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Supply chain coordination problem of assembly system under new risk measurement including defective products

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--***ABSTRACTS:*** --

Based on revenue sharing contract, this paper discusses the supply chain coordination problem of assembly system.It constructs an assembly system model consisting of an assembler and n suppliers.Due to reasons such as technology or artificial parts supplier delivered to the assembly of parts will have different degree of damage.Therefore, it is more realistic to assume that there are defective parts for n parts.The supply chain cannot be coordinated without the benefit sharing.Then, the "income sharing + subscription subsidy" contract was proposed.The study found that the contract enables the supply chain to be coordinated.This paper studies the optimal delivery quantity of component suppliers in risk aversion.Because the mean value conditional risk value model (M-CVaR) is a discussion of the benefit maximization decision of the risk situation.But it is not objective to take the profit and loss as risk factors.Because there is no risk in the part where the benefits are greater than zero.So you can only think about that part of the risk of loss.Based on this, the P-CVaR model is proposed in this paper.The model is only considers that supplier S_i revenue does not meet the expected revenue loss.The study found that the optimal supply quantity of the supplier based on P-CVaR model was not related to the decision of the assembler, but only to the degree of risk aversion.Finally, the correctness of the model is verified by an example.

Key words:*Assembly system； Demand random； Part qualification rate； Revenue sharing contract； Risk aversion.*

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I. INTRODUCTION

Machinery and manufacturing industry, as an important sector in China's industrial system, plays a very important role in the process of new China's industrialization. Machinery and manufacturing industry play a supporting role in the development of national economy, which is one of the very important pillar industries of national economy and an indispensable organic part of industrialization construction. China also puts forward the development strategy of intelligent manufacturing 2025.In the machinery and manufacturing industry, many products are assembled from different parts, such as vehicles. Assemblers usually order parts from different suppliers and then assemble them.Due to asymmetric information with other suppliers and assemblers, and even the lack of demand information in the final product market, the quantity of parts provided by suppliers cannot match the delivery quantity of other suppliers, and the result is not necessarily perfect.For example, one car needs an engine assembly, 4 tires, 2 bumper, five seats, if parts suppliers through their decisions, delivery of the parts number 2, respectively, 9, 6, 14 pieces, final assembly, 2 cars can be assembled, the remaining one tires, two bumper, four seats cannot form a complete set, can only be scrapped, the parts supplier is their loss.Therefore, how to avoid excessive waste of parts in the assembly system to generate unnecessary losses and achieve supply-chain coordination is a problem worth exploring.

Gerchak and Wang[2] were the first to study the supply chain -- coordination problem of random assembly system, but did not consider the defective parts for assembly.Due to technical or human reasons, the products received by retailers will contain some defective products. Therefore, many scholars have studied the defective products.Literature [3] established a joint inventory model with imperfect production quality of suppliers under the credit payment strategy. When the retailer orders products again, the defective products will be returned to the supplier for processing.Literature [4] established EOQ model related to product price and order quantity.Literature [5] established EOQ model related to credit period and order quantity based on partial credit payment.In these studies, it is assumed that the defect rate of products produced by the supplier is constant, that is, the proportion of the quantity of defective products ordered by the retailer from the supplier in the order volume is a fixed value.However, the fixed rate of defective products is too idealistic in real life. In many cases, the quality of products is related to the production volume. When the production volume increases, the technology becomes skilled.Therefore, in this paper, it is assumed that the pass rate of parts increases with the increase of production volume. The pass rate is a function of production volume.

In the study of supply chain benefit coordination, the most important problem is the classical single-cycle problem under uncertain demand.Based on the newsboy model, the optimal order quantity decision problem is discussed when the profit is maximized under random demand.Khouja[6] summarized the recent ten years' research on the single cycle problem.Cachon[7] studies coordination through supply chain contracts based on the classic newsboy model, in which wholesale price contracts, return contracts, supply chain -- revenue sharing contracts, quantity elasticity contracts and asymmetric demand forecasting contracts are analyzed.This paper mainly considers the application of supply chain - revenue sharing contract under random demand in assembly system.

