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Research Article

Study on Modeling and Simulation of Reliability Diagnosis of Supply Chain Based on Common Cause Failure

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Abstract: To diagnose key factors which cause the failure of supply chain, on the base of taking 3-tier supply chain centering on manufacturer as the object, the diagnostic model of reliability of supply chain with common cause failure was established. Then considering unreliability and key importance as quantitative index, the diagnostic algorism of key factors of reliability of supply chain with common cause failure was studied by the method of Monte Carlo Simulation. The algorism can be used to evaluate the reliability of f supply chain and determine key factors which cause the failure of supply chain, which supplies a new method for diagnosing reliability of supply chain based on common cause failure. Finally, an example was presented to prove the feasibility and validity of the model and method.

Keywords: Common cause failure, modeling, reliability diagnosis, simulation

INTRODUCTION

Studying reliability of supply chain has attracted much attention of scholars, experts and entrepreneurs since the Philips fire accidents in 2000 and the 911 disaster in 2001. However, the progress of researching on reliability of supply chain is clearly lagging behind compared with the research of uncertainty of supply chain and its bullwhip effect, relationship between partners in supply chain, evaluation of supply chain performance, strategy design of supply chain ,supply chain planning and scheduling, supply chain risk and so on (Li, 2009). The current research literatures on diagnosing supply chain are very rare, which mostly focuses on the evaluation of supply chain performance (Carter *et al*., 2003; Gunasekaran *et al*., 2001; Shin *et al*., 2000; Petroni and Panciroli, 2002; Chen *et al*., 2006 2007; Li *et al*., 2004; Qi *et al*., 2006). Certainly, diagnosis of supply chain is different from evaluation of supply chain performance. The purpose of the former is to identify the weak of supply chain to find improved object. The latter, however, is to judge the effect of system operation for evaluation. In the literatures on diagnosing supply chain, the document (Liu, 2006) discusses the application of KPI of supply chain based on SCOR performance measurement for supply chain management and the new concept of supply chain management and emphasizes that we should use performance measurement system to realize the concept. However, in my opinion, its essence is evaluation of performance, not diagnosis of supply chain. In the document (Li *et al*., 2007), to monitor cooperation status for supply chain partners, supply chain partnerships diagnosis management was proposed. Rule-based reasoning, case-based reasoning and support vector machines were integrated to support the diagnosis management. Wang and Da (2006) uses Petri net to select 14 key factors in supply chain operations and establish chain diagnostic model to provide a new method for diagnosis of the supply chain, but when the factors led to failure of supply chain increase and their causal relationship is more and more blurred, this method may be more complex. Guo-Hua *et al*. (2009) concentrate on the problem of reliability diagnosis of supply chain with independent cause failure. In the study failure factors caused by suppliers, manufacturers, distributors being independent of each other, which is to say that the factors leading to failure of suppliers will not lead to manufacturer or distributors fail. But in fact, there lie other circumstances, in which a factor will lead to failure of some suppliers, manufacturer and some distributors simultaneously in supply chain. It is the problem of diagnosis of supply chain with common cause failure. Based on this, the

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study extends the study of Guo-Hua *et al*. (2009) based on reliability diagnosis of supply chain with independent cause failure to the problem of diagnosis of supply chain with common cause failure.

The so-called Common Cause Failure, abbreviated as CCF, means the simultaneous failure of 2 or more events caused by some certain causes in a system. It is a multiple failure owing to some common causes (Wang *et al*., 2007), which commonly exists in engineering system, increasing the joint probability of failure in system failure mode and reducing reliability of redundant system. CCF analysis has been made use of by many countries in studying complex system reliability. Nowadays, many reliability engineering experts have established a lot of models and methods concerning common cause failure (Xie *et al*., 2004; Vaurio, 1999; Hughes, 1987; Jussi, 1998; Xie, 1998), such as beta-factor model, 2 failures rate model, common load model, basic parameters model, multiple Greek letters model, α-factor model and so on. The models above all regard CCF as additional events independent of system to be considered isolated. Strictly speaking, they could not be called as models. Despite the methods of studying CCF are large in number, their object are all concerned with the specific physical systems or the failure of machine parts. When it comes to CCF of supply chain, there is few literature.

