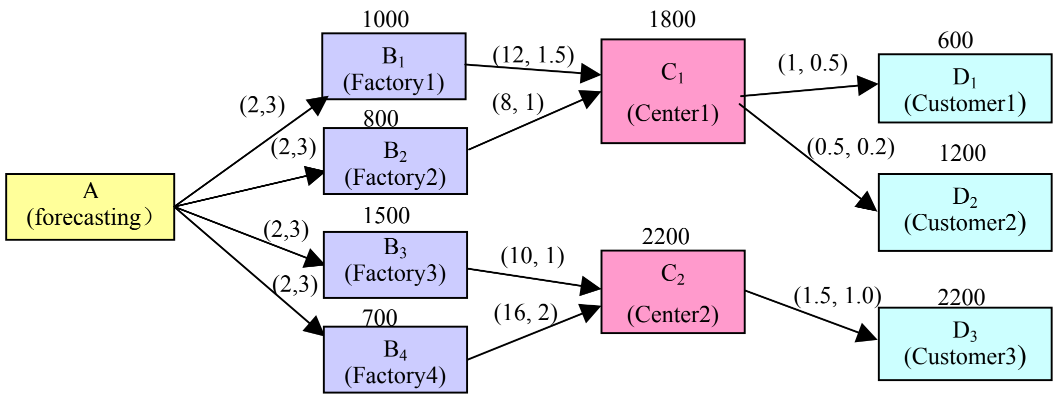

Fig. 3 A Supply Chain Network

Solution:

(1) Determine the routes and the proportions of the tasks taken by the routes

Five routes can be found in the network. The proportions of the tasks can be obtained by formula (2). See Table 1.

Table 1 The Routes and their Tasks

routes	tasks	Proportions of the tasks
① $A-B_1-C_1-D_1$	600	0.150
② $A-B_1-C_1-D_2$	400	0.100
③ $A-B_2-C_1-D_2$	800	0.200
④ $A-B_3-C_2-D_3$	1500	0.375
⑤ $A-B_4-C_2-D_3$	700	0.175
Total	4000	1.000

(2) Calculate the response time for each route by simulation

A set of random numbers are produced and the samples of the times on the arcs are obtained. The response time for each route is obtained by summing up all the times on the arcs of the routes. One thousand values of the response times on each route are obtained by simulating for 1000 times. The simulation results of the response times in the five routes are shown in Fig.2 through Fig.6, respectively, in which the X-axis presents the sequence of the simulation and the Y-axis presents the corresponding response times.