Research on the revenue sharing mechanism with uncertain requirements, the representatives of which mainly include Cachon and Lariviere[8].Blockbuster, a video-rental retailer, was the first to use the strategy, and profits grew by 40% in 2002, up from 24% in 1997.Blockbuster was hit with an antitrust lawsuit, but it turned out that revenue-sharing was the key.According to Mortimer's research and demonstration, the efficiency growth rate of Blockbuster and its upstream enterprise system is about 7% [9].Cachon et al. established the revenue sharing mechanism under the two-level supply chain model between suppliers and retailers, and proved that this mechanism can improve the revenue of the whole supply chain system. And they compare the model with the buyback model of Pasternack [10], showing that the latter is a special form of the former under the fixed retail price condition, and the former has a wider coordination scope than the latter.Cachon also illustrates the limitations of a revenue sharing mechanism, which is less effective if the vendor cannot verify the retailer's revenue, or if the retailer's behavior determines demand.Cachon et al. 's research focuses on whether this mechanism can coordinate the system.Then people refined and expanded their models.Dana and Spier[11] put multiple retailers in a perfectly competitive market in their model, which proves that the supply-chain -- revenue sharing coordination mechanism also plays a coordinating role.

In many cases, members of the supply chain will consider not only the size of the profit, but also the risk of loss.Ye fei et al. [12] studied the contract coordination mechanism of order agricultural supply chain composed of risk-neutral companies and risk-averse farmers based on CVaR.Zhong changbao et al. [13] used mean-conditional value at risk (M-CVaR) to uniformly measure decision-makers' risk preference, neutral and aversion levels, and based on this, studied the coordination problem of supply chain -- revenue sharing contract with decision-makers' risk preference level.There is no risk in the real world where there is a gain, just consider the risk of a loss.In this paper, a new P-CVaR model is proposed.This model takes into account the risk of the part of the supplier's S_i revenue that does not meet the expected revenue.

II. BASIC ASSUMPTIONS AND SYMBOLS DESCRIPTION OF AN ASSEMBLY SYSTEM

The traditional economic order quantity (EOQ) model assumes that the product is fully qualified and does not consider the quality of the product.However, due to technical or human factors, the products produced by the manufacturer may be damaged to varying degrees.Only qualified parts received by assemblers can be used for assembly. Defective parts can only be processed again, sold at a discount or discarded directly, which will bring certain economic losses.

In the assembly system constructed in this paper, it is assumed that the market demand of the final product is random, and the random demand is D, the probability distribution is F(x), and the probability density function is f(x).When the final product is sold, its market price is p.The final product consists of n parts.Without loss of generality, assemblers need only one unit for each part of a finished product.n parts are provided by n independent suppliers, and the i part given by supplier i to the assembler will have defective products, which cannot be used to assemble the final product.At the end of the activity, the assembler returns the defective products to the supplier, who is responsible for transporting and disposing of the defective products.The unit handling fee of supplier i is t_i.In general, the larger the production, the more skilled the technology, the better the product quality.In this paper, it is assumed that the acceptance rate of parts supplied by the supplier to the assembler increases with the increase of production volume.Suppose that the completion rate of part i is an increasing function of Q_i, such as, $1-\frac{1}{r_i Q_i}$, $0<r_i\le 1$.Let's take this function as an example.The quantity of part i supplied by the supplier S_i to the assembler is Q_i.Since the defective product cannot be used to assemble the final product, the part i can only be used $(1-\frac{1}{r_i Q_i})Q_i$ to assemble the final product.To simplify the model, we assume that for unsold products and unassembled parts, the cost of no storage and out of stock.