In this study, the diagnostic model of reliability of supply chain with common cause failure was established. Then considering unreliability and key importance as quantitative index, the diagnostic algorism of key factors of reliability of supply chain with common cause failure was studied by the method of Monte Carlo Simulation. The algorism can be used to evaluate the reliability of f supply chain and determine key factors which cause the failure of supply chain, which supplies a new method for diagnosing reliability of supply chain based on common cause failure. Finally, an example was presented to prove the feasibility and validity of the model and method.

MODEL OF RELIABILITY DIAGNOSIS OF SUPPLY CHAIN BASED ON COMMON CAUSE FAILURE

The model of reliability diagnosis of supply chain based on common cause failures will be structured by the method of fault tree analysis.

Fault Tree Analysis (FTA) is a technique for reliability and safety analysis. Bell Telephone Laboratories developed the concept in 1962 for the US Air Force for use with the Minuteman system. It was later adopted and extensively applied by the Boeing Company. Fault tree analysis is one of many symbolic "analytical logic techniques" found in operations research and in system reliability.

An FTD is built top-down and in term of events rather than blocks. It uses a graphic "model" of the pathways within a system that can lead to a foreseeable, undesirable loss event (or a failure). The pathways interconnect contributory events and conditions, using standard logic symbols (AND, OR etc.). The basic constructs in a fault tree diagram are gates and events, where the events have an identical meaning as a block in an RBD and the gates are the conditions.

The reasons why supply chain fails can be found from the analysis of failure mode of supply chain. The document 9 pointed out 14 factors leading to supply chain failure, in fact, there are 6 categories. Based on taking 3-tier supply chain centering on manufacturer as the object, the factors of supply chain failure be classed as follows:

- There are 8 categories for the successful operation of suppliers: production equipment being not of fault, the level of production technology to meet the requirements, reasonable production planning, complete transportation facilities, reasonable transportation plan and assurance of raw material quality and performance, smooth information communication and without human error.
- There are 8 categories for the successful operation of manufacturers: production equipment being not fault, the level of production technology to meet the requirements, reasonable production plan, complete transportation facilities, reasonable transportation plan, assurance of raw material quality and performance, smooth information communication and without human error.
- There are 6 categories for the successful operation of the distributors: Accurate market prediction, reasonable sales plan, reasonable transportation plan, complete transportation facilities, sensitive response to market information and without human error.

From above analysis about the method of fault tree analysis and the reasons why supply chain fails. So, the model of diagnosis of supply chain failure can be established. Supply chain failure is defined as the top event; Every suppliers failure, manufacturer failure and every distributors failure are defined as the intermediate events; The primary events are composed of suppliers failure cause, manufacturer failure cause and distributors failure cause. From the relationship between the top event and the intermediate events, the intermediate events and the primary events, the figure of reliability diagnosis of supply chain failure can be created, as can be seen from Fig. 1. The meaning of all symbols in Fig. 1 can be seen from section 3.(A) system description.

