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Robustness-Improvement Strategy and Modeling under Uncertainty of Chinese Catering Service Supply Chain

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Abstract

Catering Service Supply Chain (CSSC) is a new supply chain, of which Catering Service Integrator (CSI) is in the center accompany with Functional Catering Service Provider (FCSP). The core objective of CSSC is to provide different catering enterprises with supply chain services. Instability, non-standardization, specialty and diversity characteristics of the Chinese catering industry inevitably lead to demand uncertainty of CSSC, directly resulting in the uncertainty of operation and supply side. The uncertainty of supply chain system is the basis of robust optimization study, under the influence of uncertainty, robustness is extremely important to ensure stable income and continuous operation of supply chain. This research classifies various uncertainty scenarios, based on robust optimization method. Two strategies, service coordination with widely knowledge sharing, and synchronous decision with intelligent inducement, are designed to induce and integrate personalized demand to get the scale effect and the coordination of the entire supply chain. From a point of quantitative view, this research builds up robust optimization model to improve robustness of CSSC, deposing the target into two coordinated parts. The coordination is of great sense, including two objectives simultaneously, the first one aims to maximize the delivery rate of order demand, the second one aims to optimize profit of CSI and FCSP. According to data examination, the coordinative strategies and robust optimization model can effectively control the uncertainty of the whole supply chain, and then improve the robustness of CSSC.

Keywords: *Catering service supply chain, Uncertainty, Robustness, Robust optimization, Coordinative strategies, Knowledge sharing, Intelligent inducement*

1. Introduction

In the environment of economic globalization and the increasing development of regional economic enterprises, as well as the rising importance of intangible assets such as supply chain management extremely emphasizing the rapid response to market demand, a new management model came into being. Due to the chain structure, supply chain management has some features such as instability, non-standardization, diversity, complexity, dynamics, leading to uncertainty in each link of the chain. The uncertainty in the supply chain, a thorny problem, cannot be avoided in the management and decision-making of enterprises [1]. Objective of supply chain management is to reduce and even eliminate the adverse impact of uncertainty on the supply chain and improve its robustness.

The research of supply chain uncertainty-control draws the attention of many domestic and foreign scholars. From the source point of view, uncertainty lies in demand, production and

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supply link of supply chain, which cannot be fully and accurately observed, measured and forecasted [2] (Shihua Ma, 2005). Uncertainty of supply chain can be concluded into cohesion and operation aspects with the perspective of form [3] (Xiaoyuan Huang, 2007). In recent years, more and more experts concentrate on the question of how to control the uncertainty of supply chain with information sharing in the largest degree. The uncertainty performs as purchase, production and delivery uncertainty, and information asymmetry and poor communication between upstream and downstream enterprises of supply chain is the main reason [4] (Yantong Wu, 2007).

Due to the characteristics such as instability, non-standardization, diversity, complexity, dynamics, and the fact that service cannot be easily stored, the uncertainty of service supply chain differs from traditional industry supply chain. However, the current research of uncertainty mainly focuses on the industry supply chain, the study of service supply chain uncertainty still remains in the issue-raising stage, mainly analyzing existence, form and depiction of uncertainty [5] (Anderson, 2000). There is little deep research specializing in the CSSC. Because of diversity of material category, ambiguity of quality standard and volatility of price, the uncertainty of catering industry is more complicated than traditional industrial uncertainty. The deep and systematic study of CSSC uncertainty control, including its generation and control mechanisms, is of strong significance from both theory and practice perspective.

The current uncertainty optimization theory includes three methods: Stochastic programming, robust optimization and fuzzy programming [6] (Junfeng Tian, 2005). The significant feature of robust optimization is that the probability distribution function is unknown, and the uncertain parameter is described by discrete scenarios or continuous interval. The purpose is to find a near-optimal solution, which is insensitive to any observations of uncertain parameters [7]. Robust optimization was first proposed by Mulvey *et al.*, (1995) in order to seek robust solution under specific situation in stochastic optimization problems [8]. A. Ben-Tal and A. Ne-mirovski (2005) subsequently conducted a lot of research on robust optimization methodology and its application [9]. Then more and more scholars introduced robust optimization to the study of supply chain. Stephen CH Leung *et al.*, (2007) considered multi-sites manufacture under the uncertainty of manufacturing location, customer preferences, production capacity, labor standards and many other conditions, then set up a robust optimization model by adjusting the penalty parameter to determine the production planning and workforce level, and analyzed the models' robustness [10]. Nina Yan (2008) built a supply chain system which consisted of one manufacturer and several retailers with demand uncertainty, taking the substitutability of different products into account [11].

But by now, there is little research involved in uncertainty of Catering Service Supply Chain, let alone systematic study about uncertainty control and robustness improvement of CSSC based on coordinative strategies and robust optimization model. And this is the point cut of this paper.