Q_i: Parts supplier S_i delivery volume, $i=1,2,\cdots,n$;

Q_c: Assembly quantity of assembler under centralized decision-making;
Q_0: Assembly quantity of assembler under decentralized decision;
c_i: Supplier's $S_i$unit production cost, $i = 1,2,\cdots,n$;
c_0: Unit assembly cost of the assembler;
ω_i: SupplierS_i revenue sharing factor,$i = 1,2,\cdots,n$;
ω_0: Profit sharing factor of assembler,$\omega_0 = 1 - \sum_{i=1}^{n} \omega_i$;

III. CENTRALIZED SYSTEM

In a centralized system, the goal is to maximize the benefits of the supply chain.Since every part that is not assembled is wasted, it is obvious that there should be an equal amount of integrity for each part when the entire supply chain benefits the most. That is:$(1-\frac{1}{r_1Q_1})Q_1 = (1-\frac{1}{r_2Q_2})Q_2 = \cdots = (1-\frac{1}{r_nQ_n})Q_n = Q_c$ .So$Q_i = \frac{r_iQ_c+1}{r_i}$,Q_c is the assembly quantity of assembler in the centralized decision-making.
The expected benefit of the entire supply chain is:

$$\Pi(Q_c) = \mathrm{E}\left\{p\min(Q_c,D) - \sum_{i=1}^{n}[c_iQ_i + t_i\frac{1}{r_iQ_i}Q_i] - c_0Q_c\right\}$$

$$= p(Q_c - \int_0^{Q_c}F(x)dx) - \sum_{i=1}^{n}\left\{c_i\frac{r_iQ_c+1}{r_i} + \frac{t_i}{r_i}\right\} - c_0Q_c \quad (1)$$

So if $\pi(Q_c)$ take the first derivative with respect to Q_c, it can get :

$$\frac{d\pi(Q_c)}{dQ_c} = p\bar{F}(Q_c) - \sum_{i=1}^{n} c_i - c_0 \quad (2)$$

$\pi(Q_c)$ is a concave function with respect to Q_c,because :

$$\frac{d^2\pi(Q_c)}{dQ_c^{\,2}} = -pf(Q_c) < 0$$

Let equation (2) equal to zero, and get:

$$\bar{F}(Q_c^*) = \frac{\sum_{i=1}^{n} c_i + c_0}{p} \quad (3)$$

For $Q_i = \frac{r_iQ_c+1}{r_i}$,then $Q_{ic}^* = \frac{r_i\bar{\bar{F}}^{-1}\left(\frac{\sum_{i=1}^{n}c_i+c_0}{p}\right)+1}{r_i}$ (4)

By substituting equation (3) into equation (1), the revenue of the whole supply chain under centralized decision-making is:

$$\pi(Q_c^*) = \int_0^{Q_c^*} xf(x)dx - \sum_{i=1}^{n}\frac{c_i+t_i}{r_i} \quad (5)$$

When the qualified rate $r_i$increases, the qualified rate of parts will increase accordingly, and the quality of parts will improve.According to equation (3), under the centralized decision-making, r_i is no impact on assembler's assembly quantity, so product quality has no impact on assembler's assembly quantity.Only the assembly cost of the assembler, the production cost of the supplier and the market price of the finished product will affect the assembly quantity.When the assembler's assembly cost or the supplier's production cost increases, the assembly quantity decreases, and when the market price of finished products increases, the assembly quantity increases.As can be seen from equation (4), when the quantityr_i increases, the output of suppliersS_i will decrease accordingly. Therefore, under the centralized decision-making, suppliers can improve the quality of their products if they want to reduce their output.As can be seen from equation (5), whenr_i increasing, the revenue of the whole supply chain increases; When the assembly cost of assembler or the production cost of supplier increases, the income of the whole supply chain decreases.Therefore, the revenue of the whole supply chain can be increased by improving product quality.

IV. DECENTRALIZED SYSTEM BASED ON REVENUE SHARING CONTRACT

4.1 Revenue sharing contract

In a revenue sharing contract, the market price of the final product is p.For each unit of final product sold, the assembler allocates ω_i to the supplierS_i.($0 < \omega_i < 1$, $i = 1, \cdots n$)The percentage of your income that you have left is going to be $w_0 = 1 - \sum_{i=1}^{n} w_i$.All parts suppliers are aware of the revenue sharing mechanism of the assembler.In order for all companies to be profitable, the conditions must be met

$$pw_i > c_i, \quad i = 0, \ 1, \cdots n \qquad (6)$$

In the decentralized system, the supply quantity of the supplier and the assembly quantity of the assembler are decided independently, so as to maximize their own profits and have nothing to do with the decisions of other suppliers and assemblers.The expected revenue function of the supplier S_i is：

