Abstract—Supply chain is regarded as a complex system that consists of suppliers, manufacturers, vendors and logistics service providers. Robustness is the main target in supply chain management. In recent years, robust optimization has emerged as a methodology for managing supply chain risks. In this paper, we develop a method of achieving its robustness objective within a supply chain using reliability allocation. Supply chain reliability allocation tries to apply the fundamentals of engineering reliability allocation to a supply chain system, and distribute a supply chain reliability index among all its members. Furthermore, we discuss how deals with the supply chain members that had failed to meet their reliability targets.

Index Terms—supply chain, robustness, robust optimization, reliability allocation

I. INTRODUCTION

Robustness is the capability that a system function normally when it is suffering the changes of its internal structure and external environment. Robustness is a basic attribute of a system, and it goes with the uncertain questions. In recent days, robustness has been paid attention to in the nature science and the social science societies. Robustness of supply chain has been the frontier of supply chain research.

Supply chain robustness is the capability that a supply chain function normally when it is suffering the changes of its internal structure and external environment. In a supply chain system, its uncertainties result from supply, manufacturing, sales and other operational aspects, which is from the earthquake, flood, fire, production accidents, international economical environment and so on. All these could influence the normal operation of the supply chain. Robustness plies an important role in its income increase and the sustainability of the supply chain under these uncertain factors [1].

Robust optimization is a new method to solve the problems happened in the changes of its internal structure and external environment under uncertainty. When solving the problems, one of the mathematical programming deal with the uncertainty of constraint parameters, another one is the uncertainty of objective function parameter. Robust optimization mainly deal with the uncertainty of the external disturbance. So far, robust optimization has changed from SOYSTER’s linear robust optimization [2] to the recent robustness evolution theory system. Besides, the trend has been changing and developing. BENTAL[3], EI GHAOUI[4] and so on, has made some effort to for solving an excess of conversation, applied robust optimization to the problem of uncertain aggregation of ellipsoid, and gotten cone quadratic programming. BERTSIMAS[5] had provided a technology especially for the polyhedron uncertainty, through the formation of linear robustness, controlling the conservative level of roots.

Robust optimization has been widely used at the field of natural sciences, engineering, economic management, and so on. In the field of supply chain management research. Many domestic and foreign scholars make use of robust optimization and the solve many problems such as newsboy problem, allocation of resources in supply and demand, Inventory management, pricing decision-making and so on. YU[6] examines an EOQ model under uncertain the supply rate, unit order costs, unit stock cost etc. He described the definition of uncertainty and the two robustness rules based on the characteristics of input data: (1) minimize the largest stock costs in all circumstances; (2) minimize the largest leaving rates at any circumstances. VAIRAKTARAKIS[7] provides a multiproduction robustness model of newsboy problem under uncertainty, and describes demand uncertainty to utilize two kinds of circumstances, that is, Range of scenarios and discrete circumstances. BERTSIMAS[8] promoted a robust optimization method to get optimal strategy for the inventory management of single and series supply chain system under the stochastic demand. BOAKAS[9] study a H∞ control problem tracking customer demands under uncertain disturbance for manufacturer, making the smallest tracking error calculated through the application of linear matrix inequalities LMI.

These methods have made great significant progress than earlier methods, they put forward robust linear programming models, robust semidefinite programming models, robust quadratic programming models, robust semidefinite programming models based different types of data in uncertain linear programming. However, supply chain robust optimization being used in practice is the main reason, because its complication, it’s applying is random. So, simple and easy methods to ensure robustness of supply chain in theory and practice have their great value.

In this paper, we develop a method to guarantee supply chain robustness: supply chain reliability allocation. The method tries to apply the fundamentals of ACADEMY PUBLISHER
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engineering reliability allocation to a supply chain system, and distribute a supply chain reliability objective among all its members in order. Section II describes the theory and method of reliability allocation, and Section III shows how supply chain reliability allocation operates. Section IV discusses how deal with the supply chain members that had failed to meet their reliability targets. Conclusions are presented in Section V.

II. FUNDAMENTALS OF RELIABILITY ALLOCATION

Reliability allocation is to obey the reliability index provided on system design books, in a proper method, and then allocate to subsystem, equipment and components, and it will be taken into corresponding the book or the techno-economic contract. This is a decomposition process from the whole to the details, from the large to the small, from the upper to the lower. The purpose that reasonably ascertain the reliability indexes of various units is to ensure them in unit design, manufacture, experiment, acceptance. Conversely, it will improve and enhance the design, manufacture, testing, acceptance, and it will promote that designers more fully weigh the relationship among the performance, function, weight, cost and effectiveness of the system to improve product design quality.

The theory of reliability allocation as following: it distributes a system reliability objective among all its units, and their reliability indexes could not be below its criterion. The key of reliability allocation is to know the basic inequation[10]:

\[ F(R_1, R_2, \ldots, R_n) \geq R^* \]

In this inequation:
- \( R^* \) is the reliability index that a system could get
- \( R_i \) is the reliability index allocated of unit \( i \) (\( i = 1, 2, \ldots, n \))
- \( n \) is the unit number of a system.