2. Uncertainty Analysis of CSSC

China's catering industry presents the fast growth momentum of development in recent years. Supply chain is undergoing the process of gradually transforming from industry supply chain to professional service supply chain with increasingly fine division of labor [12]. Due to the short product life cycle, the personalization of demand and the high extent of resource globalization, CSSC owns a higher degree of uncertainty. It comes from three aspects, namely, category, quality and price that are further elaborated below:

1) Diversity of material category: There exists the semantic difference and delusive category of materials. Material names vary from different restaurants according to different regions, habits, culture, as well as preferences. Customer-defined names also aggravate the diversity of material category without common knowledge background.

2) Ambiguity of quality standard: Over the change of time and conditions, quality standard changes rapidly throughout the supply chain. From the lateral perspective, the catering enterprises and even different restaurants have different quality standards. In addition, along the supply chain from the supply side to the demand part, the standards vary from process to process.

3) Fluctuation of price: The catering industries' price is highly sensitive to seasonal, regional factors. National holidays or unexpected events will also bring volatility of price.

2.1. Uncertainty of Demand

Demand uncertainty refers to the great difference between the actual demand of customers and the orders of terminal market, which manifests itself very often as uncertain demand distribution in time, space, order and customer, the changes of demand structure and the deviation of demand forecast.

2.1.1 Instability: Economic globalization intensifies the uncertainty of demand at the time and space level. Customer demand is complicated and changeable, their preferences may greatly vary along lifetime. Catering industry has a wide range of customer market. In addition to local residents, domestic and foreign tourists can become the object of catering enterprises reception. The fact that needs of different groups is not all the same also leads to instability of supply chain.

2.1.2 Non-standardization: There exist various types of factors that influence customer demand, such as policies, regions, climate, culture, habits as well as personal preferences. Because of personalized and diversified demand in the catering industry, customer loyalty for a single dish is reduced and standardization is difficult to achieve, thus resulting in the uncertainty of demand.

2.1.3 Specialty and diversity: Chinese catering industry has a large amount of cuisines with an increasing speed of product innovation. Besides, different catering companies, or even different branches of the same company has its own signature dish, which is the symbol of an enterprise, as well as the critical advantage to make profit. Specialty and diversity make the catering industry difficult to standardize and mass product, resulting in demand uncertainty.

2.2. Uncertainty of Operation

2.2.1 Uncertainty of Connected Nodes: Based on the chain structure, the uncertainty of connected nodes in CSSC is regarded as the uncertainty between the enterprises (or sectors) of supply chain. It primarily performs in the defect from cooperation among the enterprises. There are two key reasons for this.

1) Complexity: The supply chain in the catering service is an integration of series of nodes, each link providing special service such as development, procurement, production, storage and transportation. In the same link of supply chain, there are also multiple types of enterprises companied with its original feature. Large number of various kinds of nodes and enterprises in the supply chain cause the complexity of the structure of supply chain.

2) *Dynamics*: The dynamic nature refers to the instability of supply chain, responsible for a lack of long-term supply chain partnership. Loss of suppliers will inevitably result in changes in the raw materials, and also loss of third-party logistics companies will increase the risk of transportation and inventory to some degree. Due to the uncertainty of service demand, the differentiation level of service demand vary widely, the prediction of demand often deviates from reality, dynamics lies in the circle of customers as well.

2.2.2 Uncertainty of Link Operation: The uncertainty of link operation refers that supply chain system is running in uncertainty conditions. Operation uncertainty that is uncertain production, transportation, cost, quality and delivery date, will directly affect the radical ability of entire service supply chain to meet customer demand. There are three reasons responsible for the uncertainty in the link operation.

1) Low degree of standardization**:** The customer's descriptions of demand do not always correspond to the descriptions of integrators and providers. The service that catering industry serves different time and place is almost not the same. Besides, the standards set by different enterprises are not uniform, resulting in unsmooth circulation of raw materials and products. All the non-standardization makes it very difficult to meet customers' demand, which results in the fluctuation of customer demand passing to the upstream of supply chain to a greater degree. So, how to realize service standardization is the huge challenge urgent to be solved.

2) Conflicts between mass production and personalized service: The requirements of customers vary from the customers' preferences with the strong desire of personalized, customized services. Service is so personalized and heterogeneous that it is difficult to define the quality and predict the demand of services. The difficulties of predicting and standardizing the various products make CSSC not undergo the large-scale production, leading to cost increase. So the balance between the scale production and personalized service of CSSC is becoming a very significant research topic.