$$\pi_i(Q_i) = E\left\{w_i p \min\left((1 - \frac{1}{r_i Q_i})Q_i, D\right) - c_i Q_i - t_i \frac{1}{r_i Q_i} Q_i\right\}$$

$$= pw_i[(1 - \frac{1}{r_i Q_i})Q_i - \int_0^{\left(1-\frac{1}{r_i Q_i}\right)Q_i} F(x)dx] - c_i Q_i - \frac{t_i}{r_i} \quad (7)$$

$i = 1,2, \cdots, n$.

For formula (7), take the first derivative with respect to Q_i, get：

$$\frac{d\pi_i(Q_i)}{dQ_i} = pw_i \bar{F}\left[\left(1 - \frac{1}{r_i Q_i}\right) Q_i\right] - c_i \qquad (8)$$

$$\frac{d^2\pi_i(Q_i)}{dQ_i{}^2} = -pw_i f\left[\left(1 - \frac{1}{r_i Q_i}\right) Q_i\right] < 0$$

For：

$\pi_i(Q_i)$ is a concave function with respect toQ_i.Let equation (8) equal to 0, and get:：

$$\bar{F}\left[\left(1 - \frac{1}{r_i Q_i{}^*}\right) Q_i{}^*\right] = \frac{c_i}{w_i p} (9)$$

Substitute equation (9) into equation (7) , under the decentralized decision, the supplier's $S_i$revenue is:

$$\pi_i(Q_i{}^*) = \int_0^{Q_i^*} xf(x)dx - \frac{t_i}{r_i} \qquad (10)$$

In decentralized decision-making, if the profit of a supplier or assembler is unrelated to the supply quantity of other suppliers and the decision of assembler, to maximize its own profit, the supply quantity of the supplier and the assembly quantity of the assembler should meet equation (9).

From equation (9): $\frac{\partial Q_i}{\partial r_i} = -\frac{1}{r_i{}^2} < 0$, Under decentralized decision making, when the pass rate r_i increases, the quantity of supplier's s_i will decrease, which is the same as under centralized decision making.From equation （10）, $\frac{\partial \pi_i}{\partial r_i} = \frac{1-Q_i f(Q_i)}{r_i{}^2}, \frac{1-Q_i f(Q_i)}{r_i{}^2}$. It can't tell if it's greater than zero or less than zero.

The assembler's expected revenue is：

$$\max_{Q_d} \pi_0(Q_d) = E[\omega_0 p\min(Q_0, \ D) - c_0 Q_0]$$

$$= p\omega_0(Q_0 - \int_0^{Q_0} F(x)dx) - c_0Q_0 \quad (10)$$

Where Q_0 is the amount that assembler is willing to assemble without considering the decision of n suppliers.

$$\frac{\partial \pi_0(Q_0)}{\partial Q_0} = p\omega_0\bar{F}(Q_0) - c_0 = 0$$

$$\bar{F}(Q_0{}^*) = \frac{c_0}{p\omega_0}$$

Th1 When the assembler sets the revenue sharing factor, it should meet the requirements， $\frac{c_1}{w_1} = \frac{c_2}{w_2} = \cdots = \frac{c_n}{w_n} \geq \frac{c_0}{w_0}$.

Proof: In the assembly system, the decisions of various suppliers and assemblers are mutually dependent and influenced, just like the principle of wooden barrel, the amount of water depends on the length of the shortest wood plank, and the amount of assembly by assemblers depends on the parts with the fewest qualified parts。