Reliability allocation in engineering system often considers the technological level, complexity, importance, and mission of the system. The method of engineering reliability allocation is generally mathematical programming, especially the dynamic programming [15]. Other methods are very little used in the engineering reliability allocation, such as the equal distribution method, comprehensive score distribution method, etc.

III. RELIABILITY ALLOCATION OF SUPPLY CHAIN

The reliability allocation of supply chain is to use the idea of reliability allocation. That is to allocate a supply chain reliability index to every members. As various difficulties to quantify many factors in such a large-scale complex supply chain system, it is not a simple mathematical programming, but is a qualitative and quantitative decision-making problems.

As to the reliability allocation of supply chain, we take use of comprehensive score distribution method. The method is that experts weigh up main factors to score every unit within a supply chain, and assign corresponding reliability index to every unit based on its score. According to the rules, we give them different score from 1 to 10. The high score is assigned to a higher failure probability.

A. A chain model of supply chain reliability allocation

A chain model of supply chain reliability allocation as following:

- Firstly, the importance of every member within a supply chain. Their sales amount are used to measure their importance within a supply chain. We give 10 mark if one has highest sales amount in a whole chain; others could get 1 to 9 mark according to their percentage of sales amount.
- Secondly, the complexity of the organizational structure of every member within a supply chain. The simplest organization could get 10 mark. Others could get 1 to 9 mark. The complexity is weighted based on amount of department in an organization.
- Thirdly, the duration of becoming a supply chain member. The shortest could get 10 mark. Others could get 1 to 9 mark according to the duration of becoming a supply chain member.

Now we need to impel the reliability index to get 0.9 on this supply chain, because of many factors: the importance, complexity of the organizational structure, and duration of becoming a member within a supply chain. Consequently, during allocation, we can set the effective factor of supplier A with 6,6,8; manufacturer B with 10,5,4; vendor C with 9,10,2. the last index would be got as table I.

The every members with a supply chain get their marks according to their accumulation of factors. The method is as follows:

1) calculate the comprehensive score of \( i \) member:

To change the default, adjust the template as follows.

\[ C_i = \prod_{j=1}^{3} m_{ij}, \quad i = 1, 2, \ldots, n \]

In this formula,
- \( m_{ij} \) — i firm score in j factor
- \( n \) — the number of companies within a supply chain.

2) calculate the total scores for a supply chain system:

\[ C_s = \sum_{i=1}^{n} C_i, \quad i = 1, 2, \ldots, n \]

In this formula,
- \( C_i \) — the comprehensive score of \( i \) firm
- \( C_s \) — the total scores of a supply chain system
- \( n \) — the number of companies within a supply chain.

3) calculate the weighted factors for every member:
\[ K_i = \frac{C_i}{C_s}, \quad i = 1, 2, \ldots, n \]

In this formula, 
- \( K_i \) — the weighted factors of \( i \) firm 
- \( C_i \) — the comprehensive score of \( i \) firm 
- \( C_s \) — the total scores of a supply chain system 
- \( n \) — the number of companies within a supply chain

4) Calculate the weighted factors for every member:

\[ R_i = 1 - K_i(1 - R^*), \quad i = 1, 2, \ldots, n \]

In this formula, 
- \( R^* \) — the needed index 
- \( K_i \) — the weighted factors of \( i \) firm 
- \( R_i \) — the reliability index allocated of \( i \) firm 
- \( n \) — the number of companies within a supply chain

For example, there are 3 members within a supply chain as figure 1: Supplier A, manufacturer B, and vendor C.

Now we need to impel the reliability index to get 0.9 on this supply chain, because of many factors: the importance, complexity of the organizational structure, and duration of becoming a member within a supply chain. Consequently, during allocation, we can set the effective factor of supplier A with 6, 6, 8; manufacturer B with 10, 5, 4; vendor C with 9, 10, 2. The last index would be got as table I.

So, supplier A, manufacturer B, and vendor C contain respectively the reliability of 0.9730, 0.9520, and 0.9758.

B. A network model of supply chain reliability allocation

As for a networked supply chain system, when we allocate its reliability, we need to treat them as a chain model: through putting respectively many supplier, manufacturer, vendor together, so it transforms itself into a chain model. By taking comprehensive allocation, we can get reliability of every different module, then we can get reliability of every member in a module. For example, if there are supplier A1, A2, A3 and manufacturer B1, B2, B3, and vendors C1, C2, C3 within a networked supply chain system. Its reliability is 0.9.

The stage of allocation:

Firstly, we treat suppliers, manufacturers, vendors as 3 modules as follows:

![Figure 2. A networked supply chain](image)

Secondly, reliability allocation within a networked supply chain. It should simulate a chain model of supply chain. There are three factors as well: (1) the importance of module in a fixed period, the one who has the largest sales accounting is the most important, we give it 10 marks; others are classified based on its sales amount, and give them 1 to 9 marks; (2) the complexity of the organizational structure in a module. The module that have simplest organizational structure could get 10 marks. Others could get 1 to 9 marks. The complexity is weighed based on the amount of department in an module. (3) the duration of becoming a member of a networked supply chain. As above, the shortest could get 10 marks, others could get 1 to 9 marks according to the rule. There are 3 modules and 3 factors: the importance of module, complexity of organizational structure and module, and duration of becoming a supply chain member: module A are 10, 4, 2; module B are 8, 8, 10; and module C are 6, 10, 9. Just as table II.