3) Decentralized decision-making: Decentralized Decision-making means that the supply chain members are always only caring about their own interests to make a unilateral decision, without considering the interest optimization of the whole supply chain. The result is to produce so-called bilateral inter-effect. The supply chain enterprises won't accept a decision that can bring overall revenue increase but their own revenue decrease, but they will accept some decision that even harms the overall interests but benefits themselves. The difference between individual interests and the overall interests is called bilateral inter-effects [13]. In the supply chain management, the bilateral inter-effects manifest as decisions with local optimization and hidden behaviors.

2.3 Uncertainty of Supply

Supply uncertainty means CSI and FCSP cannot well meet customers' demand, thus hindering the value-added process. It mainly stems from the uncertain lead-time, availability, quantity and quality of supply.

2.3.1 Uncertainty of FCSP: Due to the high extent of reliance between each node, problems of any supply point may cause the instability of the whole supply chain. Providers in each link of the supply chain inevitably have supply uncertainties, the uncertainties spread and accumulate along the supply chain, resulting in the uncertainty of the entire supply chain, giving each enterprise in the chain tremendous risks [14] (Xingfang Fu, 2006).

There is uncertainty in produce process of FCSP, such as machine malfunction. Also, in the transportation of products, there is much randomness, such as unexpected traffic accident, leading to transportation delay.

2.3.2 Uncertainty of CSI： Service integrator, the core of the CSSC, is confronted with more uncertainties in the operation of the whole supply chain. The customers' demand is unstable, CSI need to constantly respond the changes as well as synchronously update ingredients and service even development strategy. CSI not only have to deal with the changing needs of customers, but also face production, distribution and other kind of uncertainty caused by FCSP. The sudden order increase of customers, the FCSP's unpunctuality supply and many other factors could give rise to delay in delivery or arrival in advance.

3. Uncertainty Control Strategy Design

Robustness is essential attribute of supply chain system, a ubiquitous element accompanied with uncertainties [15]. It refers to the ability which maintains the system obtain high revenues and continuous running with the disturbances of uncertainty. With the gradual increase of uncertainty, the implementation of a certain supply chain strategy with robust performance plays a very important role in resisting uncertainties, as well as improving system robustness. TANG[16]thinks that certain strategies with the following special nature are claimed as robust performance: one is the efficiency performance, that is whether disturbance occurred, this strategy enables enterprises to effectively manage operational risks; the other one is elastic performance, namely whether disturbance occurred, this strategy allows enterprises to maintain normal operation. For a supply chain which lacks of protection against uncertainty such as CSSC, it is of practical significance to apply strategies with robust performance.

3.1. Service Coordination with Widely Knowledge Sharing

Coordinative Process in CSSC refers that through information and knowledge sharing can we integrate all enterprises' resources to meet customer service needs. It is cross-functional synergy process with demand and supply as the initial drive. Coordinative process can effectively achieve coordinative operation of enterprises in all links to obtain the overall optimal operational objective, including mechanisms for information sharing and service coordination [17] (Chenyan Zhang, 2007).

3.1.1. Information-sharing: As the foundation of CSSC, information flow can effectively control and reduce uncertainty. Information sharing in CSSC includes coordinative demand prediction, procurement, production and distribution plans, market strategies, etc. Efficient information sharing can increase chances to quickly response to customer demand and coordinately operate. Lack of information sharing will lead to customers' demand delayed, supply chain members cannot communicate in time, which can also lead customers' demand fluctuated, inaccurate.

3.1.2. Knowledge-sharing: Due to the diversity of raw materials and Chinese cooking artistry, it seems impossible to integrate demand from different customers to get scale effect, which makes the supply chain operation in a confused situation. However, the requirements of professional experience in each business activity make it a knowledge intensive area. Consequently, sharing mechanism of common knowledge among all members of CSSC is of great significance and necessity.

From the supply side, with the development of central kitchen model and outsourcing of supply chain, the catalogue of material and product is enlarged without control. A standard production research center could build a material knowledge base with thorough study of material feature and usage. From the demand side, knowledge sharing is based on the collaboration of members on the supply chain to reach a consensus. The purpose is to get a balance between the distinguished demand of customer and the common supply catalogue.

3.1.3 Service Coordination: Service supply chain management objectives can be summarized as the coordinative operation between CSI and FCSP using all the resources in order to meet the specific needs of customers. Service coordination refers to coordinative operation in the various enterprises or sectors, which can provide value-added value and improve the whole competitive power.

Based on information technology, coordinative innovation platform is established, service coordination can achieve joint development, production, purchase, inventory, transportation management, thus reducing the uncertainty of supply, operation and demand. Also, service coordination can effectively solve the passive acceptance of orders in the operational process with no feedback of inventory warning resulting in a backlog of orders.

3.2 Synchronous Decision with Intelligent Inducement

Synchronization decision in CSSC refers to the use of workflow technology to achieve simultaneous analysis of business decisions. To achieve synchronization decisions for important business helps to improve the coordination of enterprises and departments, providing value-added service during the flowing process of products and enhancing the transparency of the supply chain. It can start from demand inducement and intelligent matching.