First, prove it ， $\frac{c_1}{w_1} = \frac{c_2}{w_2} = \cdots = \frac{c_n}{w_n}$ .Suppose instead $\frac{c_1}{w_1} = max_i\left\{\frac{c_i}{w_i}\right\}$,then $\left(1 - \frac{1}{r_1Q_1{}^*}\right)Q_1{}^* = min_i\left\{\left(1 - \frac{1}{r_iQ_i{}^*}\right)Q_i{}^*\right\}$ .That is to say, the assembler gets the fewest qualified parts from the supplier S_1, and only qualified parts can be used to assemble the final product, so the assembly quantity of the assembler is $\left(1 - \frac{1}{r_1Q_1{}^*}\right)Q_1{}^*$。By hypothesis, existence $i \neq 1$makes$\frac{c_1}{\omega_1} > \frac{c_i}{w_i}$.That is, the supplier S_i is willing to produce more qualified parts than the supplierS_1.However, the qualified parts produced by the supplierS_i will not be used for assembly and cannot be matched with complementary parts, which is just a loss and will not bring benefits to the system.In order to reduce this part of the loss, the assembler can reduce the supplier'sS_i revenue sharing factor ω_i, inhibit its production, and make it reduce the output of part i.But it doesn't affect the number of final products until the equation $\frac{c_1}{\omega_1} = \frac{c_i}{w_i}$ is true.When the assembler reduces the profit sharing factor of the supplierS_i, his profit sharing ratio increases.Moreover, the amount of assembly has not been reduced, thus increasing the expected profit of assemblers.

Second, verify$\frac{c_i}{w_i} \geq \frac{c_0}{\omega_0}$， $i = 1,2,\cdots,n$.Otherwise, if$\frac{c_i}{w_i} < \frac{c_0}{\omega_0}$， $i = 1,2,\cdots,n$, then, the supplier's S_i optimal supply quantity is more than the assembler's optimal assembly quantity.Assembler can reduce ω_i until$\frac{c_1}{w_1} = \frac{c_2}{w_2} = \cdots = \frac{c_n}{w_n} = \frac{c_0}{\omega_0}$.In this way, the income sharing factor ω_0 of the assembler increases, and the assembly quantity does not decrease, so the income of the assembler increases.

Th2 When there is only a revenue sharing contract, the supply chain will not achieve coordination, and the optimal output of decentralized system will not be more than that of centralized system, i.e $Q_d^* \leq Q_c^*$.

Proof: We know from theorem 1， $\bar{F}[Q_d{}^*] = \frac{c_1}{pw_1} = \frac{c_2}{pw_2} = \cdots = \frac{c_n}{pw_n}$.

$$\bar{F}(Q_c^*) = \frac{\sum_{i=1}^{n} c_i + c_0}{p}$$

$$\frac{c_1}{pw_1} = \frac{c_i}{pw_i}, i = 1,2,\cdots,n$$

Then

$$\frac{c_1}{pw_1}w_i = \frac{c_i}{p}, i = 1,2,\cdots,n$$

Sum n terms on both sides of the above equation, it can get：

$$\frac{c_1}{pw_1}\sum_{i=1}^{n} w_i = \frac{\sum_{i=1}^{n} c_i}{p}$$

And because $\frac{c_1}{pw_1} \geq \frac{c_0}{p\omega_0}$,namely $\frac{c_1}{pw_1}\omega_0 \geq \frac{c_0}{p}$

So $\frac{c_1}{pw_1}\omega_0 + \frac{c_1}{pw_1}\sum_{i=1}^{n} w_i \geq \frac{c_0}{p} + \frac{\sum_{i=1}^{n} c_i}{p}$

$$\frac{c_1}{pw_1} \geq \frac{\sum_{i=1}^{n} c_i + c_0}{p}$$

Then $Q_d^* \leq Q_c^*$.Supply chain cannot be used for coordination under a revenue sharing only contract.

4.2"Revenue sharing + subscription subsidy" contract

It can be seen from theorem 2 that only the revenue sharing factor constrains the behaviors of suppliers and assemblers, and the supply chain cannot achieve coordination.

Because n parts are complementary in the assembly system, the lack of any part will affect the assembler to assemble the final product, so the assembler must order more qualified parts if he wants to assemble more finished products.In order to achieve supply chain coordination, we propose the "revenue sharing + subscription subsidy" contract.In other words, in the revenue-sharing contract, in addition to the revenue-sharing factorω_i， $i = 1,2,\cdots,n$, the assembler provides subsidies $\alpha_i$for each unit of qualified parts provided by the supplier to motivate the supplier to provide more parts.Of course, it needs to be satisfied $\omega_i \succ c_i \succ \alpha_i, i=1,2,...,n$.

