Research on Supply Chain Resilience Evaluation

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Abstract   This paper proposes the evaluation index system of supply chain resilience on the basis of analyzing the current status of supply chain resilience. The anthors compare and analyze the four evaluation methods of supply chain resilience and draw the conclusion that the black box evaluation method is comparatively simple and objective. The significance of supply chain evaluation is to balance resilience, cost and efficiency, and plan supply chain resilience for emergent events so as to renew quickly from interruption and decrease loss.
Key words   Supply chain resilience; Resilience evaluation; Index system

1 Introduction

Since USA 911 terror attack, Taiwan earthquake, 8 minutes fire accident of PHILIPS & ERICSSON, more and more researches on supply chain emergency disruptions in academic and industrial fields to probe the effective response tactic, to strengthen supply chain resilience is the most effective way, but the supply chain resilience measure is critical for supply chain resilience evaluation and also the premise of improving the quality of supply chain resilience. But there are few research literature for supply chain resilience measure at home and aboard.

2 Literature Summary

Gunderson（2000）defines resilience attribute: firstly, system can endure quantity change; secondly, system self-organization ability degree; thirdly, system study and self-adaptation degree. So the self-adaptation ability is one factor of resilience and reflects study action which the system respond disruption[1]. The research on resilient supply chain abroad is a prototype until 2001. Muckstadt & Murray（2001）point out to strengthen the cooperation relationship and cooperation intension among supply chain members and decrease the business environment uncertainty to create supply chain resilience[2]. Christopher（2003）thinks the best way to obtain supply chain resilience is to create network which can respond status change quickly*①. Rice and Caniat（2003）suggest to apply mix flexibility and redundancy to strengthen supply chain resilience[3]. As the continuous change of exterior environment and demand, the supply chain network is never stable. Haywood & Peck（2003）suggest to strengthen the management during supply chain change period. It is critical for supply chain resilience because the supply chain is easy to be attacked when it changes[4]. Lee（2004）summarizes the effective supply chain resilience standard: firstly, quick response for emergency demand and supply change; secondly, the adaptation ability along with market structure and tactic evolution; thirdly, supply chain members form unions to maximize self-benefit and the whole supply chain performance[5]. Yossi Sheffi（2005）points out resilience could enhance supply chain competitiveness and there are three ways to increase resilience: increase redundancy, improve flexibility and change company culture. To increase redundancy will affect utility and the other two factors are critical to increase resilience[6].

In China, the definitions of supply chain resilience connotation are different from each other. Haohua.Liu（2007）defines supply chain resilience: the ability of the supply chain network system to return to original or ideal status after disruption risk including the speed (manufacturing, service, supply ratio) of coming back to normal performance[7]. Haiyan.Yi（2008）thinks the supply chain resilience is the adaptation ability for the environment change including flexibility and agility. Flexibility is the mobility of the supply chain do adjustment to meet customers' requirements along with market environment and conditions change. The agility is the ability of quick response for unpredictable change of supply or demand[8].

To sum up, supply chain resilience is the ability of the supply chain to return to original or ideal status under emergency risk environment. That is like the ability of a spring to return to the original status within elasticity limit under foreign force. Supply chain resilience mainly includes structure

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resilience, information system resilience, logistic resilience etc. We discuss supply chain resilience evaluation from the index system construction perspective which includes structure resilience, information system resilience, logistic resilience etc.
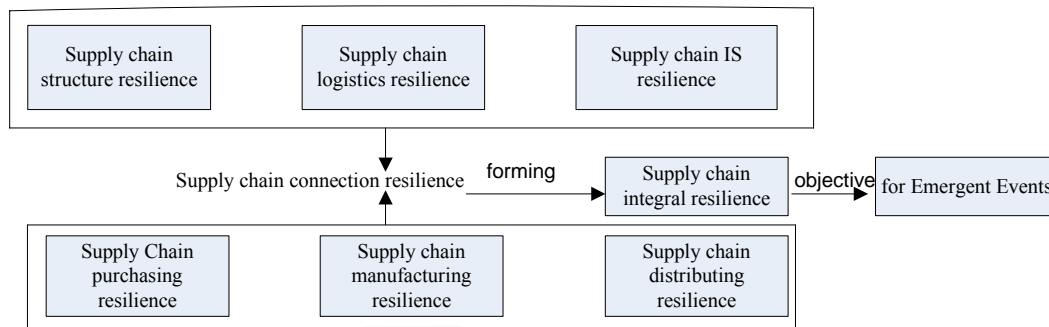
3 Evaluation Index System of Supply Chain Resilience