3.2.1 Demand Inducement: Demand induce theory was first proposed in 1966 by American scholar J Schmookler [18], and gradually introduced into China in the 1990s. Demand inducement in the supply chain of catering service refers to joint operation between upstream supply side and downstream demand side in the supply chain. Catering service integrators and functional catering service providers provide proactive guidance for customers in order to induce demand.

Demand inducement may well change the demand-driven supply chain to meet customer needs in a passive state, in order to stimulate or even create customer potential demand and reduce the risk of demand uncertainty. Active induction makes overly personalized customer orders tend to be more standardized, and resulting large-scale production can greatly reduce the operational uncertainty, achieving maximization of scale merit. Strengthen the process of demand inducement, based on in-depth understanding, digging and leading personalized services, to enormously enhance robustness of the supply chain.

3.2.2 Intelligent Matching: Intelligent matching, supported by knowledge-based intelligent decision, transfers the records of supply chain operation into the future resources available, and then learns from past experience to provide similar optimal services for customers. Intelligent matching also covers the intensive demand content, providing every single product an optimal supply chain model. Meanwhile, in the intensive-point, intelligent matching can take every economic advantage of scale to achieve integration of resources.

4. Robust Optimization Modeling of CSSC

4.1 Problem Description

Uncertainty of CSSC relates to demand, operation and supply uncertainty. When the demand uncertainty from the downstream end and the supply uncertainty from the upstream side arrive and superimpose in the middle of CSSC, the system robustness may become extremely low, seriously affecting the punctual delivery of order and the stable operation of supply chain. CSI is facing twofold dilemma that cannot effectively balance supply and demand. For CSSC which lacks of protection against uncertainty, it is of practical significance to realize robust optimization of supply chain. Therefore, in the case of considering the uncertainty of raw material supply and order demand, establishing robust optimization model is a problem worthy of study to resolve the optimal amount of order production and material order and material delivery. The model can enormously improve the robustness of the system to make order delivery rate and profit maintain higher level in a coordinative perspective.

The robust linear optimization model takes into account the multi-stage supply chain composed of a CSI and FCSP. The FCSP gains raw materials from the market to produce products as materials of the CSI. The CSI directly responses to the multiple customer demand. It is established under the environment of uncertain demand and supply based on scenario analysis to resolve the optimal operation strategies. Throughout the operation of the whole supply chain, in each specific stage, the CSI determines the optimal amount of products delivered to customers and materials ordered from the FCSP in the pursuit of order satisfaction rate and profit maximization, the FCSP also determines the optimal amount of materials delivered to the CSI on the basis of profit optimization. The structure of CSSC is as shown in Figure 1.

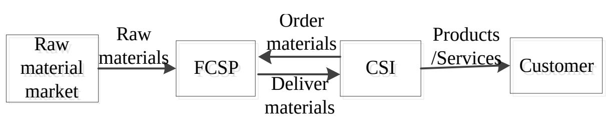

Figure 1. CSSC Structure

4.2. Parameter Definitions and Assumptions

First, put forward the following assumptions:

H1: The uncertainty of raw material supply and order demand is described by a set of discrete scenarios with known probability.

H2:Each order contains only one kind of product/service.

H3: Orders arrive at the same time in the same stage.

The parameters and their meanings associated with the model are defined as follows:

The main title (on the first page) should begin 1 3/16 inches (7 picas) from the top edge of the page, centered, and in Times New Roman 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Please initially capitalize only the first word in other titles, including section titles and first, second, and third-order headings (for example, “Titles and headings” — as in these guidelines). Leave two blank lines after the title.

Table 1. Model Parameters

parameter	parameter definition	parameter	parameter definition
j	order$(j = 1, \dots, J)$	u_i^k	unit inventory cost of material i
i	material$(i = 1, \dots, I)$	u_h^g	unit inventory cost of raw material h
h	raw material$(h = 1, \dots, H)$	o_i^k	unit inventory of material i
t	stage$(t = 1, \dots, T)$	o_h^g	unit inventory of raw material h
a_{jt}	demand of order j in stage t	k_{it}^L	inventory of material i in stage t