If the supplier's S_i revenue does not depend on the quantity of other complementary parts delivered, the supplier's S_i revenue is：

$$\pi_i(Q_i) = E\left\{w_i p \min\left((1-\frac{1}{r_iQ_i})Q_i, D\right) - c_iQ_i - t_i\frac{1}{r_iQ_i}Q_i + \alpha_i(1-\frac{1}{r_iQ_i})Q_i\right\}$$

$$= pw_i\left[(1-\frac{1}{r_iQ_i})Q_i - \int_0^{(1-\frac{1}{r_iQ_i})Q_i} F(x)dx\right] - c_iQ_i - \frac{t_i}{r_i} + \alpha_i(1-\frac{1}{r_iQ_i})Q_i \quad (11)$$

Obviously,$\pi_i(Q_i)$ is concave function with regarding to Q_i. Regarding to formula (11),$\pi_i(Q_i)$ take the first derivative with regarding to Q_i, the optimal decision of the supplier S_i will satisfy the following formula

$$\bar{F}\left[\left((1-\frac{1}{r_iQ_i^{**}}\right)Q_i^{**}\right] = \frac{c_i - \alpha_i}{pw_i} \quad (12)$$

Th3 In the "revenue sharing + subscription subsidy" contract, what the assembler sets （ω_i， α_i） will be met：

$$\frac{c_1-\alpha_1}{w_1} = \frac{c_2-\alpha_2}{w_2} = \cdots = \frac{c_n-\alpha_n}{w_n} \quad (13)$$

When the optimal delivery quantityQ_i^{**} of each supplier in the decentralized decision system is equal to thatQ_c^* in the centralized decision system, it is called supply chain coordination.The optimal delivery quantity Q_c^* is satisfied in the centralized decision making

$\bar{F}(Q_c^*) = \frac{\sum_{i=1}^{n} c_i + c_0}{p}$.The optimal delivery quantity in the decentralized "revenue sharing + subscription subsidy" contract is met$\bar{F}\left[\left(\left(1-\frac{1}{r_i Q_i^{**}}\right)Q_i^{**}\right]=\frac{c_i-\alpha_i}{p w_i}$.

Th4

In order to achieve the coordination of supply chain, assemblers only need to set the incentive mechanism (ω_I,α_i), $i=1,2,\cdots,n$ to satisfy equation $\frac{c_i-\alpha_i}{w_i}=\sum_{i=1}^{n}c_i+c_0$,that is $\alpha_i=c_0-w_i(\sum_{i=1}^{n}c_i+c_0)(14)$.

It can be seen that equation (14) expresses the subscription subsidy factor α_i as a function of another variable ω_i.Given a revenue-sharing factor ω_i, we can obtain the corresponding ordering subsidy factor α_i through (14) to coordinate the supply chain.Therefore, for each supplierS_i, the contracts that enable the supply chain to achieve coordination exist in a continuous set.

In order to achieve supply chain coordination, the contract (ω_i,α_i) between assemblers and suppliersS_i need not rely on other complementary parts suppliers.Assemblers can independently set contracts with each supplier as long as the supply chain is coordinated.

V. RISK AVERSION OF PARTS SUPPLIERS BASED ON P-CVAR

In 4.1, the expected revenue for the part supplier S_i is known as$E[\pi_i(Q_i)]$.In fact, the benefit to the supplierS_i may be greater than $E[\pi_i(Q_i)]$ or less than $E[\pi_i(Q_i)]$.If the supplier's S_i profit is not achieved $E[\pi_i(Q_i)]$, it can be considered $\{E[\pi_i(Q_i)]-\pi_i(Q_i)\}$as the loss part.The assumption is that the supplier S_i is risk-averse, hoping for as little loss as possible.There is no risk in the part where the actual profit is greater than$E[\pi_i(Q_i)]$. Only the losses$[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+$ of suppliers in the case of risk aversion are studied.