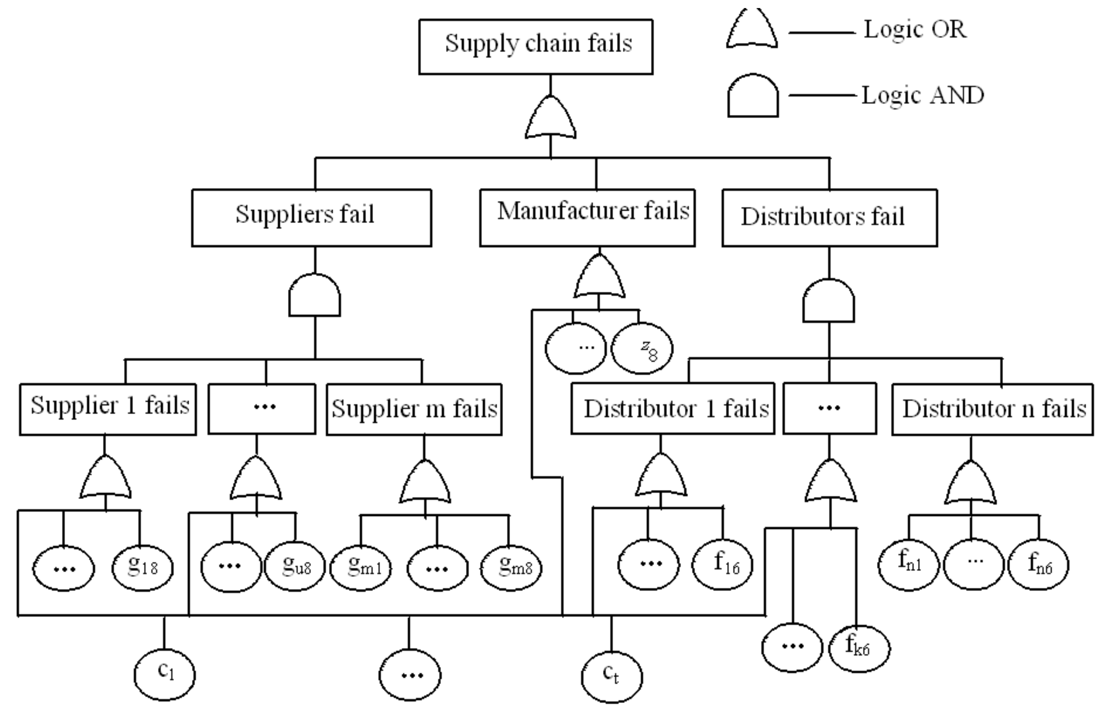

Fig. 1: The model of reliability diagnosis of supply chain based on common cause failure

SIMULATION ALGORITHM OF DIAGNOSING RELIABILITY OF SUPPLY CHAIN BASED ON COMMON CAUSE FAILURE

System description: Suppose:
S : System

There are w suppliers with common cause in supply chain system and gu(1≤u≤w) represents them:

gv(w<v≤m) : Suppliers with non-common cause
guy(1≤y≤8-t) : The y primary event without common cause of the u supplier with common cause
gvj(j = 1, 2,…, 8) : The j failure cause of the v supplier without common cause
zk(1≤k≤8-t) : Non-common primary events in manufacturer

There are p distributors with common cause in supply chain, fk (1≤k≤p) represents them:

fks(1≤s≤6-t) : The s primary event without common cause of the k distributor with common cause
fe(p+1≤e≤n) : Distributors without common cause
fev(1≤v≤6-t) : The v failure cause of the e distributor without common cause

So, the system s can be expressed as follows:

S = {ct(1≤t≤6), guy（1≤u≤w, 1≤y≤8-t), gvj(w<<m, j = 1, 2,…, 8), zk(1≤k≤8-t), fks(1≤k≤p, 1≤s≤6-t), fev(p+1≤e≤n, 1≤v≤6-t)}

Simulation algorithm: Suppose:
N : The number of system simulation
Tt : The number of common primary events' occurrence
Tguy : The number of failure of the y primary event without common cause of the u supplier with common cause
Tgvj : The number of failure of the j failure cause of the v supplier without common cause
Tzk : The number of failure of non-common primary events in manufacturer
Tfks : The number of failure of the s primary event without common cause of the k distributor with common cause
Tfev : The number of failure of the v failure cause of the e distributor without common cause
T : The total number of system operation

The simulation algorithm of diagnosing the reliability of supply chain based on common cause failure can be taken to run as follows:

Step 1: Produce a series of random numbers Rt by the method of Monte Karlo to judge status of common events. If the common events occurred, it indicates the manufacturer failed, so write down which category or categories of common causes which lead to supply chain

