Perspective in Supply Chain Risk Management

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Abstract According to the methods of analyzing the supply chain risk management, describe the results about risk identifying, risk estimating and risk controlling for the risk producing among the operation process in supply chain, and analyze the results obtained, then give some resolving methods.

Keywords supply chain; risk, review; identify; evaluate; control

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1. Introduction

It is supply chain that become one of the most competitive economic organization, in essence, supply chain is a virtual organization (virtual company), which consists of several enterprises coupled with different objectivities cooperating with the others, according to certain rules coupled with resources of physical material, information, technology, marketing, and knowledge[1][2]. Furthermore, these flows in supply chain can be input, transferred and output to/from the downstream/upstream such that supply chain value maximized[3][4]. In this sense, only these resources are integrated well by a scientific mechanism, supply chain coordination, the performance of supply chain can be improved, which has been proven by Xiaojing ZHENG and Shizhen BAI in reference[5].

Thought strong advantages supply chain has because it is a virtual company consisting of certain enterprises by cooperating together, as mentioned above, every company make decision on its own. In this sense, each enterprise in supply chain can not be controlled by the other; similarly, each company cannot control others[6]. Furthermore, although coordination is more important to supply chain management, the uncertain case happen in supply chain operation process make these decisions difficult, especially to those uncertainty happened in different sub-operation process, in which several flows needed in supply chain are changed such that it cannot be coordinated[7]. In other instance, when emergency occurs, the environment changed sharply, for example, earthquake, avalanche, economical crisis, SARS, strike, terrorist attack, H1N1, hand-foot-mouth disease, make the demand market and/or
supply market change extensively such that the coordination is out of control for supply chain and certain enterprises in supply chain are faced the hazards of bankrupting and the danger of supply chain collapsed\[9\]. However, according to the theory about Prigogine, if the system stands the edge between chaos and order, the system would have much strong creative and adaptive, so would supply chain if it stands the edge between chaos and order such that there exists some degree of uncertainty in supply chain operating process, so, some degree of risks are permitted in supply chain operating process\[9\]. As analyzed above, there are certain risks in supply chain operation, so how to manage the supply chain risk and control the risks under the certain critical threshold such that supply chain is made robustness, stability and innovative, are the main research scopes.

Fractal and self-similar are more important as far as temporal dimension and spatial dimension for the supply chain are considered. Each enterprise in supply chain plays its own role and performs certain function in supply chain operation, which makes the supply chain active; similar, differential departments operate and act on corresponding function in each enterprise; in cases mentioned above, there are several flows such as physical material, funds, information and knowledge, are transferred in the input-output process, each resource’s non-regular change can bring some uncertain risk, they can be become more complex when all these uncertainty be interacted. So, the most important thing for supply chain risk management is to identify these risks, which means that where, why and who can be occurred and what must be known in detail. We must know the risk structure happened in supply chain operation process, just they are done, supply chain risk can be said to be managed. Furthermore, the degree and probability of risk should be estimated.

There are some comprehensive and profound reviews describe the study case for supply chain risk management, see Refs.\[10\]-\[16\], which accelerates supply chain risk management to draw more important conclusions. Anyway, scientists insists that risks happened in supply chain come from its operation process including: (1) supply management. Where, supplier’s number and their configuration decision, supplier’s order imputation, the uncertainty in supply contract decision and channel competition decision are included. Each resource’s change uncertainly happen in a certain process can produce some degree of risks and induce the supply more chaos and complexity. For example, the competition happened between different channels in supply chain is a new focus in this field, if the inter-prices, quantities and time needed have not been coordinated among the enterprises, supply chain can be destroyed and faced with being collapsed. These risks come from the resources flow through the supply chain system operation processes and they have been studied by many scientists, and several corresponding and profound conclusions are emerged. (2) Demand management. Demand fluctuated randomly, on temporal dimension and spatial dimension, with the product configuration, ways of transportation is the most important risk in this field, which makes the supply chain system become bifurcation because the initial operation parameters maybe set on the critical point due to the uncertainty happened. If the uncertainty can not be identified and conducted, the butterflies effect leading to different disasters, which means that different fatal risks unpredicted can be occurred in equal probability, would be induced. (3) Manufacture and production management. It is customer’s order postponed to produced and the uncertainty in the manufacture process, especial for the manufacture mode of mass customization that have stronger competitiveness than the else one’s, which produce hug risk to the supply chain. (4) Information management. It is the bull-whip effect induced because information asymmetry among the enterprises in supply chain that produce much redundant inventory that decrease the response capability to the environment and profit obtained, so it must be weakened for supply chain operating normal. The results obtained from four kinds of risks mentioned above will be analyzed, according to the risk management process of risk identification, risk estimation, risk control and risk coordination, and the conclusions extrapolated are given on our researching perspective, which makes the scientists touch them. The following Fig. 1 describe the basic thought.

Several different sub-risks in the supply chain entangle together, and these interactions and interdependences occur among the supply chain operation process, which makes the supply chain risk management, identifying, estimating, controlling and forewarning are considered step by step, more complex, so, a supply chain risk analysis method that is called analysis-synthesis should be introduced to study their evolution laws to manage them. If and
only doing thus, the evolution law of the supply chain risk could be mastered, and be decreased them under the critical point of percolation and be controlled them.

The next sections are arranged as follow: the results of the supply chain risk identification, from each stage in supply chain operation process, should be specified in section 2. Where, these study results about uncertain factors inducing every risk perhaps happened in every stage, the probability and threatening degree of the emergence induced by these uncertain factors and the corresponding damage, are specified in this section. Furthermore, the perspective in this direction is also forecasted in this section. The estimating of supply chain risk is also important aspect for supply chain risk managing, which the conclusions obtained are shown in section 3. In this section, the single risks occurred in supply chain and their estimating methods system are shown and analyzed, so does the total risk estimating. Similar, the conclusion about supply chain risk control will be shown as section 4.

2. Risk identification

Supply chain risk that occurs in the different supply chain operation processes can be induced because of resources flowing and can be transferred because of the interactions among agent’s behaviors and the interactions among kinds of risks, which maybe bring some uncertain fluctuation to certain operation processes and bring uncertain risks to do harm to the supply chain operating. On the other hands, several different risks, like financial risk, quality risk, quantity risk, moral hazards, for example, can be produced on the same link between the upstream process and the downstream one, furthermore, every characteristic risk can produce other ones because they perhaps be induced by the common factors that makes the risk in supply chain transferred, in this sense, which makes the risks identifying process in supply chain is much complex. So, the risk categories, induced factors, probability occurred and threatening degree of these risks must be analyzed, many scientific conclusions are drawn from this aspect, and be shown as follows.

2.1. Supply management

Supply is one of the most important part in supply chain operating, in this process, only reasonable quantity and excellent quality are provided, and the supply chain system can be run as normal and the corresponding risks’ can be kept from being induced, being developed, being transferred and being aggravated. As is well known, supply
chain system, in fact, is the combination of every enterprise’s core competitiveness in this organization, this kind organization of decision decentralized can be affected by the fluctuating of the several different and random factors except what come from the environment. Reconsidering these factors, because of their uncertainty, several emergences that can bring damage to supply chain perhaps happened, these emergences maybe enlarged and/or create the other ones due to the uncertain factors transferred to the downstream process with resources flowing, which forms the supply chain’s redundancy, then forms supply chain risks[17]. Mentioned above, supply chain risks come from supply chain operating process, so the risks rely on the supply chain structure, the topologic structure of supply chain enterprises interacting, products configuration (single product, dependent products, independent products, for example), the product demand distribution (Poisson distribution, normal distribution, Lévy distribution, and so on), the enterprises’ inventory strategies in supply chain((S,s), for example) and the strategies and distribution for the loss of out-of-store, and so on[7][18]. So, the certain risks structure must be coupled with the certain supply chain structure, in this sense, an obvious conclusion can be drawn: if the supply chain structure is located incorrectly, the risks coupled with must be occurred because there exist some degree of derangement between them making the supply chain lack of adaptive and creative capability, and will be damaged when facing interruption of uncertainty. Besides this kind of risk, the unreasonable distributing of payoff between enterprises is another factor to produce several risks, because it can not only do harm to some enterprises in supply chain and invoke their enthusiasm to cooperate with some certain ones, but also do harm to supply chain to some degree. So, as for identifying supply chain correctly, two category risks must be considered: the one is supply chain structure driven and the one is payoff imputation mechanism driven. The former can be considered from the aspects of supplier selection & management, the coordination and competition between different supply channels; and the latter should be invoked from the aspect of several problems coupled with mechanisms designed that consist of order distribution between enterprises and incentive mechanism[19].

Scientists have studied supply chain risk coupled with supply management from following aspects: the competition between supply channels, which make the resources lavished and supply chain’s or/and the enterprises’ profits lost because suppliers or retailers compete with the enterprises who stand on the same stage; supplier selection and management, which means that the quantity and quality of raw material, semi-finished products and products flowed in the supply chain that decide the supply chain’s competitive capability, that is to say, it is the fittest partners selected and managed carefully that bring the strongest competitiveness, otherwise, supply chain will face hug and necessary loss even damage to supply chain; supply chain order distribution decide the upstream enterprises’ attitude to the downstream ones, if faced unfair imputation, supply chain will face the hug crises that several enterprises in supply chain’s same stage conflict to the others. The corresponding conclusion obtained by scientists for these fields will be described as follows.

(1) The competition between supply chain channels

Under the uncertain and dynamical environment, enterprises need to provide the product of low cost, high level and diversity to meet the quick response to costumer’s demand, so, more and more companies transit the strategy from make-to-stock to make-to-order, shown in [20](Muriel et al. 2006), which can not only improve the customer’s service level but also decrease the loss of market share coupled with the customer’s demand unsatisfied. However, this kind of customization makes us confused too, if the quantity, quality and time can not meet the customer’s demand, which can produce bigger risks than the other case. In this sense, Mendelson and Parlaktürk(2008) have inducted it, in Ref. [21], and a certain case of oligarch monopolization with two sellers of two-stages game problems abstracted to the operation character has been introduced, the result shows that the value of customization product relies on the competitive advantage, the company can obtain more profits if it has the dominant position when facing the same price, however, as far as the supply chain system is considered, the profit is more important than the risk in this case. Houcai Shen, Jin Xu and Zhan Pang have analysed qualitatively, in Ref. [22], the relationship among risk evading degree, uncertainty of components needed and the properties of optimal purchasing strategies, then the factors induced the corresponding risks are analysed based on the result of qualitative analysis. These results show
that it is supply chain complex structure that make the supply chain operate more complex and face those uncertain factors that induce emergence produced uncertain loss, which means that only the adaptive supply chain can fit for the flexible and random changeable of environment. So, some certain enterprises who stand on the certain stage in this field and have stronger competitiveness must be asked to take part in their own supply chain. Then, moral hazards perhaps are appeared because these excellent enterprises’ immoral behaviours coupled with their advantages.

It is inner non-coordination in supply chain that make additional risks coupled with supply chain operating produced, which come from certain companies because they make decisions for local optimization to purify their own profits maximized but not the global optimization, and which do harm to the supply chain from the strategy’s perspective. The optimal strategies for keeping supply chain enterprises from competing with each other and improving this system have been given by many scientists, shown in Refs. [24] (Shengdong Wang, 2007), Romuold (2016), Tyler Westenbrok (2019)[26] the inventory model for the supply chain that consists of supplier and retailer has been constructed according to two cases of their cooperative and competitive, respectively. Then, the Nash equilibrium point’s existence has been proven under some certain constraints, when the non-cooperative game makes sense between their interactions. However, the corresponding results for competitions between inter-chains are scarce. To resolve this problem, two competitive supply chains, where each supply chain has a manufacturer and two exclusive retailers, has been introduced[27]. The competitive relationships with ordering quantities are analyzed according to four different kinds supply chain structure under the hypothesis that the demand distribution relies on the ordering quantity, and then the effect of uncertain demand to the competitive relationship has been discussed in this scientific paper. A two stages competition between two supply chains consisting of one supplier and one retailer, based on the information sharing, has been specified in Ref. [28] by Ha and Tong. On the first stage, supplier decides whether the information can be shared, the information sharing configuration must be decided if the answer is yes; on the second stage, the ordering quantity contract or linear contract should be introduced to coordinate the supply chain. This model and corresponding results open the research in this direction. Though the results mentioned above are all based on the analysis of game theory, they are obtained by the non-cooperative game model. As is well known, the interactions between the upstream and the downstream belong to the cooperative one, in fact, so these results should be revised because they are unfit for the reality and the results’ value must be discounted. Furthermore, each enterprise in supply chain should adapt its owner strategies to fit for the environment changing, so, the cooperative dynamical game model and its Pareto optimal solution should be introduced to resolve this problem, and the risk produced in this case can be identified and controlled, which will be the dominant of studying the risk in supply chain operating process with multi-channel and/or bi-channel.

As for supply chain, once the channel-mixed strategy, the channels’ number is large or equal to 2 where one channel is the traditional one (supplier-wholesaler-retailer) and the other is B-C, was selected, the competitive and conflict between supply chain system does always exists and affects the performance of supply chain if they are handled appropriately[23],[29]. In this case, the inter-price quantified between enterprises in supply chain is the key to keeping enterprises from conflicting with the others, where the supplier decide the price \( w \), by the B-C way, that stands on the state between the wholesale price \( w \) to the wholesaler and the price \( p \) to the retailer, which can coordinate supply chain with multi-channels more effective. This kind of idea is well shown in Refs. [30]-[33]. Yun Chen, Huanchen Wang and Huizhang Shen propose some interesting results, in Ref. [14]: when the cost with E-business \( (c_e + T) \) stands on the interval \([c_e/(1-t),c_e+t]\), the inter-price should be \( \frac{1}{2}(1+c_e-T) \) and \( \frac{1}{2}(1+c_e-t) \), to B-C and traditional channel respectively; with E-business case, described as the order parameter of degree of E-business \( v \), developed widely and deeply, and with the decreasing of changeable per-costs that consists of E-business of retailer s operating, traditional channel’s operating, and the other costs coupled with E-business, the retailer’s profit of the bi-channel supply chain can be maintained or improved; the optimal price decided, in E-business channel, can not be lower than the retailer’s price, similar, the optimal price decided, in traditional supply chain, can not be smaller than the retailer’s price, i.e., the price of retailer decided in bi-channel supply chain should
be higher than the E-businessmen in bi-channel supply chain and the retailer in traditional one. Yajun Guo and Liqiang Zhao study the interaction relationship of game in Ref. [32], from the channel conflict aspect of single channel and multi-channels supply chain, and obtain some reasonable results that manufacture can enlarge the market demand by using bi-channels because this can induce retailer purchasing price decreased and make both manufacturer and supply chain improve their profit, however, this kind of decision can do harm to the retailer’s profit so that it do harm to the supply chain in a relative long time-scale due to the confliction induced between two channels. Anna Nagurney, Jose Cruz, June Dong and Ding Zhang, extrapolate the conclusions of Refs. [34]-[39] in Ref. [40] to the multi-levels and supply chain with networks structure, when retailer face the challenge when both traditional order and electronic commerce are used in this supply chain, at last the conclusion is drawn about the supply chain risk because of the competitive between supply chain channels. In that paper, $m$ products, $n$ distributors, $o$ retailers and single product are considered, where the retailer can order the products from distributors in traditional way or obtain product from the suppliers in E-commerce way. When the supply chain operates, enterprises make decision independently by relying on their owner multi-strategies that can not only consider the profit optimized but also consider risk minimized, by considering not only suppliers’ risk but also the buyers’ risk, which makes the decisions more complex in supply chain operating process interacted, then produce more complex phenomenon. Both the manufacturer’s output and the other manufacturers’ are all considered to decide the manufacturer’s behaviors, i.e., competition is permitted to exist to make the enterprises fair; both the risk function of diversity and the cost or fee function of diversity are all considered; both the retailer’s cost and the other retailers’ cost, and the corresponding payment function coupled with the risk function with diversity, are all considered to decide the retailer’s behaviors. Then the optimal strategies for each company in supply chain can be determined, so is the equilibrium condition of the supply chain operating. By analyzing the character of the supply chain system operating, the dimensions-limited invariable inequation model is constructed to describe the system’s risk, and the existence and the properties of the equilibrium state are obtained, then the convergent conditions are also given by designing a perfect algorithm. It is concluded that the interaction between the company with making decision independently and the corresponding complex induced by the interactions must be considered to decide the equilibrium state and the convergent conditions for this state. Some other researches are the corresponding linear extensions of Ref. [40]. Obviously, it is the inter-price in the supply chain that make supply chain channels compete and then produce supply chain risks, the essence of risk controlling is coordination for profits between two supplier channels. However, these conclusions introduced above are all based on the deterministic analysis, which makes the conclusions with multi-channels coordination, when emergence happens due to supply or demand changed sharply, to decrease the risk occurring. Furthermore, the behaviors of these companies are all static such that the dynamical and adaptive behaviors, which confirm with the real case, have not been considered. The faults coupled with these researches, methods and processes, and their conclusions should be improved, which will lead to the research tendency in this field.