b_{jt}	production of order j in stage t	g_{ht}^{L}	inventory of raw material h in stage t
v_{it}	order of material i in stage t	k_{i0}^{L}	initial inventory of material i in stage t
l_{it}	delivery of material i in stage t	g_{h0}^{L}	initial inventory of raw material h in stage t
d_{ht}	supply of raw material h in stage	s_{ji}^{y}	BOM coefficient of product j to material i
p_{jt}	price of product j in stage t	s_{ih}^{x}	BOM coefficient of material i to raw material h
q_{it}	price of material i in stage t	K^{Lmax}	total inventory capacity of materials
r_{ht}	price of raw material h in stage t	G^{Lmax}	total inventory capacity of raw materials
c_{j}^{y}	unit variable manufacturing cost of product j	t_{jt}^{y}	unit production time of product j in stage t
c_{i}^{x}	unit variable manufacturing cost of material i	t_{it}^{x}	unit production time of material i in stage t
f_{j}^{y}	unit production capacity consumption of product j	t_{ht}^{z}	unit purchasing time of raw material h
f_{i}^{x}	unit production capacity consumption of material i	T_{jt}^{y}	expected delivery time of order j in stage t
Y^{max}	maximum production capacity of CSI	T_{it}^{x}	expected delivery time of material i in stage t
X^{max}	maximum production capacity of FCSP		

4.3. Robust Optimization Model

The model introduces a scenario set of raw material supply and order demand: $\Omega = \{1, 2, ..., S\}$, the probability of each scenario appears as p_s, and $\sum_{s=1}^{N} p_s = 1$. Assuming production of order j in stage t by CSI is b_{jt}, order of material i in stage t by CSI is v_{it}, delivery of material i in stage t by FCSP is l_{it}. l_{it} act as the control variable, once the raw material supply and order demand are observed, it can be adjusted accordingly, while other decision variables are design variables, valid for all scenarios. Respectively, d_{ht}^{s} and a_{jt}^{s} represent supply of raw material h and demand of order j in scenario s with b_{jt}^{s}, v_{it}^{s}, l_{it}^{s} respectively corresponding to production of order j, order of material i and delivery of material i in scenario s, other parameters are identical in all the different scenarios. In addition, the model introduces two parameters, w_{1i} means unit shortage loss of material i to FCSP, w_{2j} refers to unit shortage loss of product j to CSI. That is, CSI has profit loss accompanied with unsatisfied demand.

This model considers the following three specific operational targets:

T1: CSI pursues the highest level of order delivery, namely the highest satisfaction rate of order demand:

$$\max\ Q = \sum_{s\in\Omega} p_s \frac{\sum_{t=1}^{T}\sum_{j=1}^{J}\frac{b_{jt}^{s}}{a_{jt}^{s}}}{TJ}$$

T2: Profit maximization of CSI:

$$\max\ R = \sum_{s\in\Omega} p_s \left\{\sum_{t=1}^{T}\left[\sum_{j=1}^{J}\left(p_{jt}\, b_{jt}^{s} - c_{j}^{y}\, b_{jt}^{s} - w_{2j}\, e_{jt}^{s}\right) - \sum_{i=1}^{I}\left(q_{it}\, v_{it}^{s} + u_{i}^{k}\, k_{it}^{L}\right)\right]\right\}$$

$$e_{jt}^{s} = e_{j,t-1}^{s} + a_{jt}^{s} - b_{jt}^{s}$$

$$k_{it}^{L} = k_{i,t-1}^{L} + l_{it}^{s} - \sum_{j=1}^{J} s_{ji}^{y}\ b_{jt}^{s}$$

Among them, e_{jt}^{s} represents shortage of order j in scenario s. Target 2 is the total profit maximization of CSI, of which the first expression means order revenue minus production cost minus shortage loss of products, the second term represents the sum of procurement cost and inventory cost of materials.

T3: Profit maximization of FCSP:

$$\max\ Z = \sum_{s\in\Omega} p_s \left\{ \sum_{t=1}^{T} \left[\sum_{i=1}^{I} (q_{it}\, l_{it}^{s} - c_i^{x}\, l_{it}^{s} - w_{1i}\, \varepsilon_{it}^{s}) - \sum_{i=1}^{I} \sum_{h=1}^{H} \left(r_{ht}\, s_{ih}^{x}\, l_{it}^{s} + u_h^{g}\, g_{ht}^{L} \right) \right] \right\}$$

$$\varepsilon_{it}^{s} = \varepsilon_{i,t-1}^{s} + v_{it}^{s} - l_{it}^{s}$$

$$g_{ht}^{L} = g_{h,t-1}^{L} + d_{ht}^{s} - \sum_{i=1}^{I} s_{ih}^{x}\ l_{it}^{s}$$

Among them, ε_{it}^{s} represents shortage of material i in scenario s. Target 3 is the total profit maximization of FCSP, of which the first expression is material revenue minus material production cost minus shortage loss of materials, the second term includes procurement cost and inventory cost of raw materials.

The above three operational goals combined and written in the form of goal programming, we will get robust optimization model of CSSC in uncertain environment of raw material supply and order demand.