3.1 Construction principle of the index system

Supply chain resilience index system is the standard to evaluate supply chain resilience and affect the effectiveness of supply chain resilience evaluation directly. So to confirm its construction principle is the premise of constructing specific index system. As shown in table 1, it proceed from the character of supply chain resilience index system to confirm the construction principle of it. Core enterprise should confirm the supply chain resilience evaluation index system with considering the whole supply chain and the joint participation of enterprises at each node. Because the enterprises at each node to participate the construction of the resilience evaluation index system can ensure all enterprises to understand and recognize it so as to improve the whole supply chain resilience through adjusting and improving their operation situation according to the resilience evaluation performance.

Table 1　Construction Principle of the Supply Chain Resilience Index System

principle	connotation
consistency	the index system is consistent with the basic characteristic & objective of the supply chain resilience
balance	balance supply chain resilience and cost
completeness	multi-factor, multi-level
independent	relative independent index, non-repetitive
representative	choose the representative index under the premise of completeness
feasibility	ensure it is easy to access the index value
collaborative	the index system should take into account both reflecting the whole supply resilience and the enterprises relations

Figure1　Suppiy Chain Resilience Constitution Based on System Approach

3.2 Index system constitution

As shown in figure 1, we classify supply chain resilience based on system approach. Combined with the construction principle of supply chain index system , we think the construction of the supply chain resilience evaluation index system with the cost limit as shown in figure 2. There are five levels of supply chain resilience evaluation index system, those are general objective level, sub- objective level, dimensionality level and index level (the first class index and the second class index). The general objective level indicate the whole supply chain resilience level and be divided by sub-objective level into interrelated sub-objective levels, those are structure resilience sub-objective, logistic resilience sub-objective, information system resilience sub-objective, purchasing resilience sub-objective, manufacturing resilience sub-objective, distribution resilience sub-objective. Dimensionality at each sub-objective level can indicate supply chain resilience dimension character which divided into velocity