(2) Supplier selection and management

Supplier, whose properties and state are very important to the stability competitiveness of supply chain, can become the core enterprise’s partner in long time-scale if the nodes of supply chain synchronize totally. Otherwise, the corresponding risks must interrupt supply chain operating. To keep the stability of supply chain, the standards to select partners must be the important to create a supply chain with long period and stable partnership[41]. In this sense, the index system should be constructed to decrease the uncertainty happened in the supply chain operation process and decrease the risks appeared in this case. Scientists have studied this problem and obtained several profound results, shown in Refs. [42]-[47], the famous conclusion is obtained by Chio and Hartlty, in Ref. [48], the selection standard for supplier are induced from the sampling on different kinds ones, they suppose that the capability for decreasing the cost, improving the product quality and improving the manufacturing ability are the most important factors for supplier. 156 samples are analyzed by using factor analysis, clustering analysis and multi-variables error analysis. In this sense, they draw a conclusion that the agreement on constructing long-time
cooperative partnership is the most important factor for selecting suppliers, and that the price is the most unimportant factor for it so that it can be omitted, and that the quality and corresponding transferring for products and/or service is the second important factor, and that the ability of technique and funds flowing are the third important factor. The other research results, see Refs. [49]-[61], are all extrapolated on the conclusion mentioned above. Some scientists regard that the suppliers selecting process for different industries should be varied, the conclusion with personality to the certain industries. On the hypothesis of which, Yiwei Song and Xilin Liu analyze in Ref. [62], on the base of Refs. [63]-[64], the case of mass customization manufacture mode for product structure is relatively complex that the supplier selected should be varied according to the property of the supplier, which can be divided into standards suppliers, key bought-in components suppliers and key material suppliers, and different kind supplier must be selected by the certain and personal standard. The most difficult and important selection maybe the selecting of key material suppliers, which should need four stages and each stage has its own unique standard. In this process, providing the visible service should be defined the main property for selecting supplier, and the business philosophy and business culture, fame and faith included, can be considered in the following stages. Furthermore, standards supplier’s selecting is relatively simple, in this case, the visible service, such as the quality, leading time and the fluctuating, and so on, are considered crucially. However, selecting bought-in components suppliers stands on the intermediate stage between two cases described above. As for every selecting process, every factor should be considered to be distinct to others, which are defined the index weight, the AHP methods are introduced in this paper to obtain the effect degree. Though AHP is relatively simple, it is interesting to do thus, which makes the following results are extrapolated from this paper. Boer et. propose four models, such as linear weight model of ownership cost, mathematical programming model, simulation model, in Ref. [65], to select/estimate supplier. Furthermore, several important mixed integer program models are introduced, in Refs. [66]-[67], to select supplier according to multi-standards, so does the multi-objectivity programming. These results are obtained by the certain deterministic models, there have been several stochastic conclusions for selecting suppliers are finished, Tang has considered, in Ref. [68], a supplier selecting problem with the interaction between supplier’s quality and retailer’s quality, under the stochastic case. Some other scholars have analyzed the normal and abnormal situation respectively, as for supplier and retailer, and select the suppliers based on these results. The stochastic model for this researching are not much, however, which is the main researching direction for studying.

Excellent supply chain with excellent performance should has the property of long time and stable competitiveness, where supplier management decision makes sense. In this sense, the supplier management has been a most important focus in supply chain management and supply chain risk management. There are several conclusions are drawn, for managing suppliers, by setting an incentive-supervise mechanism to maintain the supply chain to be coordinated, which can make all enterprises feel fair; otherwise, if the mechanism is unfit, the suppliers’ profits perhaps be harmed such that the profits of companies in supply chain and the supply chain system be lost. These will be specified as the following sub-section.

(3) Order distribution for suppliers

Supply chain system is constructed after selecting partners, however, the random factors must been occurred in the process, which can bring some hug loss of risks. An important case is defined as how much the downstream should buy certain products from the upstream, the unfaith and the corresponding risk would be appeared if this quantity can not determined right. In this process, several risks can be happened because of uncertain demand, uncertain supply, uncertain leading time and uncertain supplying cost[46],[69]. The results for these aspects will be described as follow.

Order distribution, a most important factor that can induce several risks, has been studied by some scientists, where the analytic methods are introduced to study the risk matched with order distribution because of uncertain demand by studying the redundancy to supply chain. Among these results, normal strategies and disruption strategy are always used to weaken the risks produced. Generally speaking, the former should be designed by a stable leading time, but not the latter. Fukuda’s conclusion shows that the uncertainty can be weakened by setting “two upper cut-
off order$^9$ of strategy $x$ and $y$ to determine the optimal order, for supply chain. However, the more heavy risks must be occurred if $x$ and $y$ are set unreasonably. So, setting the critical point of $x$ and $y$ is critical to manage risks, which lead to much uncertainty. This strategy should be specified as follow: the size of $(x-z)$ in the total order should be defined as normal forms if the initial inventory $z < x$; if $x < z < y$, then the size of $(y-z)$ in the total order should be defined as normal forms; otherwise, do not order. Scheller-Wolf and A., Tayur, S. consider a inventory model with Markovian property, in Ref. [70], at a single period, after analyzing, it is conclude that the optimal order strategy should be an inventory strategy on revising the corresponding state, as for the retailer, i.e., in every period, there exists a certain inventory level coupled with certain state, then seller decides a certain order quantity from the normal supplier such that the inventory point can close to the objectivity of inventory as far as possible after this ordering. After the first ordering, an emergency response order can be reconsidered to complete the distinct between objectivity inventory and the factual inventory. Moinzadeh, K. and Nahmias, S., in Ref. [71], extrapolate this result in a continuous time case, by constructing a $(s_1, s_2, Q_1, Q_2)$ order strategy decided by combining the normal strategy and emergency one, i.e., quantity $Q_1$ can be regarded as the normal order strategy to implement when the inventory reaches $s_1$; the emergency strategy of $Q_2$ can be complemented when order $s_2$ comes in the leading time of order $s_1$. These conclusions are drawn from the hypothesis of two-levels supply chain, the conclusion matched with multi-levels supply chain has been studied in Ref. [40], by Naguney, A., Curz, J., Dong, J. and Zhang, D., where, order distribution of enterprises in every level can be regarded as a non-linear programming problem when uncertain demand of retailer is considered: as for every retailer, the optimal order can be determined according to the wholesale price made by distributors, and as for the distributor, the objectivity for deciding optimal order is determined the optimal order quantity based on buying purchasing price, which is a multi-stage Stackelberg game problem, the criticality for optimal order should be transformed to a series of inequalities by analyzing the internal relationships among the three process mentioned above, then the optimal strategies and corresponding behaviors equilibrated are determined.

There are a few results about uncertain supply scopes, the multi-stages and multi-cycles model of supplying process is considered, and risks produced in networks supply chain because supplying objects being changed randomly are the focus, in the multi-stage operating$^{[72]}$. The two stages and multi-cycles order distribution has been analyzed by Akella, in Ref. [73]. By analyzing, determining order of raw material is defined to the content of the first stage, and in the second stage, the focus should be decided. It is conclude that the uncertain of supplying scale must be appeared in the process of purchasing raw material and that there are two critical points, one stands on the criticality of raw material ordering stage and the other stands on the criticality of producing process, in this process, which makes the optimal order quantity and the optimal produce quantity all relies on the total number of products and raw material. Tang et. extrapolate this conclusion to the general cases. However, the results about the order distribution in the supply chain with products families and multi-stages operations are absent. Gong, L. and Matsuo, H. have construct a linear decision model under the constraint of produce capability, in Ref. [74], according to the certain prior probability. Because of the complex of calculating for that model, the example analysis tool is introduced to resolve this problem, which leads to a result: when the optimal produce mechanism is compatibility constrained, this linear decision mechanism can implement the optimal order distribution to make the supply chain system equilibrated and to minimize the risks.

Supply leading time can bring supply chain certain risks too, which has been studied enough. When the leading time is random, it is regarded as exponential distribution by many scientists, based on queuing theory, however, it is also be regarded as to be a homogeneous distribution by other scholars. Whatever the hypothesis are, the corresponding results would be introduced in the part of bullwhip effect controlling$^{[75]-[77]}$. 

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The uncertain supply cost is dependent not only on the demand’s distribution but also on the properties of the retailer, furthermore, supplier’s inventory strategies decide the risk when supplier faces this uncertainty. Yue Dai, Shu-sherng Fang, Xiaoli Ling and Henry L. W Nuttle, in Ref. [78], analyze the inventory strategy of two-level supply chain with one supplier and two retailers, where the price is sensitive to market demand, and where both profits and risks are considered. Yue Dai, Shu-sherng Fang, Xiaoli Ling and Henry L. W Nuttle, in Ref. [79], extrapolate this conclusion to another case, where supplier take two strategies of backup inventory system (i.e., according to the retailer’s store level, when the demand can not be satisfied, take the strategy of breaking-off, when the store surpasses demand, operate them at lower price) and inventory system shared (two retailers have a common distribution center), and the corresponding performance is analyzed to these two strategies. It is conclude that the inventory shared is the optimal one that synchronize better profits and lower risks, and this strategy relies on several parameters of how many all companies’ costs should be considered and whether a certain punishment function exists or not such that both supplier and retailer can obtain more profits when this kind punishment is relatively higher. However, how retailer competes with the other retailer and how the profits are shared in supply chain are omitted, which makes the conclusion analyzed profoundly.

For identifying of risk, as far as order imputation in supply chain is concerned, it is order number, place and leading time that make supply faced with much uncertainty, in fact. Obviously, the results analyzed above are all based on the hypothesis that the cost is the most important thing considered, in this sense, service level, positive response, customer’s satisfaction and the synchronization for the order can not be noted yet, which would lead to the main researching direction for identifying and controlling risks in supply chain.

2.2. Demand management

Demand uncertain, the main factor producing risks, can be transferred and enlarged along the supply chain operating, which makes supply chain and their enterprises damaged[77][80][81]. The risks produced by demand changing and manufacturing respectively can be transferred in supply chain along the contrary directions as far as the two different risks mentioned above are concerned respectively, which makes the enterprises facing two totally different risks. In this sense, the risks faced by the enterprise that stands on two edges maybe the sheer risks produced by demand, or produced by supply. This complex and nonlinear interaction between risks makes them much complex. John A. Muchstadt, David H. Murry and James A. Rappold regard, in Ref. [79], that the excellent supply chain management must satisfies five basic theories, which can be described as understanding customer and constructing a supply chain with low uncertain and low lavish and constructing a dense information framework coupled with supply chain operating and with operating process. Furthermore, the customer’s leading time is shorten due to the customer’s demand changing uncertainly, which enlarges the negative effects with this uncertain changing increasing. Finally, the risks induced by uncertain demand coming from supply chain operating can be decreased by information shared and business coordinated. The results of identifying risks will be specified in following sub-sub-sections.

(1) Supply chain structure is stable: demand fluctuating randomly

The buyer’s uncertainties come not only from external environment but also from the system’s property, in this sense, entropy, a term that be used to describe the chaos degree (i.e., uncertain degree) of a system, should be introduced, where the positive entropy can be coupled with the characters and state of the system and the negative entropy can be coupled with the characters and sate of the external that can decrease the system chaos. Internal entropy, which belongs to the positive entropy, can be satisfied with the maximum entropy principle and enlarged to state of entropy maximized such that supply chain facing more and more redundancy, i.e., the maximum uncertainty of the corresponding factors would be happened coupled with supply chain developing. On the contrary, the external entropy is the syntheses of positive entropy and negative entropy, where the negative, such as knowledge updating, technology innovating, can decrease the uncertainty of the system and the positive, which can be explained
to the disturbing by environment changing randomly, can increase the uncertainty of the system. Supply chain can be innovated by introducing negative entropy, knowledge, for example, such that supply chain risk must be decreased. Furthermore, more innovation happens in the process of demand management. To decrease this kind of risk, Subroto Roy, K. Silvakuma and Lan F. Wilkinson have regarded that, in Ref. [82], the innovation strength are decided by supply chain structure, by analyzing Refs. [83]-[85] profoundly, and that this kind of innovation can keep supply chain from being destroyed. In that paper, the innovation can be divided into two categories: innovation on essence and on additional. It is conclude that: the interaction’s scope is positive correlation to the additional innovation and essential innovation; the integrating degree of IT technique is positive correlation to additional innovation, and negative correlation to the essential innovation; the asymmetry degree of commitment for the buyer and the supplier, and the interaction strength is negative correlation to additional innovation, and is positive correlation to essential innovation; the asymmetry degree of the attitude between buyer and supplier is positive correlation to additional innovation and essential innovation; the total trust degree and their interaction is positive correlation to additional innovation and essential innovation; the hidden degree of assistive technology and its interaction is positive correlation to additional innovation and essential innovation; the demand objects transforming randomly makes this system converged into a certain stability point no matter what the probability distribution of demand is; as for the triangular distribution model where the three demand parameters of minimum probability, maximum probability and most probability are considered, the conclusion shows that: the demand distribution need not be precise and can be identified, as far as the retailer is considered, because not all uncertain factors can be identified such that Scarf method is limited to calculate the model constructed, otherwise, the order number can be expressed as \( y = \mu \) because the average of demand \( \mu \) is known and deterministic; the robustness is decided by certain parameter of \( y_{\text{Scarf}} = \mu + \sigma \sqrt{\frac{r - c}{(r - c)^2}} \) if the average \( \mu \), variance \( \sigma \) and \( \sigma / \mu \) are known, which makes this system converged into a certain stability point.

As is shown that, the risks produced because of environment uncertainty called noise, which can make the supply chain facing hug unstable. If this uncertainty is written noise, then the system usually can not produce system risk; otherwise, the supply chain can produce system risk when these noises can not be identified. These studies should be the main researching direction in this field in future.