The objective function is as follows:

$$\min\ P_Q d_Q^{-} + P_R d_R^{-} + P_Z d_Z^{-}$$

Among them, P_Q, P_R, P_Z, constants large enough, mean priority factors of three operational objectives respectively. d_Q^{-} refers to unrealized satisfaction rate of order demand. d_R^{-} means unrealized expected profits of CSI. d_Z^{-} represents unrealized expected profits of FCSP. In the operation of supply chain, the first task is to ensure that the satisfaction rate of order demand remains a higher level, then we take profit optimization of supply chain into consideration, assuming the priority factors of CSI and FCSP's profit are equal. Therefore, the relationship of three priority factors can be expressed as $P_Q \gg P_R = P_Z$.

The constraint conditions are as follows:

C1: The constraint condition when target 1 transformed into goal programming form is as below.

Transformed into a form of goal planning, target 1 becomes the first item of the objective function, the constraint is:

$$Q + d_Q^{-} - d_Q^{+} = M_Q$$

$$Q - \sum_{s\in\Omega} p_s \frac{\sum_{t=1}^{T}\sum_{j=1}^{J} \frac{b_{jt}^{s}}{a_{jt}^{s}}}{TJ} \le 0$$

Among them, M_Q, a given constant, means CSI's expected satisfaction rate of order demand. d_Q^{-} and d_Q^{+} separately refer to unrealized or excess satisfaction rate of order demand. Q is on behalf of the actual satisfaction rate of order need.

C2: The constraint condition when target 2 converted to goal programming form is as following.

Converted to a form of goal programming, target 2 acts as the second item of the objective function, the constraint is:

$$R + {d_R}^- - {d_R}^+ = M_R$$

$$R - \sum_{s\in\Omega} p_s \left\{ \sum_{t=1}^{T} \left[\sum_{j=1}^{J} \left(p_{jt}\, b_{jt}^{s} - c_j^{y}\, b_{jt}^{s} - w_{2j}\, e_{jt}^{s} \right) - \sum_{i=1}^{I} \left(q_{it}\, v_{it}^{s} + u_i^{k}\, k_{it}^{L} \right) \right] \right\} \le 0$$

Among them, M_R, a given constant, means CSI's expected profit. ${d_R}^-$ and ${d_R}^+$ separately refer to unrealized profit. R is on behalf of the actual profit of CSI.

C3: The constraint condition after target 3 altered to goal programming form is as follows.

Altered to a form of goal programming, target 3 turns into the third item of the objective function, the constraint is:

$$Z + {d_Z}^- - {d_Z}^+ = M_Z$$

$$Z - \sum_{s\in\Omega} p_s \left\{ \sum_{t=1}^{T} \left[\sum_{i=1}^{I} (q_{it}\, l_{it}^{s} - c_i^{x}\, l_{it}^{s} - w_{1i}\, e_{it}^{s}) - \sum_{i=1}^{I} \sum_{h=1}^{H} \left(r_{ht}\, s_{ih}^{x}\, l_{it}^{s} + u_h^{g}\, g_{ht}^{L} \right) \right] \right\} \le 0$$

Among them, M_Z, a given constant, represents FCSP's expected profit. ${d_Z}^-$ and ${d_Z}^+$respectively means unrealized or excess profit. Z refers to the actual profit of FCSP.

C4: Constraint of CSI's maximum production capacity:

$$\sum_{j=1}^{J} f_j^{y}\, b_{jt}^{s} \le Y^{max}, \quad \forall t, s$$

C5: Constraint of CSI's total inventory capacity of materials:

$$k_{it}^{L} = k_{i,t-1}^{L} + l_{it}^{s} - \sum_{j=1}^{J} s_{ji}^{y}\, b_{jt}^{s} \ge 0, \quad \forall i, t, s$$

$$\sum_{i=1}^{I} o_i^{k}\, k_{it}^{L} \le K^{Lmax}, \quad \forall i, t$$

C6: Constraint of order production by CSI:

$$b_{jt}^{s} + e_{jt}^{s} - e_{j,t-1}^{s} \le a_{jt}^{s}, \quad \forall j, t, s$$

C7: Constraint of FCSP's maximum production capacity:

$$\sum_{i=1}^{I} f_i^{x}\, l_{it}^{s} \le X^{max}, \quad \forall t, s$$

C8: Constraint of FCSP's total inventory capacity of raw materials:

$$g_{ht}^{L} = g_{h,t-1}^{L} + d_{ht}^{s} - \sum_{i=1}^{I} s_{ih}^{x}\, l_{it}^{s} \ge 0, \quad \forall h, t, s$$

$$\sum_{h=1}^{H} o_h^{g}\, g_{ht}^{L} \le G^{Lmax}, \quad \forall i, t$$

C9: Constraint of material delivery by FCSP:

$$l_{it}^{s} + \varepsilon_{it}^{s} - \varepsilon_{i,t-1}^{s} \le v_{it}^{s}, \quad \forall i, t, s$$