dimension and domain dimension or structure dimension and domain dimension. It represents the index factors of supply chain resilience essentially.
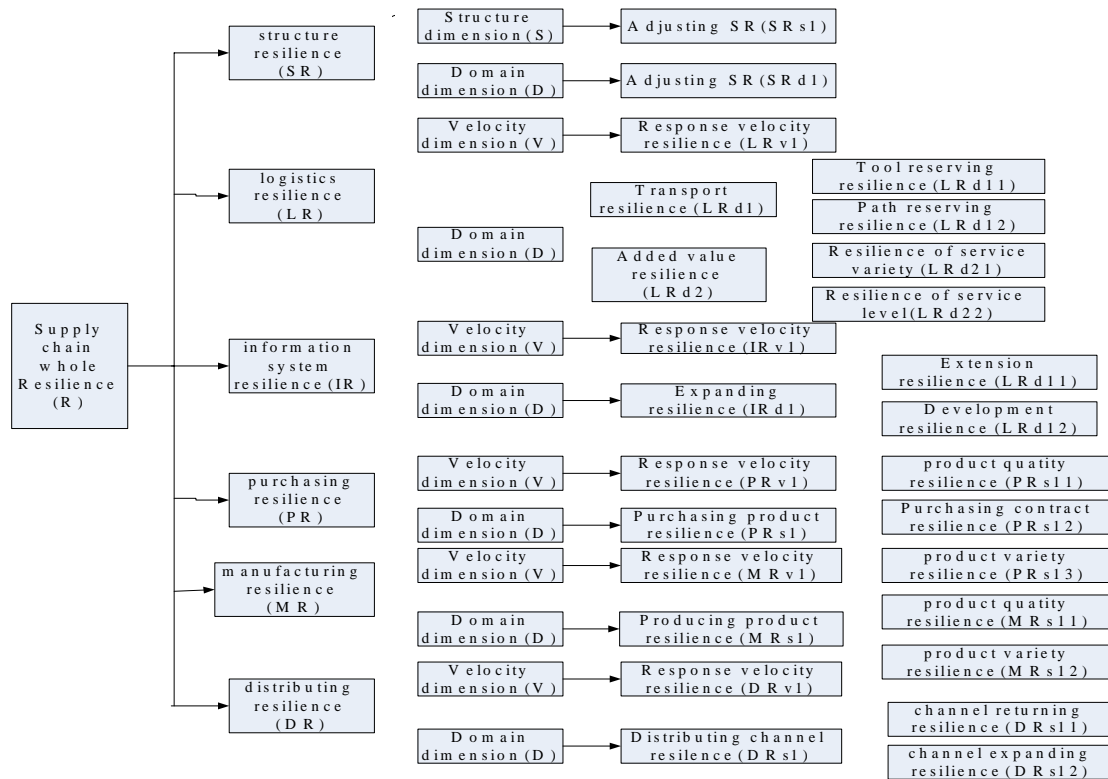
Supply chain whole Resilience (R)
- structure resilience (SR)
  - Structure dimension (S) → Adjusting SR (SRs1)
  - Domain dimension (D) → Adjusting SR (SRd1)
- logistics resilience (LR)
  - Velocity dimension (V) → Response velocity resilience (LRv1)
  - Domain dimension (D)
    - Transport resilience (LRd1)
      - Tool reserving resilience (LRd11)
      - Path reserving resilience (LRd12)
    - Added value resilience (LRd2)
      - Resilience of service variety (LRd21)
      - Resilience of service level (LRd22)
- information system resilience (IR)
  - Velocity dimension (V) → Response velocity resilience (IRv1)
  - Domain dimension (D) → Expanding resilience (IRd1)
    - Extension resilience (LRd11)
    - Development resilience (LRd12)
- purchasing resilience (PR)
  - Velocity dimension (V) → Response velocity resilience (PRv1)
  - Domain dimension (D) → Purchasing product resilience (PRs1)
    - product quatity resilience (PRs11)
    - Purchasing contract resilience (PRs12)
    - product variety resilience (PRs13)
- manufacturing resilience (MR)
  - Velocity dimension (V) → Response velocity resilience (MRv1)
  - Domain dimension (D) → Producing product resilience (MRs1)
    - product quatity resilience (MRs11)
    - product variety resilience (MRs12)
- distributing resilience (DR)
  - Velocity dimension (V) → Response velocity resilience (DRv1)
  - Domain dimension (D) → Distributing channel reslience (DRs1)
    - channel returning resilience (DRs11)
    - channel expanding resilience (DRs12)

Figure 2   Evaluation Index System of Supply Chain Resilience

4 Evaluation Method and the Analysis of the Whole Supply Chain Resilience

4.1 Evaluation method of the whole supply chain resilience

The whole supply chain resilience is the combined results of each sub-objective. We use constraint method, addition, multiplication, black-box method to evaluate the whole supply chain resilience according to the Cross-Correlation effect of each sub-objective[9].

4.1.1 Constraint method

According to constraint theory, the system performance is most affected by the weakest link. As for the supply chain system which is composed by many resilience factors, if one of the factor decides the system performance, then the factor resilience decides the whole supply chain resilience.

$$F = \min(SR, LR, IR, PR, MR, DR) \tag{1}$$

SR, LR, IR, PR, MR, DR in formula(1)correspond to structure resilience, logistic resilience, information system resilience, purchasing resilience, manufacturing resilience and distribution resilience in figure 2 respectively. According to constraint theory, the value's choice of the whole supply chain resilience is the value of F in formula (1).