(2) External environment transition-demand objects transforming randomly

Recently, more and more non-regular emergences have been happened, which gives the economy polity, society many hazards. As the main component of the economy, supply chain facing these hazards too, these risks are too hard to analyze, so, there are a few results produced in this field.

In certain conditions, especially to the non-regular emergence happened, the supply uncertainty and the demand uncertainty must be happened and make supply chain decision complex, which is a most important aspect in supply chain risk management. In this case, the enterprise that stands on the end of the supply chain need to decide who should become its suppliers from the suppliers at present, which relies on the property, frequency and strength of the emergence. Summarizing the results of Refs. [87]-[88], Haisheng YU, Amy Z. ZENG and Lindu ZHAO have
considered a two stages supply chain that consists of one buyer being sensitive to key components’ price and two suppliers, one is on aboard and dominant to the buyer and the other is in the domestic and subordinate to the buyer, where the two suppliers provide different wholesale price to the buyer, in Ref [89]. A known probability is introduced to describe supplying probability, and market demand satisfies exponent distribution. In that paper, the two corresponding strategies and their respective performances are analyzed, coupled with the key factors. The external risks thresholds $p_1^c$ and $p_2^c$ are given as for different strategies, this critical point are dependent on the proportion $\alpha_1$ of unisource supplier’s cost when the first supplier are selected and the double source’s cost when these two suppliers are selected, and depend on cost coefficient $\alpha_2$ of the second supplier operating on regular and the first supplier operating on the unisource supplier, and the cost coefficient $\alpha_3$ when the second supplier are destroyed and the unisource supplier’s of the first supplier is selected, and the price’s coefficient $\beta_1$ of the unisource supplier’s of the first supplier, and the cost’s coefficient $\beta_2$ of the unisource supplier’s of the first supplier, and the order number $x$ of the first supplier when double source suppliers are considered. It is conclude that

$$p_1^c = \left\{ (\beta_1 - e_2x)(\alpha_1 - \alpha_2) - (1-x)(\alpha_1 - \alpha_2) + (1 + \beta_2)(1 + \delta - \delta e_2) \right\}$$

and

$$p_2^c = \left\{ (\beta_1 - e_2x)(\alpha_1 - \alpha_2) - (1-x)(\alpha_1 - \alpha_2) + e_2(1 + \beta_2)(1 + \delta) - e_2(1 + \delta) - 1 \right\}$$

Furthermore, the double source suppliers is apt to be selected than the unisource supplier’s of the first supplier when $p > p_1^c$; when $p \geq p_2^c$, the second supplier can be opt to be selected as the unisource supplier than the double source suppliers; when $p < p_1^c$, selecting the second supplier is better; when $p_1^c < p < p_2^c$, it is better to select the double source suppliers. This result is much important to select suppliers when external emergence happening and effecting supply chain. However, there are some faults in these researching, the important one is the results are obtained based on the deterministic analysis, so the random changing of all parameters can not considered, which gives the scientist certain research direction. The second, there are few results are hypnotized on complex and networks supply chain that is expressed the characters of the reality, and must be the mainstream for supply chain suppliers selecting for decreasing risks occurred.

When non-regular emergence happened, there are several hug uncertainties produced and these risks can affect supply chain operating normal by making many cycles of supply chain operation change randomly such that some risk events are produced to lead to risks, however, there are few results obtained in this field that will specify in the section of risk control.

(3) Competition between sellers

The competition between sellers can decrease the performance by making the non-coordination in supply chain, which should be resolved. All incentive strategies are regarded as an important mechanism to keep sellers from competing with the others, and they are important to risk management[25][41]. Hongsheng Chu, Hansheng Suo, Jingchun Wang and Yihui Jin have extrapolated the result of Ref. [90], and analyzed the problem with low efficiency to supply chain operating because there are great inconsistencies among each enterprise’s incentive degrees, and have studied the effective coming from the competition between the sellers and the attitude to risks of the coordinative characters.
After obtaining the corresponding Nash equilibrium solution, the conclusion is drawn that the total ordering quantity could increase with the competition degree, and the risk evading makes the total ordering quantity decrease. In this paper, the loss-averse model is introduced to describe the attitude towards evading risk of seller, i.e., the $i^{th}$ seller’s utility can be expressed to $\Pi_i(\Pi) = \{\Pi_i, \Pi_i, \geq 0, \lambda \Pi_i, \Pi_i, < 0\}$, where the contract between supply chain is introduced to equilibrate the enterprises’ incentive of decision and to make all companies coordinated. In this process, they have supposed that supply chain is coordinated if every enterprise’s decentralized decision is identical to the centralized decision. In this case, the profits obtained in centralized decision need that we should consider the supply chain regarding as a whole system, the objectivity of this system should be denoted by expected profit $\Pi$ provided that the risks is neutral, where middle-price $w$ is not exist, then $\Pi(q) = p\int_0^q f(x)dx + p\int_q^\infty f(x)dx - cq$ and the corresponding optimal ordering quantity is $q = F^{-1}(p-c)/p)$, where $f(x)$ is the probability density distribution function of demand and $F(x)$ is the corresponding probability distribution function. By analyzing above, it is conclude that: ① competition makes total order quantity increasing, and the risk evading attitude makes the total order quantity decreasing; ② when the risk evading factor $\lambda$ is smaller than a certain threshold $\lambda(n)$, there exists a wholesale price contract making the supply chain system coordinated, where $\lambda(n)$ depends on the price $p$, cost $c$, quantity $q$, demand distribution function $F(x)$, which can be described as

$$\lambda(n) = \frac{(p-c)/p - 1/q\int_0^1 F(x)dx}{1/(n-1)c/p.F(cq'/p) + 1/q\int_0^q F(x)dx} + 1,$$

so, some degree of competition between enterprises can be permitted in order to decrease the faults coupled double marginalization effect and total ordering quantity decreased because of risk evading; ③ when the risk evading factor of seller is smaller than a certain threshold, the relative simple wholesale contract can coordinate supply chain more effectively; furthermore, with enlarging of competition, the effect of risk evading strategies to system’s performance could be decreased, which is shown that the threshold of risk evading factor is loosened. After studying Refs. [92]-[93], Yuming Xiao and Xianyu Wang consider the enterprises’ behaviors in Ref. [94], and a Stackelberg game model has been constructed to study supply chain coordination and risk sharing, when the marginal cost of supplier and retailer are all decreased with the quantity increasing. The conclusion shows that the buy-back contract, where supplier permit retailer to return of goods to wholesale as to the products that can not be sold and the price of back-buy should be decided by combing marginal cost, ordering price and satisfaction rate of market demand, and the rate of risk-shared between two companies is decided by the rate of marginal cost of two companies when the optimal ordering quantity are satisfied, can be coordinated well. Then, another Ref. [95] of them extends this conclusion to someplace, where ① the information is perfect and shared, the cost structure and the demand distribution are all known by everyone, ② the price is a constant and the market is a random variable whose distribution is invariable and continuous and differentiable; ③ the cost of supplier is the function of his product’s number; ④ retailer’s cost is the increasing function of marginal cost of ordering quantity for retailer; ⑤ all enterprises’ risks are neutral; ⑥ the decentralized decision in this supply chain can be described as the following process that supplier provide a wholesale price $w$ to retailer and the products that can not sell could be back to wholesale as the price of $\alpha w(0 < \alpha < 1)$, where $\alpha$ is the discount parameter made by supplier. The conclusion shows that this kind of buy-back contract can decrease the risk happened in supply chain according to the strategy of risk shared.
2.3. Produce/Manufacture management

(1) Risk identifying in supply chain producing and manufacturing

The random of products structure and demand object makes supply chain producing and manufacturing faced much uncertainty, which needs core enterprise, the manufacturer, decide a certain and adaptive customer order delay point. Ahead of the point, mass producing mode is introduced to decrease the operation cost of supply chain, and behead of this point, the customization model is taken to satisfy the diversity demand\(^3\).\(^9\),. So, the delay point determined in mass customization manufacture mode is much too important to supply chain to improve the performance of supply chain operating. The detail process will be shown:

![manufacture process]

However, there are some uncertainties in this process because of predicting, in this sense, many conclusions are emerged to decrease this uncertainty. Changyin Gao, Shuming Fu and Ming Li have introduced block building mechanism of products modular designing to mass customization manufacture mode, in Ref. [97], and have proposed the corresponding process and results. Ziqiang Zhou, Mujun Li, Wei Zhao and Lianguan Shen introduce the dynamical virtual designing structure, in Ref. [98], and propose a method of constructing and describing the product families by charactering language, and the produce virtual model of mining and producing, according to the personal demand, then, this model can be transformed to a VRML model to let customer observe and scan. Li Zhang and Zongyan Wu specify the product families’ spectrum analysis result, in Ref. [99], based on the analysis process described as follow: firstly the customers’ demand structure, then describe the different demand as corresponding weights that be obtained by AHP method; after the basis function system being constructed, the mapping method for function fields and physical fields and the calculating methods and judging methods of sub-functions are given to the product’s modules constructed then to the model of products configuration. From another aspect, the deploying effectively for product families can bring some degree of risks, in this field, Biao Shu and Xiaojian Han, in Ref. [100], have analyzed the produce mode and its characters, then the product model and product deploying, and the other content have been studied. Furthermore, they regard it is true that the customer’s order delay point can be quantified if and only if the generalized components and customized ones must be mined. It is the method for component controlling and predicting that make scientist confuse, Guoning Qi and Fuyun Liu, in Ref. [101], propose a new tool of complex networks to construct the mass customization manufacture for predicting components and their evolution law based on the parameters changing in the corresponding complex networks model of mass customization manufacture. However, the essence of this kind of manufacture mode can not be described correctly, so, the generalization in-degree is introduced by Xiaojing Zheng, in Ref. [102], to revise this model and propose a fit model. In this paper, the equilibrium networks and non-equilibrium networks are mentioned to distinguish the short time-scale changing and long time-scale changing, respectively. Then the components’ quantity can be predicted according to this model.

Though ERP(MRP II), JIT and TOC are generally used in supply chain, the real supply chain can not be formed if the business re-organizing can not be finished. In this case, there are several risks facing to supply chain such that the processes in supply chain operating are changed with environment developing. Many scientists give some profound conclusions in this field. Xiaojing Zheng and Chengyao Zheng have divided the operation manufacturing
processes into different sub-processes, in Ref. [103], into certain kernels and certain peripheries by TOC analysis techniques. Then the bottlenecks of these processes are obtained and a corresponding Multi-nominal-Logistic model synchronized with all enterprises in supply chain system is constructed, by calculating this model, the bottlenecks in supply chain operating are gotten. After judging the odds ratio for every resource, the corresponding buffers and their sizes are decided by quantifying the corresponding nonlinear stochastic differential function if the power-law distribution of the supply chain’s operation processes is gotten. This process can help us to quantify the bottles and buffers that can consists of both spatial and temporal ones respectively, in supply chain operating process, which is valuable to the studying. However, this results is obtained based on the property of supply chain’s kernels’ time-varying slowly or stably and the peripheries’ time-varying quickly, which means that this results will lose effectiveness if the emergence happens. In fact, the supply chain manufacture is relative complex, nor is the risks, which needs the profound conclusions emerged.

(2) The uncertainty happened in designing process

Similarly, there exists some degree of uncertainties in supply chain designing process because the personal demand varied quickly coupled with quick changing market; on the other hands, supply chain actually is the combination of all core competitiveness for the corresponding enterprises in supply chain, which ask that there are several degree of uncertainties in designing process that perhaps lead to risks, the loss of blank, superposition, dislocation, and so on, and which forms another field in supply chain risk studying[72],[104]. Unfortunately, there are few researching results in this field.

(3) Moral hazards (lazy, inferior quality) in supply chain manufacturing

There are certain cases of adverse selection, lazy and venture in supply chain manufacturing process because of the information hidden intentionally, which makes the supply chain inventory enlarged, producing time extrapolated, quality decreasing, and other forms of moral hazards in supply chain manufacture[105]-[109]. These moral hazards occurred in supply chain manufacturing process could bring certain losses, which can be transferred and enlarged along with the supply chain operating and which must be controlled under the threshold for percolation of risks in supply chain. There are few scientific results obtained in this aspect, which will be introduced in section 2.4, profoundly.

2.4. Information management

Generally speaking, the risks in supply chain system perhaps are happened in all processes including the interactions from supplier, manufacturer to retailer, so, how to plan, organize, coordinate and control the information flow in supply chain and improve and optimize the supply chain profits are the most important thing for supply chain management. As well known, the supply chain’s operating efficiency can be decreased and supply chain operation costs can be increased, in the transferring process of information in supply chain, because the information is distorted from one process to another such that the supply chain’s profits are destroyed, which is called information risks of supply chain[2],[80],[104],[110]. So, a conclusion could be drawn that supply chain information risk consists of two categories: one comes from the uncertainty property of information itself, which can be decreased by information innovated; the other one is induced due to information distorted. Each enterprise makes decision for manufacturing and supplying, based on the information, demand information, for example, obtained from their neighbors, which would make the demand information enlarged back-forward from the supply chain and which makes the demand qualities of the upstream accepted is larger than the downstream accepted, which is called bullwhip effect. Bullwhip effect depends on the information shared in supply chain, so, it is regarded that information sharing is the effective ways to resolve this effective. The two kind information risk of supply chain will be specified as follow.

(1) Ways of information management
It is the information management of supply chain that make the information received precisely and transferred accurately in the information channel, which can improve the transforming capability from information to knowledge. If these management parameters are received incorrectly, the false information and asymmetry information will be happened such that bring some degree of risks relying on information structure and information transferring process. In this sense, the process of exposing process of information hidden is more important to decreasing the information risks of supply chain, which is obvious; another useful way is to decrease supply chain information risk by sharing information between the enterprises in supply chain, in this case, the multi-mass decision techniques should be introduced to weaken to diversity of the information recognition. Obviously, there perhaps induce heavy risks in supply chain if a certain and well done mechanism can not be supported.

Information, in fact, is an objective thing existing in the world, which can be retorted by enterprises because of their creative feeling process. Information can be transferred from one enterprise to another along with supply chain operating, because of recognizing error happened, the information accepted must be retorted and can make decision wrongly, which can take certain risks. This kind of information judging process can be expressed heavily when demand and supply are uncertain. Tiaojun XIAO and Danqin YANG, in Ref. [111], construct a risks shared and information revealed mechanism to a certain supply chain that consists of a single retailer and a single supplier, then the reliability of this mechanism is analyzed. It is conclude that the information interaction strategy is important to the risk sensitive effect to retailer’s order number. When the part supplier shared is large enough (or small), the price of the retailer with high risk disgusted will be higher (lower) than the price of the retailer with low risk disgusted. Furthermore, as to the retailer’s contract, the optimal price and the optimal service level of type $L$ retailer should be expressed respectively as $p^*_r = w + N_1$ and $s^*_r = \beta N_1 / \eta_r$, depending on minimum wholesale $w$, risk disgusted degree $\beta$ and information truth $\eta$, when the retailer reports his information truth $\mu_{M_r} = \beta^2 / 2$; however, the optimal price and the optimal service level of type $H$ retailer should be $\bar{p}^*_r = \bar{w} + N_2$ and $\bar{s}^*_r = \beta N_2 / \eta_r$, respectively, where the $\bar{\cdot}$ express the maximum value of corresponding variables, and the corresponding optimal price and the optimal service level of type $M_2$ supplier should be $\bar{p}_{M_2} = c_2 + N_3$ and $\bar{s}_{M_2} = \beta N_3 / \eta_{M_2}$. This conclusion has been accepted by a lot of scientists, as shown in Refs. [112]-[113], and extrapolated in some certain cases, the difference just consists in the researching methods and the parameters’ precision.