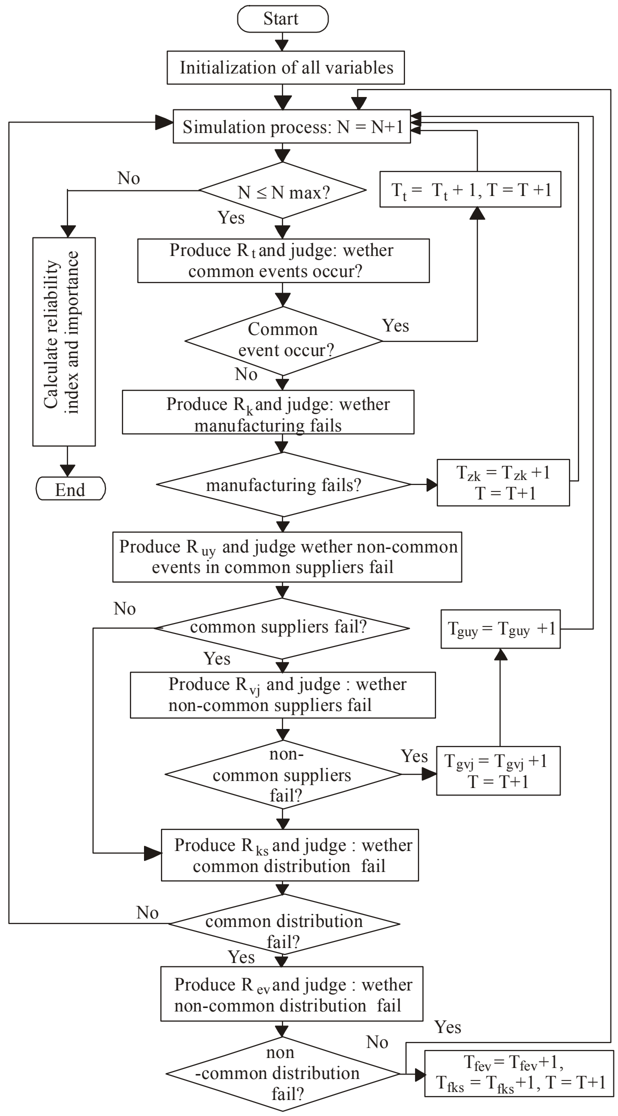

Fig. 2: The simulation process of reliability diagnosis of supply chain based on common cause failure

fails, make Tt = Tt+1, T = T+1 and the next simulation is carried out; If the common events did not occur, it indicates the manufacturer didn't fail, program will turn to step (2).

Step 2: Again produce a series of random numbers Rk to judge status of primary events without common cause in manufacturer, which can be used to judge whether manufacture fails. If it fails, write down which category or categories of non-common causes which lead to supply chain fails and make Tzk = Tzk+1(1≤k≤8-t), T = T+1, the next simulation is carried out; If it doesn't fail, program will turn to step (3).

Step 3: Again produce a series of random numbers Ruy to judge status of primary events without common cause in common suppliers, which can be used to judge whether common suppliers fail or not. If they fail, write down which category or categories of non-common causes which lead to common suppliers fail, that is guy and program will turn to step (4); if they don't fail, program will turn to step (2).

Step 4: Again produce a series of random numbers Rvj to judge status of primary events of suppliers without common cause, which can be used to judge whether suppliers without common cause fail or not. If they fail, write down which category or categories of causes which lead to them fail and make Tgvj = Tgvj+1, Tguy = Tguy+1, T = T+1, the next simulation is carried out; If they don't fail, program will turn to step (5).

Step 5: Again produce a series of random numbers Rks to judge status of primary events without common cause in, which can be used to judge whether common distributors fail or not. If they fail, write down which category or categories of primary events which lead to them fail, that is fks, program will turn to step (6); If they don't fail, it indicates supply chain works successfully in this time and the next simulation is carried out.

Step 6: Again produce a series of random numbers Rev to judge status of primary events of distributors without common cause, which can be used to whether distributors without common cause fail or not. If they fail, write down which category or categories of primary events which lead to them fail and make Tfev = Tfev+1, Tfks = Tfks+1, T = T+1, the next simulation is carried out; If they don't fail, it indicates supply chain works successfully in this time, the next simulation is carried out.

Step 7: Repeat the above process until the end of the simulation, then calculate system reliability index and key importance of every primary events and sort them, so key factors can be determined, which offers a new way to prove supply chain. Figure 2 shows the simulation process of reliability diagnosis of supply chain based on common cause failure.

Through calculating the values of T_t/T, Tg_{vj}/T, Tg_{uy}/T, Tz_k/T, Tf_{st}/T, reliability of supply chain and key importance of every event can be obtained, and then the key factors can be found.

EXAMPLE STUDY

One certain manufacturer-centered supply chain consists of 3 suppliers (indicated by g1, g2 and g3, respectively) who are up to supplying parts and components to next manufacturer; one manufacturer (indicated by z) and 2 distributors (indicated by f1 and f2). The factor" Unreasonable transport plans" is the common cause factor of supplier f1, manufacturer z and distributor f1, because their transportation plans are done by the same transportation company.