4.1.2 Addition

The whole supply chain resilience (general objective) is the integrated inflection of constitution factors (sub-objective). If the effect to the whole supply chain resilience of each factor is different but the function is parallel, then the whole supply chain resilience is the weighted mean of each factor resilience.

$$F = \rho_1 SR + \rho_2 LR + \rho_3 IR + \rho_4 PR + \rho_5 MR + \rho_6 DR \tag{2}$$

SR, LR, IR, PR, MR, DR in formula (2) correspond to structure resilience, logistic resilience, information system resilience, purchasing resilience, manufacturing resilience and distribution resilience in figure 2 respectively. ρ_i is the weight of each factor resilience (sub-objective)，$\sum_{i=1}^{6} \rho_i = 1, 0 \le \rho_i \le 1$ 。

4.1.3 Multiplication

If the whole supply chain resilience by multiplying each factor of supply chain system, the whole supply chain resilience be expressed by formula

$$F = SR \times LR \times IR \times PR \times MR \times DR \tag{3}$$

Formula(3) SR, LR, IR, PR, MR, DR correspond to structure resilience, logistic resilience, information system resilience, purchasing resilience, manufacturing resilience and distribution resilience in figure 2 respectively. This method apply to series collection relationship for factors.

4.1.4 Black box method

Black box is the system which neither couldn't be opened nor observed its inner state directly. For example, we can only define the structure and parameter of our brain through input and output of the information. Black box method provide an important road to realize things especially for the system with complex inner structure and the system which human beings haven't resolved yet. Black box theory indicate that if the inner structure of a system is not clear or impossible to understand, we could research the system performance through the relationship between system input and system output and no need to consider the inner structure of the system. Within the supply chain system, as the complex interaction among resilience factors, it is difficult to analyze the inner structure. So we use black box theory to evaluate whole supply chain resilience without considering the inner structure. So the whole supply chain resilience could be evaluated by output resilience response for input of the supply chain system, as shown in the figure 3.
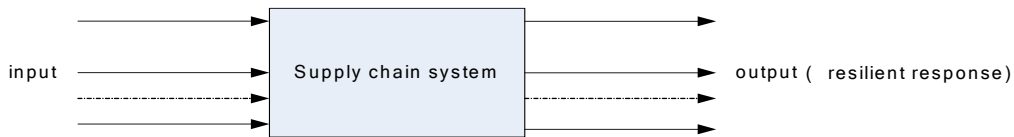

Figure 3　Black Box Method for Supply Chain Resilience Evaluation

4.2 Comparative analysis of supply chain resilience evaluation method

Table 2　Comparative Analysis of Supply Chain Resilience Evaluation Method

Evaluation method	reference	calculative method
Constraint method	System constraint principle	evaluate the resilience value of each subsystem, choose the minimum value of subsystem as the whole supply chain resilience value
Addition	superposition principle	evaluate the resilience value of each subsystem, choose the weighted mean value of subsystem as the whole supply chain resilience value
Multiplication	multiplication principle	the whole supply chain resilience value by multiply the resilience value of each subsystem.
Black box method	black box theory	evaluate supply chain response index value, the whole supply chain resilience value is the weighted mean value of the output resilience index

In table 2, constraint method, addition and multiplication need to evaluate the resilience value of each factor, but black box method is just evaluate the output resilience response index. So the calculation amount of the black box method is much less than other methods and more operational. What's more important, the black box method can ignore the inner structure of supply chain resilience system and evaluate the whole supply chain resilience through evaluating supply chain resilience response index directly. So compared with other three methods, black box method is much simple and objective.

5 Conclusions

Resilience is different from other evaluation indexes such as cost, efficiency and quality. It expresses as a potential ability, which is the response ability for emergent events but not an action. It comes with the emergency and is difficult to evaluate when it hasn't shown yet. Since the definition and classification of

supply chain resilience is disunity and limitation, there is no uniform and valid method. So there are few research for supply chain resilience measure.

The evaluation of supply chain resilience didn't be solved well is one of the reasons that resilience concept didn't be highly regarded in supply chain decision. So in this paper, we build the evaluation index system of supply chain resilience, analyze and compare the four possible evaluation methods, propose the black box method as it's much simple and objective. The significance of supply chain evaluation is to balance resilience, cost and efficiency and plan supply chain resilience for emergent events so as to renew quickly from interruption and decrease loss.

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