Information is valuable to supply chain, including what conditions information can be shared, what kind information can be shared, whom the information can shares to and which way the information can be shared, which depends on the supply chain structure. Gang Li, Shouyang Wang, Gang Yu and Hong Yan, in Ref. [114], have studied the value of information sharing, where the orders depending on demand related, bullwhip effect and the corresponding criticalities are considered. The similar conclusions are drawn in Refs. [82], [115]-[122] according to different supply chain structures. Another mechanism, decision decentralized mechanism, are introduced in Ref. [123]-[124], by Alan Scheller-Wolf and Sridhar Tayur, to describe the performance when information sharing are considered, where the demand is random and the state is dependent on each other and the bi-suppliers have different leading time with changing deterministically, then the threshold for information sharing is given.

As is well known, it is information shared that make the supply chain competitive. However, several enterprises may be faced being bankrupted if there no any certain coordinative mechanism resolving the profit distribution between enterprises in supply chain. In this sense, some certain inventive mechanisms should be introduced to supply chain to let enterprises cooperate together. So, a lot of incentive mechanisms, concluding incentive of order contract, incentive of buy-back contract and incentive of return of goods contract, are regarded as the effective strategies to evade supply chain risk. Although these mechanisms mentioned above can coupled with a certain and single strategy, the mix-strategies are sometimes provided that they can be more useful than each certain pure
strategies, however, which can not be confirmed by scientists. The next section will introduce some conclusion about the three strategies. ① order contract incentive. Tsay (1999) in Ref. [125] discusses a quantity resilient contract, that dealers provide a predictive purchase plan and promise buying certain proportionate products, at the same time, suppliers should make sure these products provided on time. This kind of mechanism demands product price have resiliency for product quantity, which will actively stimulate the tendency of suppliers cooperating. Therefore, determining the contract proportion in the order contract is much important in the contract designing. It is conclude that this proportion is a function between the price and the quantity resilient. In certain range, these contracts can decrease the cost coupled with the demand changed uncertainly, which makes retailer will to provide precise market information to the supplier. Of course, this interval relies on the supply chain structure, such as supplier’s number, market competitive degree, products configuration, product demand distribution, and so on. Cachon and Lariviere have studied the two stages flexible ordering contract, in Ref. [126], to incentive the retailer to predict market demand, the process can be described as follow, the retailer provide the initial prediction for the market demand and adjust his own initial order according to market characters. The two stages programming tool should be introduced to decide strategies taken in different stages, because of the complexity of the analysis process coupled with two-tired decisions, which means that the quantity decided in the contract should be divided into two parts reasonably according to a certain proportion, and which is depended on the supply chain characteristics. Furthermore, the game between retailer and supplier are analyzed to make sure that the supervising mechanism constructed can make the supply chain share the real and reliable information predicting and make supply chain operate better. The other results can be recognized to the extension of this result. ② return commission contract. The return commission can be divided into the spatial return commission and the temporal one, and the spatial return commission can be divided into price discount contract and quantity discount contract. Taylor has introduced a return commission strategy, in Ref. [127], to incentive the retailer to improve the market demand precisely, where the linear return commission and objectivity return commission, which is a kind of spatial return commission, are introduced respectively, which is effective to the coordination. In this paper, the coordination and bi-win influence can be analyzed according to the objectivity return commission strategy and the linear return commission strategy, which concludes that the objectivity return commission strategy is more feasible than the linear return commission strategy, however, neither the parameters in detail nor the conditions for the two strategies can be specified; furthermore, the strategies introduced in this scientific paper is constructed from the perspective of the retailer but not from the supply chain perspective, i.e., the common strategies according to the enterprises in supply chain system decisions, a better one, should be set, which should be improved. ③ return of goods incentive. Xiaohang et al., in Ref. [128], have studied how the manufacturer decide the strategies for returning of goods in the directed channel to do good to manufacturer and retailer, it is conclude that the supply chain profit obtained when the strategy of return of goods as information is shared is larger than the profit obtained when the strategy of return of goods as information is not shared. Xiao Hang and Srinivasan have extrapolated this result, in Ref. [93], to the case that supplier can ensure that retailer can obtain the enough profit in this asymmetry information by using the total and sheer strategy about return of goods when the retailer will to share its market demand information. The mode of information shared and the value of incentive mechanism for information sharing are analyzed in these scientific papers, however, what information of the corresponding enterprises should be shared in the certain supply chain structure, to whom the information should be shared, what frequency of information should be shared, and the criticality of supply chain information shared, can not be specified, which should be the researching focus in future. To resolve these problems, the principle-agency models, in Refs. [129]-[131], are introduced to study the information sharing mechanism. In this sense, a multi-objectivities principle-agency model is constructed, to analyze the optimal incentive mechanism for sharing information in the interaction between the core company of the supply chain and the other companies, and to interpret the improvement process of the partnership of the enterprises in supply chain. It is the subordinate supervising mechanism that make the non-core enterprises share their information strongly according to the current incentive structure. A common conclusion is drawn in these scientific papers that the marginal substantiation rate
of the supplier effort cost is the key to information shared rationally and incentive the supplying behaviors operated normal, so, the corresponding order parameters must be the most important thing. Similarly, how to construct the new supply-demand function, i.e., how to decide the profits distribution mechanism in supply chain, is the key to this problem resolved. However, the information shared mechanism, in the supply chain with relative simple and without complex product families where all products are not i.i.d. and the leading time is complex and changeable, is scared, and will be the mainstream for studying. Furthermore, the behaviors of the enterprises in supply chain studied are supposed to be rational, and the non-rational behaviors, coupled with the corresponding model should be studied. The last but not least, the two levels supply chain coupled with the linear models have been considered but not the networks one, which will be focused in future.

(2) Bullwhip effect

It is information asymmetric property or information transformation delayed that produce bullwhip in supply chain operating, which bring many redundancies to the system decreased by several strategies, a most important one is information shared. On the contrary, the company’s knowledge, hidden knowledge and explicit knowledge included, will lead to unreasonable thing happened that the corresponding companies in supply chain system will faces the subsistence crisis if the knowledge is revealed unreasonably. Furthermore, how the information is shared in supply chain and what is the sharing information’s frequency should be considered according to the corresponding supply chain structure. If this is not done well, there is not only bullwhip but also moral hazards that makes supply chain damaged. This phenomenon has been firstly proved in theoretical occurred in supply chain by Lee. H. L, in Refs. [84],[132], even if all enterprises make decision rationally to optimize their owner’s benefit. To prove this existence of bullwhip effect, the case that the variance of the order is larger than the variance of the demand, in a supply chain with a single manufacturer and several retailers are considered, where the retailer knows the demand distribution that satisfies a AR(1) process, and where the retailer is rational and would take the optimal order-up-to order strategy. Furthermore, the four factors, predictor-corrector, order quantity decided, price fluctuation and shortage game, are defined to the bullwhip effect’s inducing reasons, which is important to study this effect. Many results obtained are mostly satisfied as normal distribution and the leading time is a deterministic constant, see Refs. [133]-[138], the corresponding researching contents are the quantifying methods of bullwhip effect, the inducing reasons of bullwhip, the control of bullwhip effect, and so on. (The results according to the bullwhip effect controlling will be specified in the section of risk control). The corresponding conclusions are the extrapolation of: demand predicting method can affect the bullwhip effect’s size, furthermore, the effect degree by using moving average predicting method is larger than by using index smoothing forecasting method; the bullwhip can be enlarged with the complexity of supply chain’s structure increased and the predicting period extrapolated; the effect degree produced in the supply chain with several products (or product families) correlated is more complex and heavier than the ones produced in the supply chain with a single product or several independent products. However, the multi-stages supply chain and networks supply chain are seldom considered, neither is the case of the supply chain with product coupled with stochastic demand.

Why the bullwhip can be produced in supply chain operating has been studied by several scientists from the aspect of properties of resources and their flowing in supply chain operation process. Yu Hai, Xiaowo Tang and Debing Ni have regarded that, in Ref. [139], whether bullwhip effect existed in supply chain or not and what property the bullwhip has relies on the demand prediction accuracy, the state of cost function and the behaviors decided of the downstream companies. On the condition that the rational retailer can observe the market information but the supplier can not, it is conclude that the bullwhip effect can be decided by his cost function of character affected by the stochastic interruption, and that whether bullwhip effect can be produced or not depends on the predicting mechanism of the retailer and the character of the retailer’s prediction results expressed in the cost function, and that there are no bullwhip effect occurred in supply chain if the resources flow the supply chain as a linear form from one company to the neighbor but there exists certain bullwhip effect if the resources flow the supply chain satisfying a certain power-law that the exponent is larger than 1.
It is the demand prediction that make scientists focus on when studying bullwhip effect, in this sense, some certain and feasible predicting methods should be introduced to decrease it in supply chain system, and some profound conclusions are drawn to explain that the effect degree of different methods on predictor-corrector and to decrease this effect. In Ref. [136], a case of market information changing as ARMA(1, 1), a smooth time sequence model, is considered by Hong Liu and Ping Wang, for a certain case that supply chain is multi-stages and all enterprises predict the demand information by mean-squared error and decide the order by order point method, then the corresponding simulation model is constructed and the bullwhip effect in supply chain is obtained and the corresponding effect factors is analyzed too. It is conclude that the bullwhip depends on the relation between correlation coefficient $\rho$ and mean average coefficient $\theta$, and that the correlation coefficient $\rho$ if $\rho \in (-1,1)$, and should decrease with $\rho$ if $\rho$ is close to $\pm 1$. Furthermore, there is no bullwhip effect in supply chain when $\rho \leq \theta$ and the bullwhip effect exists if and only if $\rho > \theta$. ② the bullwhip effect should be decreased with $\theta$ increasing. ③ bullwhip effect becomes more complex when the demand and the leading time is random. Truong, Ton, Hien and Duc. Huynh, in Ref. [140], consider a two-stages supply chain with one supplier and one retailer and single product, in this paper, the supply chain’s bullwhip effect and the risks coupled with bullwhip effect decided by average variance minimized method are analyzed when the product’s quantity and leading time is stochastically changed according AR(1,1) and ARMA(1,1) respectively. It is conclude that bullwhip is a random when the time-scale is larger than a certain threshold and the predicting is converged into a certain constant independent on time $t$, as far as the product prediction of leading time satisfying randomly to AR(1,1) and ARMA(1,1) is concerned. When product quantity needed satisfies AR(1,1), the retailer’s order could be increased with customer’s demand quantity standard deviation $\sigma_d$ increasing, but the bullwhip effect could be decreased; the bullwhip effect could be increased with leading time’s average $\mu_L$ and $\sigma_L$. When the demand satisfies ARMA(1,1), the same conclusion can be drawn, the difference is there is much heavier and more complex than the former.

It is inventory that affect bullwhip effect in supply chain, which has been studied enough. Chang Luo, Suling Jia and Huiwen Wang consider, in Ref. [141], two cases, delay of arrival of goods is first-order exponent delay and the pure time delay respectively. In this paper, the demand and the corresponding changing are not considered because they regard the demand forecasting as an external factor and because the prediction’s affectivity can affect the stability of supply chain system. Where, the parameters of transit inventory $WIP = \int_{t_0}^t [OR(t) - AR(t)]dt + WIP_{t_0}$ and inventory $WIP = \int_{t_0}^t [OR(t) - AR(t)]dt + WIP_{t_0}$ (they all depend on the D-value of real order $OR$, goods arrived $AR$), volume of goods arrived $AR$, adjustment of inventory $AI = \alpha_r(I^{*} - I)$ ($I$ express the transitory inventory), adjustment of transit inventory $AWIP = \alpha_{awp}(WIP^{*} - WIP)$, projected available balance $IO = D + AI + AWIP$, real order quantity $OR$, inventory adjustment coefficient $\alpha_r$, transit inventory adjustment coefficient $\alpha_{awp}$, delay time $DT$ and demand $D$ are considered. By analyzing, the inventory $S(t) = \int_{t_0}^t [I(t) - I^{*}]dt$ is introduced to describe the different size between the real inventory and the expectation inventory in interval $[t_0,t]$, when the supply chain system is interrupted, and the $S$ curve is introduced to judge the system’s stability. The conclusion is specified to: ① the size of step value of demand can not change the convergence of correlate fluctuation, anyway, the value of $I^*$ can only affect the ultimate stable level and independent on the fluctuation of inventory (or order quantity). ②
the stability of supply chain relies on the system’s structure, i.e., the interaction of two negative feedback control loops (inventory control, and WIP control), where the effect factors, subjective preference and demand changing, can affect the stability of the system must be implemented by the two negative feedback control loops mentioned above. The strategy combing decreasing the adjustment of inventory $\Delta I$ and increasing the adjustment of transit inventory $\Delta WIP$ (i.e., decrease $\alpha_i$ and increase $\alpha_{awip}$) can improve the system’s stability, which is effective if and only if the right and below zone of $s'$ in the delay system and PTD system, however, the converse strategy must be introduced when the system stands on the left and upper zone of $s'$. ② the order decision relies on the demand information $D$ of downstream enterprise, the transit inventory information $WIP$ of the upstream enterprise, and delay information $DT$. The supply chain system’s property of feedback should be developed dynamically such that system stable cutoff can be changed and make the stability of the controlling strategy should be invalid if the information mentioned above can not be obtained accurately, which means that sharing information can improve the supply chain’s stability to decrease the bullwhip effect in supply chain. The cost should not be minimized as far as the minimization stable level $C^*$, i.e., inventory fluctuating convergence, is concerned. ④ there exists an optimal threshold so that it relies on the structure of real inventory management capability and inventory cost in supply chain operating\cite{142}. This conclusion is complemented by Chang Luo, Suling Jia and Huiwen Wang, in Ref. [143]. In the other aspect, Qingren Cao, Min Zhou and Xuefeng Song suppose that the terminate demand is a first-order self-regress process, in Ref. [144], then analyze the supply chain’s order strategy completed in a deterministic stable period according to the demand fluctuated, the conclusion shows that: when the demand of supply chain’s partners is i.i.d., the average $E(D_i)$, and the variance is $Var(D_i)$, the added to supply chain partners’ demand fluctuation can be described as $B_i = 1 + \frac{(T_i - 1)E(D_i)^2}{Var(D_i)}$, which relies on the downstream partner’s average of demand $E(D_i)$, the variance $Var(D_i)$ and the order leading time $T_i$; as for $K$-stages supply chain, where $K \geq 2$ and the $k^{th}$ ($k = 1, 2, ..., K - 1$) stage partner’s demand satisfies the property of independent distribution of average $E(D_k)$ and variance $Var(D_k)$, and each company in every stage uses the same order strategy with certain deterministic period, and the order leading time is $T_k$, and the same maximum inventory level, furthermore, each company orders the product from their upstream randomly and independently in the certain period, then the added to the $k^{th}$ partners’ demand fluctuation can be described as $B_k = \prod_{i=1}^{K-1} \left( 1 + \frac{(T_i - 1)E(D_i)^2}{Var(D_i)} \right)$, which can be extrapolated linearly to the other cases.