<table>
<thead>
<tr>
<th>Members</th>
<th>Factors</th>
<th>Total score</th>
<th>Weighted factor</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier module</td>
<td>80</td>
<td>0.0635</td>
<td>0.9937</td>
<td></td>
</tr>
<tr>
<td>Manufacturer</td>
<td>640</td>
<td>0.5079</td>
<td>0.9492</td>
<td></td>
</tr>
<tr>
<td>Vendor module</td>
<td>540</td>
<td>0.4286</td>
<td>0.9571</td>
<td></td>
</tr>
<tr>
<td>Supply chain</td>
<td>1260</td>
<td>1</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Thirdly, we use comprehensive method to allocate reliability of suppliers module. To postulate the importance, complexity of organizational structure, and duration of becoming a supply chain member of supplier A are 10, 7, 5; of supplier A2 are 4, 10, 9;
and them of supplier A3 are 2,5,10. We allocate it, and get the reliabilities of suppliers A1, A2, A3. Just as table III.

Fourthly, we use comprehensive method to allocate

TABLE V. A CHAIN MODEL OF SUPPLY CHAIN RELIABILITY ALLOCATION

<table>
<thead>
<tr>
<th>Members</th>
<th>Total score</th>
<th>Weighted factor</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer B1</td>
<td>80</td>
<td>0.1013</td>
<td>0.9949</td>
</tr>
<tr>
<td>Manufacturer B2</td>
<td>150</td>
<td>0.1899</td>
<td>0.9904</td>
</tr>
<tr>
<td>Manufacturer B3</td>
<td>560</td>
<td>0.7089</td>
<td>0.9640</td>
</tr>
<tr>
<td>Manufacturers module</td>
<td>790</td>
<td>1</td>
<td>0.9492</td>
</tr>
</tbody>
</table>

Fifthly, we use comprehensive method to allocate reliability of manufacturers module. To postulate the importance, complexity of organizational structure, and duration of becoming a supply chain member of manufacturer B1 are 4,10,2; them of manufacturer B2 are 3,5,10; and them of manufacturer B3 are 10,7,8. We allocate it, and get the reliabilities of manufacturer B1, B2, B3. Just as table IV.

TABLE IV. A CHAIN MODEL OF SUPPLY CHAIN RELIABILITY ALLOCATION

<table>
<thead>
<tr>
<th>Members</th>
<th>Total score</th>
<th>Weighted factor</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor C1</td>
<td>420</td>
<td>0.4667</td>
<td>0.9800</td>
</tr>
<tr>
<td>Vendor C2</td>
<td>180</td>
<td>0.2000</td>
<td>0.9999</td>
</tr>
<tr>
<td>Vendor C3</td>
<td>300</td>
<td>0.3333</td>
<td>0.9857</td>
</tr>
<tr>
<td>Vendors module</td>
<td>900</td>
<td>1</td>
<td>0.9571</td>
</tr>
</tbody>
</table>

Lastly, suppliers A1, A2, A3 reliability are 0.9973, 0.9972, 0.9992; manufacturers B1, B2, B3 reliability are 0.9949, 0.9904, 0.9640; vendors C1, C2, C3 reliability are 0.9800, 0.9999, 0.9857.

IV. DISCUSSION

Supply chain system reliability index is the target of the all companies with a supply chain, it need to be distributed to every member using reliability allocation, so we can ascertain the different feasible reliability indexes for every member. If they could not achieve their reliability indexes, we can use these methods as follows:

Firstly, it must achieve its reliability index to a deadline, otherwise it will be disused, and we choose other company to replace it to achieve its target.

Secondly, we could not eliminate it, but after observation about other firms, we choose the best one which is coupled with it to form a parallel subsystem. So the supply chain system can get it reliability target. Traditional supply chain is often the mechanism for a single supplier in a section, lacking of reliability and flexibility. To make sure the stability, important products should be provided by more than 2 suppliers or when there are some problems, it will result into big risks. Multiple suppliers bring not only sufficient flexibility, but also supplier competition, and ensure a steady supply.

V. CONCLUSION

This paper have mentioned a method to guarantee supply chain robustness: supply chain reliability allocation. We put forward chain and networked models of supply chain reliability allocation. The models are based on engineering reliability allocation. Under specific characteristics of supply chain, there are the generality and individuality between them. supply chain is not only a chain of information, capital, and material, but also an added value chain. After all, supply chain system is complicated, stochastic, fuzzy and unsteady, it’s a developing system, it’s much more complex than engineering system. So, the method mentioned in this paper is not too perfect to need improving further in the future.

REFERENCES