C10: Constraint of expected order delivery time:

$$b_{jt}^{s} \left(t_{jit} + t_{jt}^{y} \right) \le T_{jt}^{y}, \quad \forall j, t, s$$

Among them, t_{jit} means the longest purchasing time of materials needed by order j.

$$\theta_{ji} = \begin{cases} 0, & s_{ji}^{y} = 0 \\ 1, & s_{ji}^{y} > 0 \end{cases}, \quad \forall j, i$$

$$t_{jit} = \max\left(\theta_{j1}\, t_{1t}^{x},\ \theta_{j2}\, t_{2t}^{x},\ \theta_{j3}\, t_{3t}^{x} \dots\dots \theta_{jI}\, t_{It}^{x}\right), \quad \forall j, t$$

C11: Constraint of expected material delivery time:

$$l_{it}^{s}(t_{iht} + t_{it}^{x}) \leq T_{it}^{x}, \quad \forall i, t, s$$

Among them, t_{iht} refers to the longest purchasing time of raw materials demanded by material i.

$$\sigma_{ih} = \begin{cases} 0, & s_{ih}^{x} = 0 \\ 1, & s_{ih}^{x} > 0 \end{cases}, \quad \forall j, i$$

$$t_{iht} = \max(\sigma_{i1} t_{1t}^{z},\ \sigma_{i2} t_{2t}^{z},\ \sigma_{i3} t_{3t}^{z} \dots\dots \sigma_{iH} t_{Ht}^{z}), \quad \forall i, t$$

C12: Non-negative constraint:

$$b_{jt}^{s},\ l_{it}^{s},\ v_{it}^{s},\ d_{Q}^{-},\ d_{Q}^{+},\ d_{R}^{-},\ d_{R}^{+},\ d_{Z}^{-},\ d_{Z}^{+},\ e_{jt}^{s},\ \varepsilon_{it}^{s},$$
$$Q,\ R,\ Z \geq 0$$

5. Empirical Case Study

This research applied the coordinative strategies and robust optimization model into practical operation of a CSI, monitoring operating results on real-time basis. The uncertainty–controlling comparative analysis table and the benefit analysis table are made, details are as follows

Table 2. Uncertainty Control Effect

		control effect		
strategies	demand uncertainty		operation uncertainty	supply uncertainty
service coordination	diversity-reducing	balance demand and supply	unified purchasing amount decreased by 1-2%	material integration
	stability-improving	long-term cooperation	joint purchasing cost decreased by 0.5-3%	stable supply
		rate of menu-changing increased	set completed	long-term cooperation
demand inducement	standardization	cleaned-converting rate increased to 80%	cost decreased diversity of material category weakened	matching supply and demand level elevated
		preserved-converting rate increased to 60%		
	stability-improving	rate of tasting-difference reduced to 10%	ability of demand forecasting increased	industrial transformation
intelligent matching	diversity-reducing	dish category simplified by 10%	service capacity increased	standardization
	stability-improving	seasonal dish price stabilized	stability of quality increased	
		demand stably increased	scale operation	bulk supply

From the data on Table 2, it shows that, through the implementation of a series of such information/knowledge sharing, service coordination, synchronous decision, demand inducement and intelligent matching, one can increase the stability and standardization level of supply chain, reduce its diversity, take effective control of the uncertainty of customer demands. At the same time, the scale of operation and stability of supply are reinforced, which is weakening the uncertainties of operation and supply. Also the matching level supply and demand is enhanced, which consolidates a long-term partnership in CSSC. In a word, the coordinated strategies effectively control uncertainty and extremely improve robustness of CSSC.

Table 3. Benefit Analysis

	cost decreased		benefit improved
customer	human resource cost decreased	basic operator cost decreased by 1/3	table turnover rate improved 50%
		key technical staff cost decreased by 1/4	average customer price improved ￥2-5
		staff dormitory decreased by 20%	shop expansion speed improved 50%
	fixed assets cost decreased	kitchen area decreased by 10-30%	dish gross profit increased by 10-20%
	operating cost decreased	water cost cut down to 40%	speed of serving improved 0.5 minutes
		electronic cost cut down to 90%	rate of tasting-difference reduced to 10%
		gas cost cut down to 80%	
		maintenance cost cut down to 80%	
	utilization rate of raw materials increased to 95%		
CSI	purchasing cost decreased	unified purchasing amount decreased by 1-2%	service charge increased by 10%
		joint purchasing cost decreased by 0.5-3%	deep-cooperated customer added by 10
	production cost decreased by 1-3%		brand recognition up to 90%
	attrition rate decreased by 80%		customer complaint reduced by 50%
	inventory cost decreased by 5%		stable level of income raised
	shortage cost decreased by 10%		stable level of order delivery rate raised
FCSP	attrition rate reduced (caused by standardization) by 60%		deep-cooperated customer added by 10
	cost decreased(caused by coordination) by 1%-5%		potential cooperated customer added 100
	advertising cost decreased by 10%		1-3 years long-term cooperation plan

As described in Table 3, the robust optimization and robust strategies such as service coordination, synchronous decision not only reduce uncertainty of the supply chain of the catering industry, but also help all parties in supply chain reduce costs, increase revenues, and reduce risk in order to achieve a win-win situation. CSSC achieves enormous robustness-improvement in the point of qualitative combined with quantitative angle.