It is the virtual organization that make the bullwhip effect exist in supply chain, in this sense, the properties and state of bullwhip effect is decided by the special supply chain topological structure. Many scientists think that there is heavier bullwhip effect in the longer supply chain, and there is more complex bullwhip effect in the supply chain with more complex product family. I.e., it is supply chain structure that decide the properties and state of bullwhip effect in supply chain. Jianxin You, Minggang Sui and Jiazhen Huo, construct a z-zone model for multi-inventory system in cycle supply chain in Ref. [145] and analyze the corresponding bullwhip effect. The conclusion shows that the transfer function of inventory relies on the parameter $\alpha$ in exponent move method, reclaim rate of product $k$, delay time $L_e$ to the demand of the reclaim product, the leading time for reproducing $L_R$, reclaim quantity $R$...
and the leading time for producing; and the minimum condition is $\rho^* = \frac{3/2\alpha^2 + \alpha^3 - 19/6\alpha^2 + 4\alpha/3}{2(\alpha^2 - 1/2\alpha + 1/3)\alpha^2}$, the optimal reclaim time is $\frac{-(2k-2k^2 + (\rho\alpha - 2(1+\rho\alpha-\alpha)))/(1/2-\alpha))}{k^2-2k+4/3}$.

However, the conclusions obtained are based on the linear hypothesis, as for the non-linear and complex, time-varied cases, there are no profound conclusions are drawn, which gives us a very important researching direction.

As well known, weakening bullwhip effect is another important research direction, where VMI, collaborative-planning-forecasting & replenishment are studied to implement this objectivity, which can be seen in Refs. [146]-[149]. These scientists prove that the information sharing mechanism can weaken the bullwhip effect in supply chain and decrease the expectation cost for supply chain operating. The VMI, collaborative-planning-forecasting & replenishment are specified in Refs. [150]-[155], as for the latter, the forecasting are independently revised to $D_t = d + \psi_t^p + e_t^p$, where $\psi_t^p$ and $e_t^p$ are parameters of forecasting combined, and this conclusion can be extrapolated $D_t = d + \rho D_{t-1} + \psi_t^p + e_t^p$. The conclusion is that this forecasting method revised can decrease bullwhip effect to hug degree. In this sense, a problem called anti-bullwhip effect is introduced by Li G, in Refs. [156]-[157], it is interesting and must be a main researching direction for bullwhip effect.

(3) Supply chain adverse selection and moral hazard

Because of the information asymmetry, adverse selection and moral hazards are produced in supply chain, which is one of the most important research directions in future. The research conclusions show that it is moral hazards that bring some negative effects to supply chain, such as delaying to transfer commodities to the downstream, providing the false information to the upstream and false products to downstream, and so on. Because of them, not only the profits of the other enterprises’ and the supply chain’s but also the others’ enthusiasm for coordinating with each other are destroyed, and in turn its owner’s benefits are destroyed. So, they should be controlled below a receivable degree. On the contrary, as is well known, sheer synchronizing does not bring the maximum profits to the supply chain in fact, only partial synchronizing does. It is partial synchronization that make the supply stand on the edge between order and chaos, which brings infinite creativity and adaptability to the supply chain and gives the main mine of the competition capability to supply chain\[108\]. So, some degree moral hazards are permitted to exist and they do not do harm to the supply chain if they are lower than a certain threshold. Therefore, it is most important to mine the threshold of moral hazards percolating in supply chain, when the evolution law for moral hazards in supply chain has been gotten. In this sense, it is proved right in Refs. [6], [10]-[13], [20]-[21] that there must be some degree moral hazards in supply chain, furthermore, the supply chain and the enterprises perhaps be damaged by them only and only if the moral hazards exceed a threshold decided by the configuration of the supply chain. So, they can not be disappeared sheerly, but can be controlled them below the threshold. To do this work effectively, the inherent inducing mechanism and the transferring mechanism about it must be known clear, which makes mining the threshold precise.

It is proved that there do exist some degree of moral hazards in supply chain, in Refs. [158]-[163], and that the moral hazards in supply chain system should be controlled below the threshold determined coupled with supply chain structure. Therefore, although we can not disappear completely supply chain moral hazards, we can also control it at a certain scale, which is a feasible and effective. In order to control it effectively, the internal induced mechanism and transfer mechanism of the supply chain moral risk as well as their rule must be known, which is critical to quantify the threshold for risk percolation. As well known, identifying moral hazards in supply chain is most important thing to manage them, in this sense, some cases, such as contract fraud and providing false information, and so on, are named moral hazards. However, the essences for them are not induced accurately. There are several hypothesis are introduced in evading this problem: the first, all moral hazards can be integrated into a inseparably one that satisfies Gauss distribution, so, how moral hazards are transferred from one to anther and the
Moral hazard prediction and control is a pair of coupling problem, which is the mainstream for managing moral hazards in supply chain. Bo Zhang and Huang Peiqing, in Ref. [164], think the expectation payoff, to retailer in supply chain, of the new product must be uncertain if the marginal demand of consumers for the new product in the market that has only one monopoly manufacturers (upstream enterprise) is unknown. However, vendors can select the non-price variables to influence consumers' willingness to marginal consumption of the new product, and then affect his unit new product benefits. In addition, some non-price factors of the manufacturer can also affect the value of the products in the market, such as high level and high quality design and product of accurate market positioning, national promotions. Furthermore, we set that the vendors' unit gains for new product is \( x \), and the marginal payment willing for accepting this new product can be decided by consumers which be affected by following two factors: one is the investment for the public propaganda and product quality of new products, expressed by \( q \); another is selling attempts of retailers, \( m \). Meanwhile, revenue \( x \) can be affected by uncertainty factors coming from the uncertain market, which is expressed by random variables \( \theta \). Set \( x = g(q, m) + \theta, c(q) \) and \( d(m) \) stands for the cost of manufacturers and distributors respectively, and \( c^0, c^* > 0, c(0) = 0, c(\infty) = \infty \), \( d^* \geq 0, d^* > 0, d(0) = 0, d(\infty) = \infty \) the random variables \( \theta \) has continuous probability density function \( f(\theta) \) and cumulative probability distribution function \( F(\theta) \) during interval \([\theta L, \theta H]\). The random variables \( x \) has probability density function \( h(x|q, m) \), cumulative probability distribution function \( H(x|q, m) \). We can see that \( h(x|q, m) \) changed along with the effort extent of contracting parties. Contract

\[
\max_{q,m} x^F = g(q, m) + \bar{\theta} - c(q) - d(m), q \geq 0, m \geq 0
\]

has been solution of the game with three stages. In the first phase, distributors and manufacturers together select the repurchase price \( \alpha p \). In the second phase, the contracting parties try best to maximize their profits, then, gain \( \bar{\theta} \), and vendors know the size of the unit of new product yields \( x \). In the third phase, vendors decide whether to return according to the unit product revenue \( x \) realized. If return, he will sell to manufacturers by repurchase price. In this contract, the supply chain members enterprise achieving equilibrium, \( \theta_c = \alpha p - g(q, m) \), and the corresponding optimal decision on the return marginal value for the agent is \( x_c = \alpha p \); the agreement can be reached if and only if \( \alpha p = g(q^*, m^*) + \bar{\theta} \). By doing so, the corresponding moral hazards can be controlled effectively. In general, scientists think moral hazards in supply chain must be existed because there is some certain information asymmetry occurring in the supply chain operation process, as well as every enterprise operate indecently and the profitability, which can be regarded as the profound reason for moral hazards producing. Some scholars regard the supply chain enterprise as an agent according to their behavior rules, which interact with other enterprises and external environment, in this sense, the supply chain moral risk prediction and control system have been constructed by Luís M A Bettencourt, David I. Kaiser, see Refs. [165]-[166]. In these scientific papers, the adaptive strategy, incentive-supervision-constraint mechanism, has been discussed. The conclusion is that under effective constraints on supervisors (under the premise of supervisor’s effort level line up with earnings), moderate motivation and punishment on the downstream enterprises is an effective method of weakening supply chain moral hazards. But since the two results are based on moral hazards identified fuzzification or make one of the moral hazard based on simple extrapolation, and the diversity and complexity of supply chain moral hazards have not be considered, so the accuracy of this conclusion is reduced greatly. This kind of incentive-supervision-constraint mechanism is constructed on the determining enterprise in many Refs, but whether the
objects managed should be defined as the whole enterprise or concerned people can not be determined, which makes these conclusion revised.

It is inducing mechanism and transferring mechanism that make moral hazards in supply chain operating, which should be regarded as the most important field for studying moral hazards in supply chain. However, due to the complexity of induction and transmission mechanism, it is difficult for us to accurately predict the moral risk, some Refs. [23]-[25], [107]-[108], [167]-[174] have adopted some relatively new theory methods, such as statistics, probability theory (stochastic time series), game theory (evolutionary game theory), MAS and corresponding model constructed, such as Stackelberg model, Betrand model, random time-varying system model and so on, the generation and development of moral risk are given a more explicit explanation, among which the moral conclusion of game theory model is more extensive. Incentive-supervision-constraint mechanism of these models is introduced as well as the applications range. Suppose that (1) the principal profit impacted by the agent's effort level and exterior productivity, and agent effort level is invisible; (2) production impact rate can be divided into two kinds — good and bad; (3) the principal pay wages to agent in addition to remuneration to the supervisor; (4) risk is neutral of the principal, agent and supervisor, and the corresponding conclusions are drawn: (1) even if all are completely rational nodal enterprises of the supply chain, there still certainly exist some degree of moral hazard; (2) the moral risk of supply chain is the nonlinear sum of each enterprise’s, the nonlinear is mainly the consequence of the interaction of enterprises according to the relatively simple rules, it is precise because the interaction, risk will be enlarged; (3) because not know the real reason of production of moral hazard, cannot predict the supply chain moral hazard, but can identify the supply chain moral risk characteristics, and can describe by adopting different methods; (4) it is hard to understand the severity of moral hazard generated in different organization. If the above four questions can be solved, then the supply chain moral hazard can be forecasted and controlled.

As mentioned above, if and only if the moral hazards in supply chain exceed a certain threshold, which can do great harm to the entire system. However, till now there is not right or profound conclusion for the decision of this threshold method, not to mention the control. This is the second major problems of moral hazards. In Refs. [175]-[177] there is the preliminary inquiry of this problem, more profoundly conclusion still can not be obtained. This is due to the virtual organization of supply chain, not likely to completely constraint the behavior of each enterprise from the global. And just as supply chain management theory, only when the system stands on the edge of chaos and order, the whole supply chain huge adaptability and create ability just may be stir up. In view of this, the existing of certain moral risk in the supply chain is inevitable, as long as there is a supply chain, there is moral risk, and it is difficult to grasp the degree. By combining phase transition theory and non-equilibrium statistical physics, the criticality of moral hazards can be determined. However, various research results have very big different, it was hard to say who is right or wrong. Refs. [178]-[179] had a preliminary discussions about moral risk evolution rule, the power-law distribution. However, considering that each organization (or enterprise) is tons (or tissue) gathered together, in which all decisions are formulated by most people, which effectively inhibit the occurrence of the risk, because different views were offset each other in the decision-making process; Otherwise the decision will be unable to implement, because there exists plenty left point of view. In addition, there are a lot of people play different effects in the supply chain: some people work together with other people in the organization (enterprise) in the process of operation, while others working with people in other organizations (enterprise). Because people are creative and flexibility, and they could violate organization rules in the work. Once there was a case, there is moral hazard, and it, at first, will be transferred to the person who has interaction with him, this also explains the emergence of moral hazard and the propagation process in the supply chain. However, anytime there are inflows and outflows of personnel in the supply chain enterprise, which makes the supply chain dynamic and form a complicated system. If one part person produced moral hazard problem, and pass it on to other people, then total moral risk will be massive and complex[180]-[184]. If the degree of moral risk is more than a threshold, which would endanger supply chain; if not, can it can be ignored. In this sense, past research could not make good further explanation, and it is very important to study from the perspective of people.
Mentioned above, from the aspects of people to study the supply chain moral hazard, then there must be a critical value that can destroy the interests of the supply chain members, and the critical value will become the key of resolving the problem. By constructing a model of non-equilibrium statistical physics theory, the avalanche possibility of various sizes of moral hazard and the possibility and the critical condition of big range over percolation in the supply chain system operation process can be analyzed. So by constructing a heterogeneous Ising model, regarding the resources flow change rule in the core of supply chain link as interaction rules, interactive three tired-echo model is constructed, so the evolution law and percolation criticality of moral hazards in supply chain can be gotten, as well as the robustness and weakness coupled with random attack and intentional attack respectively, which should be a most important research direction.

Known as the results mentioned, the supply chain risk’s identifying mostly focuses on a certain operation process, as well as a certain single risk integrated linearly by several risks, where these risks studied are always be expressed as the profit lost. However, the non-synchronization between enterprises’ behaviors in supply chain and the non-coordination between enterprises in supply chain can not be considered, which makes the transitory behaviors of enterprises in supply chain are considered but not the behaviors in long time-scale in identifying supply chain risks\[15]\[184]\[185]. In this sense, the researchers merely regard supply chain as the combination of the loose enterprises which regards profits as the only goal, rather than as this concept that long-term partnership. In their consciousness, not completely separated supply chain with supply chain, and the research conclusion is more suitable for supply chain. In addition, there are various risks in the supply chain operation process, a very complex synthesis has been formed by interaction at each stage, different risks should be understood at different stages, as the incentives of different risks are different, accordingly, risk identification should determine the structure and change of the risk, which must be the mainstream of supply chain risk studying in future.

3. Risk estimate

3.1. The method of risk estimation

Profoundly speaking, the supply chain risk is identical to the random of the supply chain operating, it is the uncertain happened in supply chain and it is given to the supply chain some degree of loss, which should be estimated by objective methods and/or subjective methods. To show this, a generalized model is constructed as follows:

In this system, the perturbation expresses all the uncertainties coming from the environment and the system, which makes the system face two different cases emerged which can not only improve the system’s competitive but also destroy the system’s operation, the latter is called the risk emergence which can make some loss to supply chain. So, if the supply chain risks need to be estimated accurately, the certain transfer functions must be determined: which consists of the coupling between input of resources and output of risk events, the coupling between perturbation and risk events, and the coupling between management parameters and risk events, and the coupling between risk event and the loss of supply chain’s profits. Thus, several models should be introduced to finish this
estimation process. However, because of the complexity of the risks mentioned above, there are certain distinction from the estimation obtained from the models to the results obtained from the reality, in this sense, our objectivity is to give a optimal error estimation system, i.e., the feedback mechanism should be added to the model to adjust the model to fit for estimating accurately\[^{[41]}\][[^{[186]}][[^{[190]}]]]. The results according to supply chain risk estimation are almost obtained based on the stable, deterministic and linear model of subjective estimation model, which makes the process understood though these methods can not describe the characters and evolution law for these supply chain risk.

In this section, several problems will be specified: how to construct the supply chain risk index system, what methods are to be introduced to estimate the supply chain risk, and how to determine the reviewers. Noted please, the last problem are always be omitted such that makes the estimation result are diverse too far, which consists of how many, what configuration and what property the reviewer should be selected, and so on, which is specified as follows.