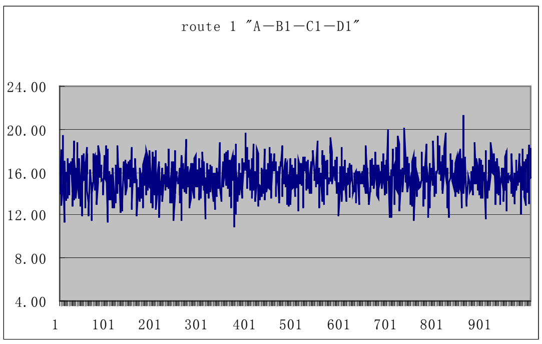

Fig.4 The Response times of Route 1

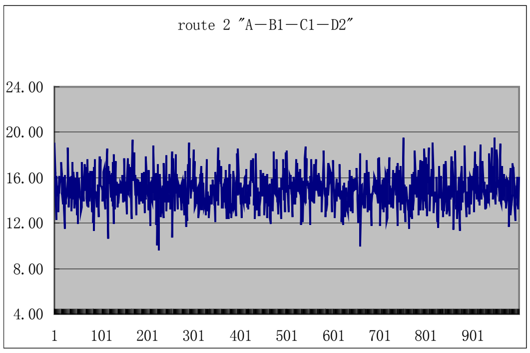

Fig.5 The Response times of Route 2

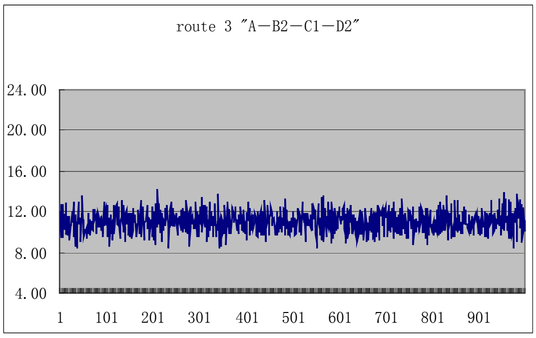

Fig.6 The Response times of Route 3

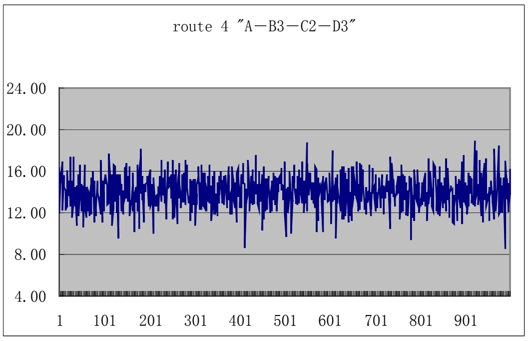

Fig.7 The Response times of Route 4

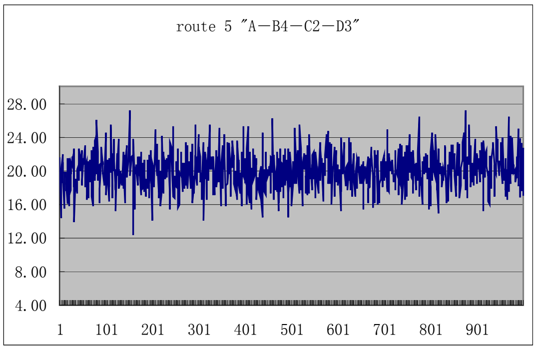

Fig.8 The Response times of Route 5

Then, the average value $\overline{T_i}$, the variance $\sigma_i{}^2$ and the standard deviation σ_i of the response time on route *i* (*i*=1,2,3,4,5) are calculated by formula (3)~(6). See Table 2.

Table 2 The Simulation Results of the Response Times for the Routes

Routes	Average Response	Variances (day^2)	Standard deviations
① $A-B_1-C_1-D_1$	15.48	2.54	1.60
② $A-B_1-C_1-D_2$	15.02	2.40	1.55
③ $A-B_2-C_1-D_2$	11.04	1.15	1.07
④ $A-B_3-C_2-D_3$	14.09	1.97	1.40
⑤ $A-B_4-C_2-D_3$	20.06	5.37	2.32

(3) Calculate the correlation matrix ρ of the response times among the routes by formula(7)

$$\rho = \begin{bmatrix} 1 & 0.0107 & -0.0132 & -0.0614 & 0.0013 \\ 0.0107 & 1 & -0.0040 & 0.0280 & 0.0311 \\ -0.0132 & -0.0040 & 1 & -0.0238 & 0.0233 \\ -0.0614 & 0.0280 & -0.0238 & 1 & 0.0049 \\ 0.0013 & 0.0311 & 0.0233 & 0.0049 & 1 \end{bmatrix}$$

(4) Calculate the average response time $\overline{T}$, its variance σ^2 and standard deviation σ in the whole supply chain network

The statistics results are obtained by formula (8)～(10) . They are as follows:

Average time: $\overline{T}$ ＝14.8254(days)

The variance of the response time: σ^2 ＝0.5628 (day^2)

The standard deviation of the response time: σ ＝0.7502 (day)

4. Summary

A practical simulation model is established for calculating the response time of a supply chain network in this paper. There are some advantages of the simulation model:

(1) The response time obtained by the model reflects the response behavior of the integral network because it considers the response time of every route, the task and the influences among the routes.

(2) The model describes the stochastic characteristics of the time-based variables in a supply chain network. It obtains not only the average response time, but also the variance and standard deviation of the response time.

(3) The model considers the tasks taken by each route. The more tasks a route takes,

the bigger influence the route has on the response time.

(4) The model is a practical one. It can be established and run easily.

References

[1] Xu Xianhao, Ma Shihua, On the Multi-Stage Control Model in the Supply Chain Network, The Journal of Huazhong University of Science and Technology, vol.26, July, 1998

[2] Robert S. Kaplan, David P. Norton, the Balanced Scorecard-Measures That Deive Performance, Harvard Business Review, Jan-Feb. 1992

[3] Ma Shihua, Li Huayan, Lin Yong, An Application Research of Supply Chain Performance Measurement Using Balanced Scorecard, www.chinawuliu.com.cn/papers/content/2103-1-90.htm, 2002

[4] Huo Jiazhen, Sui Minggang, Liu Zhongying, Study State of Enterprise and Supply Chain Performance Measurement, Journal of the Tongji University, Aug. 2001

[5] Shao Xiaofeng, Ji Jianhua, On the Criteria for the Evaluation on the Competitive Power of a Supply Chain, Forecasting, vol.6, 2000

[6] Ding Yizhong, Jennifer Shang, Management Science: Modeling and Solving Using Spreadsheet, The Publishing House of Tsinghua University, March 2003