Enplanement: g15 = z5 = f15, they represses the same common cause factor. Figure 3 shows the structure of 1 certain manufacturer-centered supply chains.

According to analyzing the statistical data in Table 1, 2 and 3, which came from the process of the supply chain running 500 times from 6 to 9 in 2007, the probability of the common cause factor is 0.03, the supplier g1 has 4 failure factors g11, g13, g14 and g16, their probability is 0.390, 0.080, 0.120 and 0.150, respectively; the supplier g2 has 3 failure factors g24, g26 and g28, their probability is 0.040, 0.180 and 0.100, respectively; the supplier g3 has 3 failure factors

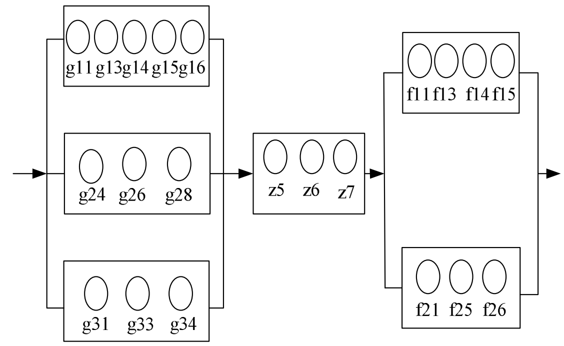

Fig.3: The structure of one certain manufacturer-centered supply chain

Table 1: Statistics of failure factors of suppliers

Failure factors	Supplier 1	Supplier 2	Supplier 3
Incomplete production equipment	195	0	40
Production level is not high	0	0	0
Unreasonable production plan	40	0	85
Imperfect transportation facilities	60	20	30
Unreasonable transport plans	15	0	0
Flaw raw material and product	75	90	0
Impeded communication of information	0	0	0
Human error	0	50	0

Table 2: Statistics of failure factors of manufacturer

Failure factors	Manufacturer
Incomplete production equipment	0
Production level is not high	0
Unreasonable production plan	0
Imperfect transportation facilities	0
Unreasonable transport plans	15
Flaw raw material and product	10
Impeded communication of information	19
Human error	0

Table 3: Statistics of failure factors of distributors

Failure factors	Distributor 1	Distributor 2
Inaccurate market prediction	17	5
Unreasonable sales plans	0	0
Unreasonable transport plans	15	0
Incomplete transportation facilities	0	0
Insensitive response to market	6	13
Human error	5	70

g31, g33 and g34, their probability is 0.080, 0.170 and 0.060, respectively. The manufacture z has 2 failure factors z6 and z7, their probability is 0.020 and 0.038. The distributors' f1 has 4 failure factors f11, f12, f15 and f16, their probability is 0.034, 0.140, 0.012 and 0.010, respectively; the distributors' f2 has 3 failure factors, which are f21, f25 and f26 and their probability is 0.010, 0.026 and 0.140, respectively.

Through 50000 times of simulation, system unreliability is 0.155120. When choose one simulation of 50000 times as the result, importance of every primary events can be seen as follows:

W {c1} = {0.196751};
W {z6, z7} = {0.121325, 0.220603};
W {g11, g13, g14, g16} = {0.186178, 0.038938, 0.055699, 0.070139};
W {g24, g26, g28} = {0.038164, 0.172898, 0.095668};
W {g31, g33, g34} = {0.076973, 0.169030, 0.0558277};
W {f11, f12, f15, f16} = {0.035714, 0.135895, 0.010830, 0.010701};
W {f21, f25, f26} = {0.011088, 0.028623, 0.150722}.

From simulation result, supply chain's reliability is 0.844880. In this example, there are 20 factors which lead to supply chain fails. According 28 principles, that is the key factors accounting for 20% and non-critical factors accounting for 80%, 4 factors can be as key factors, which are {z7, c1, g11, g26}. These factors are the weak of the supply chain, which needs to be strengthened the control.

CONCLUSION

Diagnosing reliability of supply chain based on common cause is a new challenging problem. Relative to the diagnosis reliability of supply chain based on independent cause failure, common causes increases the complexity and difficulty of diagnosing supply chain's reliability. After the model of diagnosing reliability of supply chain based on common because failure is constructed by the principle of fault tree analysis, simulation algorithm of it is implemented, which is a good solution to measure reliability of supply chain and to diagnose key factors causing supply chain fails.

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