(1) Constructing the estimation index system

The subjective method for estimating supply chain risk are always used, in this process, how to decide the character vector space is the key to estimating the risks because they can describe accurately the characters of risks occurred such that ones can judge which kind of risk is happening in supply chain operating process. However, as far as the researching results are considered, there are few profound conclusions emerged in this field. According to the process and methods of risk estimation, firstly, a corresponding index, logistics, fund flow and information flow are included, could be introduced to describe the risk’s characters. In this process, there are several hidden vectors, information, knowledge, for example, are introduced such that they cannot be quantified, which makes estimation difficult and inaccurate. Several scientists estimate the risk by deleting the corresponding hidden index to analyze conveniently. However, this is irresponsible behaviour. Furthermore, the scientists always can not distinguish the supply chain risks to company risks, which makes the index that should belong to the company risk introduced non-axiomatically to the supply chain risk’s estimated, and which leads to the wrong result because supply chain is an inseparable system that consists of several enterprises. In this sense, there should be some conclusions emerged as far as the supply chain risk indexes are concerned.

Although supply chain is a complex system that consists of several risks occurred in system operating, the single risk’s estimating is important according to the analytic-synthetic analysis method of complex system analyzed, the results obtained almost are focused on the variable of logistics and fund flowing. Ruifeng Yu, Yanmin Ren, Yu Wang and Liwen Liu, in Ref. [191], construct the risk index coupled with the credit loan of supply chain, they considered synthetic one, which consists of the index of fund strength (fund possess ratio by his own, current ratio, quick ratio), operating state (increasing ratio of market income, market ratio of product), fund credit (loans repaid ratio, dividend payout ratio), performance state (return on sales, the growth ratio of payoff) and development perspective (industry prospect, enterprise sustainable development ability). Then the risks mapping to supply chain structure and cooperative mechanism are estimated, which conclude the product competitive capability of terminal product (such as market sharing, the ratio of cost to profit, the appearing on the market ratio of new product, customer satisfaction degree), supply chain system management can cooperation risk (such as the rationality of supply chain structure, the information shared degree and communicating level), revised value of dependent state (the profits ratios, flexibility of meeting an emergency). Finally, the BP nervous networks method is introduced to estimate. However, because many indexes are considered in this estimation process, there are set repeatedly for several indexes, which lead to some negative effect on estimating; furthermore, there are several indexes’ data that can not be obtained directly such that decrease the accurateness of estimating. However, the profound results can not be obtained as far as the risk coming from inventory, transportation and customer satisfaction are concerned.

There are many scientific results have been obtained as far as the synchronization indexes are concerned, due to the risk classified and the corresponding risk characters. Donglin Liu and Chunxiang Wang consider this thought as right, in Ref. [192], the supply chain risk is classified into congenial risk, cooperative risk, knowledge risk,
information risk and inventory risk, and think they are inseparable and should be the complex one of combining the risks that are independent and dependent and of combining the risks that are in parallel and in serial, respectively. After calculating the different risks’ probability distribution, the supply chain’s risks can be described as the system’s average, variance, entropy, risk degree, and so on. Youling Jiang, Jiaqi Yang and Jun Yang, in Ref. [193], analyze the capability risk of cooperative partners, cooperative scale risk, moral hazards, enterprise cultural risk, single supplier risk, information transferring risk, logistics risk, safety risk, inventory risk, organization risk, economy environment risk, law environment risk, competitive risk, emergence nature-produced risk and war risk, then the synthesized estimation model combining fuzzy evaluation and artificial neural networks evaluation are constructed to specify all kind of risks mentioned above and their sensitive analysis. The similar conclusion can be found in Refs. [194]-[197]. The more profound conclusion is described in Ref. [197], by Ma Hanwu, Ma Qinrong and Fu Guohui, the interacting properties of the risk induced factors are analyzed, so does the risks’ interaction effect. In this sense, a new method, structure function, is introduced to estimate the risks in supply chain, which is valuable to scientists.

As described above, the relation between the character vectors, i.e., indexes, and the state variables, i.e., the inducing factors, of supply chain risk has been not distinguished, nor has been the couplings in the risk evolution, which makes these results need to be revised. In this sense, finding the order parameters for describing the supply chain risks is the key to describing them, and it is a most important thing to estimate them. Borda order value, a new parameter, is introduced in Ref. [198], by Jun’e Liu, Hongliang Zhang, Shaobo Li and Yongliang Liu, to estimate the supply chain risk, the corresponding process is shown in detail: set $N$ is the number of risk factors, $i$ is a certain risk, and $k$ is a special criterion; risk matrix $R = \{R_{ik}\}$ described the risk level of risk $i$ with criterion $k$ have two criterions- $k=1$ describe risk effect $I$ and $k=2$ describe risk probability $RP$, then the Borda value of risk $i$ is identical to $b_i = \sum (N - R_{ik})$. Obviously, this parameter can describe supply chain risk more accurately.

As we well known, the character vectors of risk character is a time-varied one, in fact, where the order of the system can be changed with system developed (i.e., the vector sets forms a stochastic process). If the supply chain risk can be recognized as a system, then the vectors according to the initial, the middle and the end, respectively, perhaps are to be different to describe the dynamical property of the supply chain risk index. In this sense, the complexity with dynamical property is emerged in the temporal dimension and the spatial dimension. So, the weight should not be a stable constant that is given by most scientists, but must be a weight process revised based on the feedback from results. When the time-scale is large, the weight revised system can be regarded as a slow time-varied and weak dependent system. Furthermore, in a certain time-scale, several main factors must be considered and the other factors can be omitted considering supply chain risk; with the system varying, especially when the system stands on the criticality, the factors considered just now are equilibrated for producing supply chain risks, so, only those negligible factors’ changing weakly affect the supply chain risk heavily. This thought is realized in Ref. [199], by Shizhen Bai and Xiaojing Zheng, in this Ref., an estimate-feedback-revise mechanism for every company in supply chain is specified, which is described as follow:
Obviously, this method of estimation-revision to state vector is more valuable, which will become the mainstream for supply chain risk estimating, where, stochastic time-varied system theory, Bayes learning theory and BP neural networks theory can be introduced.

(2) Estimating of single risk and integrated risk

Subjective estimation methods are always to be used because supply chain risk are produced due to the uncertainty coupled with the system decision parameters and the environment parameters, which include AHP, fuzzy evaluation method, grey evaluation method; on the other hand, objective method, such as entropy weight, is introduced to the study of supply chain risk estimation. Furthermore, the distinction between them is: the former insists that the value of index could be given by people, and the latter insists that the value of index could be collected from the real data of supply chain operating. Liu Y., Wu H., Luo M, in Ref.[200] analyze the logistics flow, capital flow, information flow in supply chain system and integrate them to the whole as a resources flow. For each resources flow, the article gives the corresponding risk indicators and expert assessment method that is used to determine the size of each risk of indicator. The next step is to determine the size of the overall risk with integrating risk by fuzzy calculation. Jiang Xiaogan, Chen Fenglin, Wang Feng propose risk estimating system of supply chain in Ref.[201] referring to three levels-enterprise internal, operations between enterprises and external supply chain risk. In that article, logistics risk and organizational risk are the most likely to happen in the upstream and downstream enterprise of supply chain, the impact of logistic risk general, the impact of organizational risk very small, the impact of information to supply chain little despite the possibility of risk occurrence of information highly. Although the possibility of cooperation risk is too low among the various business risks, some risks happen suddenly whose damages are particular large. In external risks of the supply chain, the destruct of natural environment brings is the strongest wave enough to cause paralysis of supply chain, whose likelihood is medium. Domestic economic environment is mostly prone to the risk and the failure is general; the risk possibility of legal environment changing is moderate, destructing in general. In that paper, making the three levels above mentioned from small to large, from the "point" to "line", "face" develop layer by layer, each process should be through the choosing the evaluation factors, ensuring the effective extent of evaluation factors, determining the likelihood of evaluation factors, calculating the results of evaluation, and finally obtained by linear superposition the size of the overall risk of the
supply chain. Following this idea, Ma Hanwu, Ma Qinxong and Fu Guohu in Ref. [202] establish the operating structural model of supply chain, in accordance with the fuzzy evaluation method to determine the overall risk of supply chain. Zai-Li Yang, Jin Wang and Steve Bonsall in Ref. [203] by using fuzzy set theory, define and analyse the subjective risk of container supply chain according to the size of brittle. M. Van De Voort, H. Willis, D. Ortiz in Ref. [204] analyze the container supply chain risk, and propose the eigenvectors of this type of supply chain are threat vector, brittle, results / importance and terrorism, which are occurrence according to certain random probability. Because risk can be changed dynamically with time-varying, Cengiz Kahraman in Ref. [205] evaluates the risk by fuzzy set theory, simulation, catastrophe theory, artificial neural network technology. However, he only discusses it in philosophical level, do not explore this in depth, but it has great scientific value. There are a number of other documents, this is no longer cumbersome.

Probability theory and its extension have great value in the supply chain risk assessment. Thomas Kull, and David Closs in Ref. [206] consider a three-layer supply chain (suppliers, distributors and retailers) risks. By using statistical hypothesis test method, the following hypothesis are considered: when the second layer supply is uncertainty, the organization's (retail) planed inventory holding time and supply chain risks are negative correlation; when the second layer supply is uncertainty, the first layer of (or distributor) planed inventory holding time and supply chain risk are negative correlation; when the second layer supply is uncertainty, supply chain planed inventory holding time and supply chain risk are negative correlation. In the analysis, the risk is primarily to consider the impact coming from the probability of supply chain failure, during time and customer satisfied. Through testing some conclusions have been given that inventory holding time is not the sufficient condition for sensitivity risk causing by supply chain failure, the other parameters such as inventory strategy parameter, collaboration of supply chain, the characteristics of advance-time of the second layer suppliers and its dynamic change law, and the interaction among these parameters affect the supply chain risk in great level. David Bogataj and Martija Bogataj in Ref. [207] based on probability theory describe the system unsynchronized by difference between the input and output of various parts of supply chain operation, and divide supply chain risk into process(production, distribution) risk, demand risk, quality risk, environment risk and takes them measure risk and brittle in frequency space. By introducing Laplace transform and fitting, the overall risk of supply chain is described. Based on corresponding results of Ref. [207], Mark Goh, Joseph Y. S. Lim and Fanwen Meng in Ref. [208] deeply analysis risk assessment system of global supply chain with multi-stage network model, in which the article deal with each risk indexes according with Moreau-Yosida regularization and do search globally by genetic algorithm, so obtain the overall risk of supply chain. Zu Kun, Chai Yueting, Yang Jiaben in Ref. [209] thought that the agile supply chain risk analysis, an important part of agile supply chain management, is the principal means to analysis uncertainties impact for the system. From the objective of agile supply chain running, uncertainty factors of the agile supply chain include three levels: system layer, collaboration layer, physical layer. In that, putting the change of the various layers assessment index of system as the final results, the paper presents an analysis method about agile supply chain uncertainty problem, namely risk analysis, and gives the risk analysis process of agile supply chain. Risks will be divided into market environment uncertainty risk, uncertainty risk of collaborative process among the entities, internal uncertainties within the entities. Market environment uncertainties factors include the uncertainty of product characteristics and uncertainty of market characteristics. Specific uncertainty factors include geographical features, seasonal differences, consumer preferences and product characteristics. Collaborative process uncertainties between the entities include supply, production, storage, transportation, sales and other links. Various aspects can express their collaborative manner and expected results by order form, including product or service names (NP), number (QP), Price (PP) and order completion time (TP). All this parameters excepting NP may change before the completion of the collaborative process. The uncertainties of affecting QP, PP, TP are the ASC entity uncertainties in the collaborative process, which includes the responsibility factor and non-responsibility factors. Responsibility factor is uncertainty caused by collaboration unilateral or both, including the entity's financial position, technical factors, etc; non-responsibility factor means the uncertainty caused by non-cooperative reasons, including policy
factors, natural disasters. Uncertainties within the entities are the main affective factors to the entity income (In) and the general cost (Co). ASC entity as an autonomous / semi-autonomous social economic system with the characteristics of complex systems, from the perspective of social and economic system is a kind of very complex analysis issues. And determining the supply-demand chain risk analysis and risk management to service the common goal of the system, so the results of risk analysis demand: ① reflecting the results and possible system loss during operation; ②giving the quantitative relationship between the size of loss and uncertainty factors (risk factors). The article constructs a function according to a target expected \( T(RES) \), the results of risk events leading to \( R(RES) \), risk factors \( F \), the probability distribution of risk factors, \( p(F) \), the risk factor \( GF(RES) \), risk event triggers \( CR(RES) \) and the probability caused by risk result \( P(R(RES)) \). External risks is described as \( E\left(\sum_{i=1}^{N} \alpha_{i} R_{i}(Re,q)\right) = \sum_{i=1}^{N} \alpha_{i} \int_{r} p(F_{i}) dp(R_{i}(Re,q) \leq r) \); Uncertainty factors among the entities in collaborative process constitute the collaboration risk of the entities, which affects collaborative process embodying whether the order form can be accurately completed or not. In that the \( QP, PP, TP \) is the core content of the order. Once obtaining the deviate values \( \Delta QP, \Delta PP, \Delta TP \) from the expected values \( QP, PP, TP \) and the probability \( P(\Delta QP), P(\Delta PP), P(\Delta TP) \), the destroy between the entity collaborate process is not difficult to estimate. Uncertainty factors within the entity constitute the internal entity risk, which is ultimately reflected in the entity income (In) and cost composition (Co).

Internal entity risk analysis does analyze following the above formula with Co and In as the index object. This approach is the main ideas of assessment the supply chain risk. Jiang Youling in Ref. [210] according this line of thought under the method of BP neural network estimates some contents about supply chain: (1) partner ability risk, (2) cooperation scope risk, (3) moral credit risk, (4) enterprise cultural risk, (5) exclusive provider risk, (6) information transmission risk, (7) information security risk, (8) logistics risk, (9) inventory risk, (10) organizational risk, (11) economic environmental risk, (12) legal risk, (13) competition risk, (14) natural disaster risk, (15) war risk. Jiang Min, Meng Zhiqing, Zhou Gengui in Ref. [211] studied the procurement CVaR model with a single cycle and multi-cycle multi-product portfolio of supply chain. By using the conditions risk value (CVaR) theory by multiple products procuring from multiple suppliers spreads the risks that result from uncertainties in order to achieve minimal loss. Firstly, CVaR model with single period multi-product portfolio for procurement and supply has been given, and then, the multi-period and multi-product portfolio CVaR model for procurement and supply are discussed, finally the numerical results can be obtained. More accurately, the article assumes that in a sales cycle, a vendor purchases \( n \) kinds of products (goods) from the suppliers, because of existence different price and quality between different products, they have different market demand. \( \xi \) means demand variable of this product, which indicates the random risk factor resulting from inventory loss in market. \( X_{i} \) is the order quantity of the i-products.

So the losing function of the \( n \) kinds of products is \( f(x,\xi) = \sum_{i=1}^{n}(y_{i} - h_{i})(x_{i} - \xi)^{+} \),and obtain the distribution function and cumulative distribution function of \( \xi \). Assuming \( \psi(x,y) \) mean the probability of loss not more than \( y \) with purchasing product \( x \). \( \alpha \)-CVaR could be defined \( \phi_{\alpha}(x,y_{\alpha}(x)) = (1-\alpha)^{-1} \int f(x,z)p(z)dz \) (where \( y_{\alpha}(x) = \min\{y \in R: \psi(x,y) \geq \alpha\} \)) a loss value about decision \( x \) under confidence level \( \alpha \). Based on this, decision making problems with conditions risk such as multi-product portfolio purchasing and inventory can be determined. After a series of derivation this problem converts into a linear programming problem, making the decision easier. Because of the multi-properties and the interaction between several properties, the Multi-Objectivity programming method can be used to coordinate and integrate these risks happened in supply chain operating. Cunlu Zhang, Zipe Wang, Peiqing Huang and Jianwen Luo propose that, in Ref. [212], the risk caused by supplier can
be expressed by time delaying, quantity shorting and place mistaking. Similarly, the reasons that producing the supplier risk can be described as the wrong behaviors of the staff, mismanagement, the equipment breakdown and breaching of contract intentionally, and so on. Furthermore, the risk can be induced because of environment fluctuating, such as natural disaster, political unrest and economical crisis happened in the place of supplier located. The supply chain system that consists of \( n \) suppliers is a decision making system relying on the reliability in fact, the total risk level in supply chain is called supply chain risk, i.e., the probability of supplying abnormally. Provided that all suppliers are independent with each other, obviously, by binomial distribution theory, the supply chain risk can be described as 

\[
P_i = \sum_{i=0}^{n} \binom{n}{i} (1 - P)^i P^{n-i},
\]

which can construct multi-objective programming model for the supply chain risk controlling by combining the risk and cost minimized.