6. Conclusion

Starting with the analysis of supply chain uncertainty, this research investigates the robustness-improvement and uncertainty-control of CSSC on the basis of coordination strategy and robust optimization modeling. The achievements of the research can be concluded in the following perspectives:1) dividing the cause of uncertainty in CCSC into demand, operation, and supply uncertainty; 2) concluding that service coordination and synchronous decision can reduce the incidence of uncertainty, thereby improve system robustness; 3) building up the robust optimization model in consideration of demand and supply uncertainty with two coordinated objectives: order delivery and profit maximization; 4) applying coordination strategy and robust optimization modeling into practice to test its effectiveness and practicability in the point of qualitative and quantitative angle.

The research concludes that robustness-improvement and uncertainty-control of CSSC from the perspective of coordinative process are effective based on robust optimization. So far, the research hasn't fully or systematically showed quantitative index of category, quality and price uncertainty yet. Whether the strategies and robust optimization model are effective in the long-term run, need continuous actual test by related enterprises. In the future, the authors will conduct further exploration with the support of more evidence data.

References

[1] B. Xie and X. Wang, "Choosing R&D or advertising for competing firms in uncertain market", Journal of Industrial Engineering and Management, vol. 7, **(2014)**.
[2] S. Ma, Editor, "Supply Chain Management", China Machine Press Beijing, **(2005)**.
[3] X. Huang and N. Yan, "Research progress of supply chain robust problem", Chinese Journal of Management, vol. 7, **(2007)**.
[4] Y. Wu, "A Study on the value and strategies of information sharing under the supply chain uncertainty", Guangdong University of Foreign Studies, **(2007)**.
[5] E. G. Anderson and D. J. Morrice, "A simulation game for service-oriented supply chain management: Does information sharing help managers with service capacity decisions", Production and Operations Management, vol. 9, no. 1, **(2000)**.
[6] J. Tian, "Optimization model and algorithm research under the uncertainty of supply chain", Southwest Jiaotong University, **(2005)**.
[7] A. Deng and Z. Nie, "Robust optimization review of uncertain supply chain", Statistics and Decision, vol. 21, **(2009)**.
[8] J. M. Mulvey, R. J. Vanderbei and S. A. Zenios, "Robust optimization of large-scale systems", Operations Research, vol. 2, no. 43, **(1995)**.
[9] A. Ben-Tal, B. Golany, A. Nemirovski and J. P. Vial, "Supplier-retailer flexible Commitments Contracts: A Robust Optimization Approach", Manufacturing and Service Operations Management, vol. 7, no. 3, **(2005)**.
[10] S. C. H. Leung, S. O. S. Tsang, W. L. Ng and Y. Wu, "A Robust Optimization Model for Multi -site Production Planning Problem in An Uncertain Environment", European Journal of Operational Research, vol. 181, **(2007)**.
[11] N. Yan and X. Huang, "Research on robust Stochastic optimization of multi-retailers competition under demand uncertainty", Chinese Journal of Management Science, vol. 8, **(2008)**.
[12] K. Wei, J. Gou and R. Chai, "Creation of Customer Evaluation Model in the Catering Industry Supply Chain Ecosystem", Journal of System and Management Sciences, vol. 4, **(2014)**.
[13] SAHINF and ROBISONEP, "Flow coordination and information sharing in supply chains: review, implication, and directions for future research", Decision Science, vol. 33, no. 4, **(2002)**.
[14] X. Fu and Z. Li, "The uncertainty and its strategies in enterprise supply chain", Commercial Studies, vol. 2, **(2006)**.
[15] H. N. Pollock, Editor, "Pingping Li, Translator", Uncertain science and uncertain world. Shanghai science education press. Shanghai, **(2005)**.
[16] C. S. Tang, "Perspectives in Supply Chain Risk Management", International Journal of Production Economics, vol. 103, no. 2, **(2006)**.
[17] C. Zhang, "Logistics service supply chain coordination", Science Technology and Management, vol. 9, no. 5, **(2007)**.
[18] J. Schmookler, Editor, "Invention and Economic Growth", Harvard University Press Cambridge, **(1966)**.