Many scientists regard supply chain system as a complex system, where there exists complex and changeable interaction between each company and every process, which makes the risk produced in the system having the property of random both in spatial dimension and temporal dimension and this random characters can be resolved by complex networks. Complex networks can identify the transferring process and diffusion process of risk happened in supply chain operating, in this sense, the risks transferring process and diffusion process must be the mapping to the supply chain and supply chain risk topology, which can draw a conclusion, in essence, about supply chain transferred and diffused. Anna Nagurney and Qiang Qiang have described the supply chain risk configuration and the strength produced in every organization, in Ref. [213], so has done the risks transferring, which is valuable. In this scientific paper, weight in the complex networks weighted has been introduced to describe different resources flowing state in current and in the future, and a method called Nagurney-Qiang measurement has been analyzed about these risks. However, the profound conclusion is lack. Xiaojing Zheng, in Ref. [214], has constructed a Multi-Local-Networks model to specify the moral hazards happened in the supply chain operating process, from the human view, and moral hazards about the laziness and speculation can be analyzed, similar to their evolution law and the percolation criticality for supply chain moral hazards. In this paper, a graph which grows by adding single edges at discrete time steps has been considered, at such a vertex may or may not also be added. For simplicity we allow multiple edges and loops. In what follows, to choose a vertex \( v \) of \( G(t) \) according to \( d_{out} + \delta_{out} \) means to choose \( v \) so that \( P(v = v_i) \) is proportional to \( d_{out}(v_i) + \delta_{out} \), i.e., so that \( P(v = v_i) = (d_{out}(v_i) + \delta_{out})/(t + \delta_{out} n(t)) \). To choose \( v \) according to \( d_{in}(v_i) + \delta_{in} \) means choose \( v \) so that \( P(v = v_i) = (d_{in}(v_i) + \delta_{in})/(t + \delta_{in} n(t)) \), where all degrees are measured in \( G(t) \). To choose a vertex \( v \) of \( G(t) \) according to \( (d_{out}(v_i) + \delta_{out})' \), means to choose \( v \) so that \( P(v = v_i) \) is proportional to \( (d_{out}(v_i) + \delta_{out})' \), i.e., so that \( P(v = v_i) = 1 - (d_{out}(v_i) + \delta_{out})/(t - 2 + \delta_{out} n(t)) \). To choose \( v \) according to \( (d_{in}(v_i) + \delta_{in})' \) means choose \( v \) so that 

\[
P(v = v_i) = 1 - (d_{in}(v_i) + \delta_{in})/(t - 2 + \delta_{in} n(t)),
\]

where all degrees are measured in \( G(t) \). The model is: for \( t \geq t_0 \) the case of \( G(t + 1) \) from case \( G(t) \) according to the following rules: 1) With probability \( \beta_1 \), add a new local-world that has some vertices and edges; 2) With probability \( \beta_2 \), we add a new vertex \( v \) together with an edge from \( v \) to an existing vertex \( w \) in a local-world chosen arbitrarily, where \( w \) is chosen according to \( d_{in} + \delta_{in} \); 3) With probability \( \beta_3 \), add an new vertex \( w \) and an edge from an existing vertex \( v \) to \( w \) in a local-world chosen arbitrarily, where \( v \) is chosen according to \( d_{out} + \delta_{out} \); 4) With probability \( \beta_4 \), add an edge from
an existing vertex \( v \) to an existing vertex \( w \) in the same local-world, where \( v \) and \( w \) are chosen independently, \( v \) according to \( d_{out} + \delta_{out} \) and \( w \) according to \( d_{in} + \delta_{in} \); 5) With probability \( \beta_{s} \), delete an edge in a single local-world from \( v \) to \( w \), where \( v \) and \( w \) is chosen according to \( (d_{out} + \delta_{out}) \), \( (d_{in} + \delta_{in}) \); 6) With probability \( \beta_{e} \), add an new edge from an existing vertex \( w \) belonging to an local-world to anther existing vertex \( v \) belonging to anther local-world chosen arbitrarily, \( w \) and \( v \) are chosen respectively according to \( d_{in} + \delta_{in} \) and \( d_{out} + \delta_{out} \). In this sense, the complex networks coupled with moral hazards can be analyzed by complex networks method, the conclusion is that, the moral hazards evolution law is \( p_{i} \sim C_{in} i^{-X_{in}} \) (where \( X_{in} = 1 + 1/c_{1} \), \( C_{in} \) is a positive constant number, and \( c_{1} = (\beta_{1} + \beta_{2} + \beta_{3} + \beta_{4} + \beta_{5})/(1 + \delta_{in}(\beta_{1} + \beta_{2} - \beta_{3})) \) ) and \( q_{i} \sim C_{out} j^{-X_{out}} \) ( where \( X_{out} = 1 + 1/c_{2} \), \( C_{out} \) is another positive constant real number, and \( c_{2} = (\beta_{1} + \beta_{2} + \beta_{3} + \beta_{4} + \beta_{5})/(1 + \delta_{in}(\beta_{1} + \beta_{2} - \beta_{3})) \) ), the combination distribution for moral hazards input-output can be said \( f_{ij} \sim C_{in} i^{-X_{in}} \) and \( f_{ij} \sim D_{ij} j^{-X_{out}} \). Obviously, this law is very important to risk estimating, the risks can be calculated by integrating the moral hazards probability density function. However, the autocatalytic cases, the carrier of moral hazards can simulate the others immoral behaviors while interacting with the other, of supply chain moral hazards can not be considered in this paper, which must be the mainstream areas in future.

3.2. The distinct risk result estimated by different estimator

(1) Estimator

Deciding the estimator is more valuable than the estimating process, in fact, which means that the different estimators in an identical group can obtain the totally different estimating results, limited by the environment, sentiment, and so on, to the identical risk happened in supply chain operating. In this sense, how many estimators and what structure of them should be invited to take part in this estimating process are the important things to decide. However, the corresponding results are few such that the supply chain risk estimating process can be improved a lot. By simplifying this problem, and abstracting the person to three different people, the optimistic ones, the pessimistic ones and the objective ones, where the estimating value can be lowered by the optimistic ones, and be enlarged by the pessimistic ones. Unfortunately, the objective ones do not exist in reality, so the two formers should be considered. To explain this, the effect for risk estimating on these three kinds estimators is specified as Fig. as follow:

![Fig. 5. property of estimators](image-url)
However, almost all conclusions for this field have evaded this question, through few conclusions (see Ref. [215]) regarded the proportion of the pessimistic ones to the optimistic ones should be set to 6:4 in experientially, the proof process is lacked. As is well known, the estimators can not be independent on the others and their decision must be affected by the others, which forms an effect called herd behavior, i.e., the results coming from authority can affect the others’ decision[216]. However, the normal distribution for decisions are supposed but not the Levy distribution in reality, which should be a main direction for studying.

(2) Aggregate for the results estimated different mass

According to Darwin’s theory, different mass focus on different thing, which makes the difference happened according to risk estimation results. So, how to aggregate the different results to certain one is an important research direction. As for this question, Wanhua Qiu specifies the result by AHP method, in Ref. [217]-[218], according to the $m$ mass. The corresponding judgment matrix $A_1, A_2, \ldots, A_m$, and $A^* = \left( \begin{array}{c} w_i \\ w_j \end{array} \right)$ is the total judgment matrix if there exists matrix $A$ such that $A = \phi^t A_1 \oplus \phi^t A_2 \oplus \ldots \oplus \phi^t A_m$, where $\phi^t L = \frac{1}{\sigma^2} / \sum_{L=1}^m \frac{1}{\sigma^2 L}$, $(L = 1,2,\ldots,m)$, matrix $C = (c_{ij})_{m \times m}$, the sum, which be defined as $A \oplus B = C$ where $c_{ij} = a_{ij} + b_{ij} (i \leq j, i, j = 1,2,\ldots,n)$, $c_{ii} = c_{ii}^{-1} (i < j, i, j = 1,2,\ldots,n)$ of $A = (a_{ij})_{n \times n}$ and $B = (b_{ij})_{n \times n}$, minimize the diversity from $A^*$. In this sense, matrix $A$ is the aggregated matrix of $A_1, A_2, \ldots, A_m$, and AHP estimation method revised improve the process. Of course, there are other aggregated methods for the estimation results for different single risk have been used, which consists of a new field supported by probability theory.

The estimation of the risk of supply chain, in fact, is a very complex system engineering, which consists of every operation process and every kind of risk in supply chain, and the system risk that can interact with each other and form more complex risk[219]-[224]. In this sense, the risk can not be really estimated if the scientist can not realize this property, which must be the main research direction for supply chain risk estimating.

4. Risk control

Risk control could be expressed from two aspects: first, the internal risk, is produced because of the random fluctuation of the system factors during the conventional supply chain operation processes; second, the internal risk, is produced because of supply chain facing the un-conventional incident suddenly where supply chain external environment change unexpected. For former, controlling each of operating links of supply chain could solve these problems; more importantly, the best way is controlling risk from integrated aspect. There are several reasons explaining this opinion. A single process risks could not make great dangerous for total operation of supply chain as long as the other process risks do not happen at the same time, it is not threaten the integrated operation of supply chain. It is mentioned in Ref. [6] that supply chain, autonomy-system attributes which could fix the risks and make it back to the normal state, is a complex adaptive system. If and only if somewhere links’ risk delivering with the operation process of supply chain causes other links’ risks and makes percolation occur in the supply risk, this kind of destruction will be huge for supply chain. Furthermore, because of complexity, the self risk of supply chain does not mean the linear addition of all part risks, so the integrated risks is the main study object in supply chain analysis process.

From another point of view, supply chain risk controlling is actually equivalent to the stability controlling, which is weakened as much as possible the uncertainty of the supply chain, making it possible to operate on the attractors, so that the synergy (coordination) emerges too. However, the previous content has been proposed, the appropriate
supply chain uncertainty is main reasons of supply chain innovation and fast adaptation. All uncertainty could not be completely eliminated; on the other hand, environment changing constantly, new things continuing to occur, supply chain innovation has become an inevitable trend. Therefore, unknown, new things, phenomenon continuing to produce, uncertainty may not be completely eliminated. This idea fully in line with the thought of robust control and adaptive control system, therefore, supply chain risk controlling study basically conduct along this line of thought.

Note that, the risk controlling process, in which the system state should be observable/identifiable, controllable, is not all cases controlled. From this perspective, supply chain risk identifying, risk estimating is the basis of the risk controlling. It also the premise of the system is controllable. If the risks lie in the nonlinear interactions among the risks, this identification before controlling is very important. At present, many studies do not really explore this part of content, but assume that the system is completely observable/identifiable, controllable and is a deterministic system (not include the characteristics of random time-varying systems), while random time-varying risk of supply chain system is precisely a typical nature. The credibility of its conclusions should be further explored. Here is the basic control idea:

4.1. Internal risk controlling of supply chain system

The most effective approach is robust controlling, or brittle controlling for supply chain risk management. The following describes the situation on the domestic and international research.

(1) Risk controlling during operation process

As mentioned above, all aspects of supply chain have all kinds of risks in operation process. These aspects of risks need to be controlled within a certain range, which built on the basis of risk identifying and this process need to be controlled. That is, it must know the causes of risk, the mapping relationship between the reason and the size of the risk, the interaction between the risks and its formulation of integrated risks. In that premise, 6-Sigma management methods could be used to control it. Refs. [229]-[235] alone this line of thought carried out some analysis in operation process risks. These are some general preliminary ideas, of course, there are some articles on risk controlling for a more profound study. Some analysis on them will be specified as follows.

Robustness analysis of the manufacturing process risk is one of the main content in supply chain operation risk controlling, and research achievements at home and abroad are not abundant. The first content is the measure of the robustness. Qiming Zou, Tao Yu, and Haiyang Sun proposed in Ref. [236] makes system robustness in the manufacturing process according to the system operation robustness (R_o), system internal robustness (R_i), system usefulness robustness (R_u) and fuzzy algorithm integrate itself. Jose A. Faria in Ref. [237] followed characteristics
of manufacturing system, put Refs. [238]-[239] the conclusion extrapolated, and by induction expresses the operation characteristics of all operation links through graph theory. Meanwhile, using probability theory to determine the all parts possibility of risk and dangerous came from failure of operation and calculate the entire manufacturing system risk. In fact the risk assessment process is also used in the whole supply chain risk management process. Then the risk possibility and the harm of manufacturing system have been given, and the key parts of its controlling are identified.

Bullwhip effect is the main risks brought by supply chain information management. The controlling method is stochastic control, robust control, $H_\infty$ control and so on. This section has been given a more detailed exposition in 2.4. But there are information uncertainty and distortion during the transmission caused by information risk. Ki-Uk Kim, Hyun-Suk Hwang and Su-Hwan Jeong in Ref. [240] carried out some research on robustness of information gathering according to the hardware design technology and data transmission theory.

Supply chain risk comes from transferring and exchanging resources flow during the operation process. There are some researches about this control area. Inneke Van Nieuwenhuys and Nico Vandaele in Ref. [241] put Ref. [242] extrapolate to the research result that consider product delivery system of two level supply chain (one supplier, a vendor, a product) reliability analysis. In that article, providers achieve the delivery of bulk product transfer through multi-delivery of independent and identically distribution in transaction processes, and introducing synchronization describes the overall performance of the process. By using system variance to express synchronization degree and simulation model, the order splitting strategy that can respond the state of transaction is obtained.

There are other risk control studies in the operation process, but the basic process and the basic method are similar, the conclusion also has self-similarity.

(2) Integrated risk control of supply chain

As mentioned above, supply chain risk system can be regarded as a complex adaptive system, in which the various risk agents have interaction with the all aspect links, and do a complex evolution. Therefore, the supply chain system risk controlling has greater significant. The difficulty lies in the risk integration, that is, the inherent risk of the supply greater. So under normal circumstances, the main method of using this theory, the linear description as follow:

$$X_{i+1} = A_{m_i,n_i}X_i + B_{m_i,n_i}w_i$$
$$Y_i = C_{m_i,n_i}X_i + D_{m_i,n_i}v_i$$

About the control equation with random time-varying characteristics, most of the studies are given the features of A, B, C, D in the equation and the criterion of convergence during the control process (whether exponential convergent or Lyapunov convergent), then, determine the risk degree under this condition. There are also some of the methods such as robust control, fuzzy control used to solve these problems [147],[182].

Previously mentioned, the purpose of risk control is to improve the robustness of supply chain system, in which process, there are two major problems: risk measure and risk controlling. Measure of system robustness is the primary task of robust control. Measure is similar to the risk assessment, research in this area we can refer to part 3 of the content. Another key element is to controlling methods: fuzzy control, stochastic control, robust control, adaptive control, etc. However, due to the complexity of management system, the main study abroad focuses on robust control. In many robust control studies, the process of robust control model is very complex and it difficult to use conventional methods to analytical solution. To solve this problem, the current study has some similar treatment: to be translated into an optimization model. Of course, this solution and basic idea of control is very difference. But if you get the correct conversion method, we can obtain more accurate conclusion; Put the constructed model do linear process and it becomes relatively simple, for example, in randomized controlled process, we assume its interaction satisfies Levy distribution. There are some similar treatment ways in references.
It could be said that this kind of simplification achieved some success. In this approximation, we can obtain more accurate conclusions. For the risk control of universal supply chain, some conclusions can refer to more complete. The most typical is Ref. [243] by Dimitris Bertsimas and Aurelie Thiele. This article based on Ref. [72], [244]-[249] and robust control theory focuses that 1) the robust control model is transformed into linear and mix integer programming model; 2) under determine behavior, analysis multi-dimensional problem caused by uncertainty demand; 3) when cost are not fixed, the robust is transformed into linear programming; when cost are fixed, the robust is transformed into mix integer programming problem; 4) robust programming is equivalent to four optimal strategy based on dynamic programming. By re-scale and relative approximation to the uncertainty of system, determine the linear structure. When demand $w_k$ is in a random state and its value interval is $\left[ \overline{w}_k - \overline{w}_k, \overline{w}_k + \overline{w}_k \right]$.

Conclusion as followed: without limiting the storage capability, if costs are not fixed, the optimal robust inventory strategy is $[S, s]$. exist constants $p$, $h$, and $S_k = w_k = \overline{w} + \frac{p-h}{p+h}(A_i - A_{i-1})$, relate to average demand and the coefficient constraint of two moment before and after. If costs are fixed, the optimal robust inventory strategy is $[s, S]$, and $s_i = x_0 - \sum_{j=0}^{i-1} w_j$, $s_j = -\sum_{i, j \neq i} w_{i,j+1}$, $j \geq 2$. $L_j = t_{j+1} - t_j$, $L_j = \left[ \frac{pL_j - c_{l_j-l_{j-1}}}{h+p} \right]$, $S_j$ the same as no fix inventory; and the optimal robust control is add one item to the optimal solution of programming and this item is $2ph \sum_{i=0}^{\infty} A_i$. If limiting the storage capability, article will set a constant as a limited range. Through which we obtain the similar results. The latter part of this article makes conclusion spread to the network supply chain. Due to the complexity of solving, article simulates the results through numerical simulation. It is mentioned by Jiawang XU, Xiaoyuan HUANG, Nina YAN in Ref. [250] that risk is divided into a number of relative sequence operations process according to characteristics of supply chain operation process, analyzing internal mechanism of risk electronic network supply chain which include multi-vendor and multi-customers under the condition of demand uncertainty. So we could build a multi-objective robust control and optimization model making meet customer demand, the total cost not exceed a certain value $TC$, the utility size of supplier capacity not less than a certain level $\alpha(0 < \alpha < 1)$ to eliminate uncertainty risk in supply chain. Because of its computational complexity, the article will transfer robust control and optimization model into several independent objective programming models giving corresponding constraints. The model has effectively solved coordination among the multiple conflicting objectives in robust control process of supply chain, whose method could be extrapolated to the other similar robust operating optimal system of supply chain. Of course, using a model simplification during the handling process and simplifying a number of multi-independent objective goals but not considering complex emergence phenomenon caused by non-linear interaction among targets, which is a hot research point in the future. In fact, due to the increased emphasis on the environment, closed-loop supply chain is increasingly becoming one of the key areas in supply chain research area. The type of risk control of supply chain naturally has become a focus. However, the results of research are not many and lack of a deeper conclusions. The most typical is Huang Xiaoyuan, Yan Nina’s article in Ref. [251] that proposes a more in-depth analysis for closed-loop supply chain risk control and spread some conclusion about Refs. [252]-[255], which thought the uncertainty of supply chain has two forms: 1) the uncertainty of external connection and unexpected events, mainly on the cooperative. In order to eliminate the uncertainty of connection, we need to increase cooperation and coordination between enterprises or departments; 2) the uncertainty of the internal operation. The main reason of system running instable is lack of effective control mechanisms in organization. Controlling failure is a source of instability and uncertainty in organization management. Closed-loop supply chain has more uncertainty than the traditional supply chain, mainly from the uncertainty in reverse channel operation, that is the uncertainty of demand and supply of materials recovery, the uncertainty of recovery rates and waste products remanufacturing, as well as the uncertainty of time-delay of product recycling and remanufacturing. A close-loop
supply chain system model with uncertainty time-delay is constructed: the inventory of k minutes is $x_k$, the ordering of $k$ minutes is $u_k$, $w_k$ is the demand of $k$ minutes, the cost or benefit of system output is $z_k$, time-delay is $\tau$, dimension inventory parameter matrix of state equation is $A$ and $A_k$, controlling parameter matrix is $B$ and $B_k$, the external disturbance parameter matrix is $F$; the inventory parameter matrix of output equation is $C$ and $C_k$; control parameter matrix of output equation is $D$ and $D_k$, the external perturbation parameter matrix of output equation $G$.

$$
x_{k+1} = Ax_k + A_kx_{k,1} + Bu_k + Fw_k
$$

$$
z_k = Cx_k + (D + \Delta D)u_k
$$

where, $x_k = (x_{1,k}, x_{2,k}, x_{3,k})$, $u_k = (u_{1,k}, u_{2,k}, u_{3,k})$, $A = \begin{bmatrix} 1 & 0 & \alpha_k \\ 0 & 1 - \beta_k & 0 \\ 0 & 0 & 1 - \alpha_k \end{bmatrix}$, $A_k = \begin{bmatrix} 0 & 0 & \alpha_z \\ 0 & -\beta_z & 0 \\ 0 & 0 & \alpha_z \end{bmatrix}$, $B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ and $E = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$, $C = (c_x, c_l, c_1)$, $D = [c_n, c_i]$, $\Delta D = [c_n, c_i]$. for any given $\gamma$, if there is a definite matrix $Q, S_1, S_2$ and matrix

$$
M = \begin{bmatrix}
-Q + A_kS_1A_k^T & AQ + BM & F & 0 & 0 \\
-Q & QC + M^TD^T & M^T & Q & 0 \\
F^T & 0 & -\gamma^2I & 0 & 0 \\
0 & CQ + DM & 0 & -I & 0 \\
0 & M & 0 & 0 & -S_2 \\
0 & Q & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -S_1 \\
\end{bmatrix}
$$

bounded within $\gamma$, correspondingly, state feedback control law is $u_k = MQ^{-1}x_k$. Xiaoyuan Huang in Refs. [256]-[257] extrapolate this conclusion to the huge closed-loop supply chain including a manufacture, a supplier, and further distribution, re-manufacturing, reuse capable. The manufacturer completely deals with recycling of waste products and re-processing. Multi-objective robust dynamic supply chain operating model is established under customer demand uncertainty.

From a certain perspective, the robustness and stability is a pair of synonyms. Therefore, the robustness control of supply chain risk in this case is equivalent to the stability management of supply chain. Some literatures conduct control research from the stability of supply chain aspect and obtain some useful conclusion. The most typical article is in Ref. [258], which analyze the stability of the two-layer and multi-layer supply chain and can be expressed as equation

$$
R_\gamma(t) = \prod_{y_1} \prod_{y_2} \left[ 1 - (1 - R_\gamma(t)) \lambda_{y_1} \prod_{y_2} (1 - p_{y_2})^{\gamma_0} \right],
$$

Finally, a corresponding integer programming model to determine the appropriate strategy for all parties is constructed. Of course, this conclusion thinks of all the supply chain process as a deterministic problem, ignores its randomness, which makes the scientific value of conclusion reduced greatly. How to overcome this deficiency will become a hot and difficult research field.

Fragility and robustness, a relative term, have great effect to improve the stability of the supply chain. Controlling the fragility of capital flow is actually a main content of robust control of supply chain. In this regard, Rajendra K. Srivastava, Tasadduq A. Shervani and Liam Fahey consolidate the research result Refs. [259]-[261] in Ref. [262], which analyze fragility and fluctuation of capital flow from the macroeconomic environment, industry and business point of view. It is thought that it is difficult to improve the fragility and fluctuation of capital flow in macroeconomic environment, and just to adapt. The source of fragility is competitors behavior, new competitors entry, substitute products emerge, customer preference change, distribution channels update, products slow-moving, developing speed fast and so on; The main reasons of fluctuation of capital flow are competitor behavior, consumer behavior,
channel behavior, supplier actions and product flow; The first reason of fragility of capital flow are the product development, difficult to expand existing product lines, broken relationships with key suppliers, damaged market reputation, key customers left and break-even point too high; The factors caused capital flow fluctuant are the capability between meeting product demand and arrangement product, with a stable marketing strategy, changing of sale force mix and the relationship among major accounts. Finally, three strategies to control the vulnerability of capital flow are proposed: product and manufacturing process innovation, coordinating the relationship between customer and central figure of market-driven, improving the demand transfer process and marketing initiative management. But the article did not give the specific size of parameters. There are more valuable conclusions with the continuous development of supply chain risk management in this research area. Since this study is part of edges of the supply chain and accounting areas, more valuable research have not appeared in this field. Refs. [263]-[265] also verified this conclusion.

In the System control management field, if the threshold has been determined, the effective control strategy is to implement control and quality management. Jana Žel, Katarina Cankar, Maja Ravnikar, Marjana Camloh and Kristina Grudin in Ref. [266] using basic thought of quality management PDCA and standard ISO/IEC 17025 control the resources various and determine the control interval of each index and control method through data mining and knowledge discovery method; Hans-Pater Wlendahi, Gregor van Clemiskl and Carsten Begemann in Ref. [267] establishing the supply chain operation framework and assessment logistics performance with the SCOR approach, obtaining a certain amount of data by sampling method and doing data mining, define customer demand of supply chain and build logistics model determining supply chain logistics performance. Meanwhile, that paper ensures supply chain robustness of the logistics operation using dynamic assessment and real-time control. So Young Sohn, In Su Choi in Ref. [268] construct the basis fuzzy quality function subordinates model of supply chain robustness in the theory of fuzzy systems, but the article did not reach substantive conclusions.

Basically, the results of these studies point out the basic characteristics of supply chain risk control. But some issues remain unresolved: supply chain risk, whatever in operation process or supply chain system risk, generally occur transport phenomena and each risk factors have interaction between them. Then it is actually a control problem of complex adaptive system. But research in this area is basically a vacancy. It will be the research direction of supply chain risk control.

4.2. Supply chain risk control under unconventional emergencies

The greatest crisis supply chain facing is environment mutation. If a disturbance of the external environment greater than a threshold value, the supply chain will be damaged. However, since this mutation is built on a small probability event, it is difficult to predict what kinds of unusual incidents will impact supply chain. So, it is difficult to manage by using early warning methods, only using scenarios strategy to deal with the supply chain coordination. But, this coordination should be established in some condition that the supply chain has sufficient rapid response capacity. For these reasons, research in this area is not very rich.

When external demand changes, supply chain will face enormous risks. Yu Hui, Chen Jian, in Ref. [269], based on Refs. [270]-[273], regard that the retail of supply chain use ‘Make to order’ strategy facing certain back contract coordination mechanism (coordinated strategy of buying back contract and demand distribution are not related) extrapolate to the ‘Make to stock’ strategy, and from this point of view do some more profound research. The article points out: supply chain under buy-back contract environment has a strong robustness facing demand distribution great change caused by retailers suffer emergency. (Note: Pasternack pointed out that in ‘Make-to-order’ strategy coordination supply chain with the buy-back contract and demand distribution is not unrelated. the study of this article is: Make-to-stock approach) That is the buy-back contract realized the coordination of emergency response with demand in a small size change; At the same time optimal order quantity of supply chain system is not change. However, when the demand size changes for a large-scale, the optimal order quantity of supply chain system will
change and supply chain is no longer coordination under the original contract. Emergencies result in the cost increase in supply chain operating process, only the companies, involved in the supply chain, share by certain rules and expensive the cost to maintain the entire interests of the supply chain and achieve a coordinated response to emergencies. Through mathematical analysis there are following conclusions: supply chain under the buyback contract has strong robustness. When the incident causes the market size little increase or decrease, the original buy-back contract mechanism could achieve coordination. The main point is that the optimal order quantity of supply chain does not change; when emergency make market size large change, the original buy-back contracts can not be implemented again to coordinate the supply chain. Using of adjusted buy-back contract \( T(w_{\text{anti}}, q, b) \)

\[
( w_{\text{anti}} = w + \frac{\lambda}{q} (\lambda(q-q^*)^+ + \lambda_2(q^*-q)^+) )
\]

can achieve coordination response for emergency. Emergencies cause the costs increase in supply chain, it must make each enterprises involved in the supply chain commit together according to certain rules of the corporate to maintain the common interests of the entire supply chain. Because the incident causes the market size little increase or decrease, the optimal order quantity of supply chain system will not change, so supplier will not change the production plan. That is for the original production plans, the demand distribution (scale) forecast does not need to particularly accurate. Therefore, enterprises do not have to spend a lot of cost to pursuit of accurate prediction of demand, but it must strengthen the awareness of emergency, timely detection and evaluation the impact of supply chain emergency to make a timely response. On this basis, Hui YU, CaiHong SUN and Jian CHEN in Ref. [274] using the same lines extrapolate the above results to obtain the conclusion that coordinating supply chain to ensure the robustness when supply chain face a sudden disruption due to environmental mutations. The article adds a sudden increment \( \Delta \) on the normal demand and determines their own cost - benefit relationship. Then simulating the constructed results, obtain some numerical results. There are a number of articles, most of them amend some conclusions on this basis and do some extrapolation.

At present, there are not too many studies on supply chain risk caused by supply sudden change, but it does exist. The typical example is some suppliers collapsed due to irresistible force causing supply chain to face a lot of pressure, as well as including under irregular emergency circumstance risk control problem of supply chain with very short supply. In spite of emphasizing the importance of coordination, but the actual research has not yet begun. Ref. [269] does some preliminary exploration on this field, whose results have been given in front of some description, this is no longer cumbersome. Research in this area will be an important direction, particularly in this circumstance where unexpected events frequently occur driving of unconventional natural this study is very significant [275] [278].

However, research for this problem exists to some extent. The main problem can be summarized as following: the control objectives of these studies are often single, focusing on profits, while ignoring the agile reaction, coordination, and other issues of supply chain [279] [282]; when emergency comes, this change based on normal distribution in the external environment generally selects a critical value, then above this threshold analyze the distribution and result supply chain risk [283] [285]. In fact, the risk under normal circumstances meets the power-law distribution rather than the normal distribution, which trait should be given to analysis [286] [288]. Paper are not to distinguish the unconventional nature of emergencies, which is driven by natural factors, or social factors in the end [289] [291]. The two different kinds of evolution of external shocks are not the same, so the control of the supply chain risk should also be different. These issues will guide the research in a more deepen area.

5. Conclusion

Supply chain competitive capability relies not only on its owner capability of profit obtained but also on the risk management capability. So, risk management is much important to improve the supply chain’s performance. However, the conclusions drawn in this field almost be based on the deterministic cases but not the stochastic ones, which shall give us the researching direction in future.
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