CVaR is specifically defined as follows:

$$CVaR_\eta[g(\cdot)]=E\left[g(\cdot)\middle|g(\cdot)\ge z_\eta\right] \quad (15)$$

z_η is VaR defined as follows:$z_\eta=\inf\{z|P(g(\cdot)\le z)\ge\eta\}$.Where, $g(\cdot)$ is the loss function of decision makers, and η is the risk aversion coefficient.

Equation (15) CVaR is equivalent to the following formula:

$$CVaR_\eta[g(\cdot)]=\frac{1}{1-\eta}\int_{g(\cdot)\ge z_\eta}g(\cdot)f(x)dx \quad (16)$$

CVaR measures the average of losses above $VaR_\eta(0<\eta<1)$ and ignores those below VaR_η, so it can only measure risk aversion or neutral, which is incomplete.Consider both the lower and higher losses where the return does not meet the expected return.The new definition of P-CVaR model is as follows：

$$\begin{aligned}&\mathrm{P-CVaR}_\eta\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\}\\&=\theta E\left\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\middle|[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\le z_\eta\right\}\\&+(1\\&-\theta)E\left\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\middle|[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\ge z_\eta\right\}(17)\end{aligned}$$

Coefficient θ describes the degree to which the supplierS_i attaches importance to the profit below the quantile. The larger the coefficient θ is, the less the supplier S_i attaches importance to the part where the loss exceeds VaR.

$$E\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$$

$$= \int_{[\mathrm{E}[\pi_i(Q_i)]-\pi_i(Q_i)]^+ \le z_\eta} [\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ f(x)dx$$

$$+ \int_{[\mathrm{E}[\pi_i(Q_i)]-\pi_i(Q_i)]^+ \ge z_\eta} [\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ f(x)dx$$

$$= \eta E\left\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ \middle| [\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ \le z_\eta\right\}$$

$$+ (1-\eta) CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} \quad (18)$$

so

$$E\left\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ \middle| [\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ \le z_\eta\right\} = \frac{1}{\eta} E\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} - \frac{1-\eta}{\eta} CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$$

(19)

Therefore, equation (17) can be expressed as:

$$\mathrm{P-CVaR}_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$$

$$= \theta\{\frac{1}{\eta} E\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} - \frac{1-\eta}{\eta} CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}\} + (1-\theta) CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$$

$$= \frac{\eta-\theta}{\eta} CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} + \frac{\theta}{\eta} E\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} \quad (20)$$

$$\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)$$

$$= pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx - \min\left\{\left(1-\frac{1}{r_iQ_i}\right)Q_i, D\right\}\right] \quad (21)$$

$E\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$

$$= pw_i \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} \left[\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx - x\right]^+ f(x)dx$$

$$= pw_i \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx} \left[\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx - x\right] f(x)dx$$

$$= pw_i \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx} F(x)dx \qquad (22)$$

Now let's do the following, $CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\}$

Let $G_i(v, Q_i) = v + \frac{1}{1-\eta} E\{[[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+ - v]^+\}$

$$= v + \frac{1}{1-\eta} \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx} [pw_i\left(\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx - x\right) - v]^+ f(x)dx \qquad (23)$$

$$CVaR_\eta\{[\mathrm{E}[\pi_i(Q_i)] - \pi_i(Q_i)]^+\} = min_v\{G_i(v, Q_i)\} \qquad (24)$$

1） When $v \le 0$,

$$G_i(v, Q_i) = v + \frac{1}{1-\eta} \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx} \{pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx - x\right] - v\} f(x)dx$$

$$= v + \frac{1}{1-\eta}\{pw_i \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx} F(x)dx - vF[\left(1-\frac{1}{r_iQ_i}\right)Q_i - \int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i} F(x)dx]$$

$$\frac{\partial G_i(v,Q_i)}{\partial v}=1-\frac{1}{1-\eta}F[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx]$$

2)When $0<v<pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\right]$,

$$G_i(v,Q_i)=v+\frac{1}{1-\eta}\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-\frac{v}{pw_i}}\{pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i\right.$$

$$\left.-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-x\right]-v\}f(x)dx$$

$$=v+\frac{pw_i}{1-\eta}\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-\frac{v}{pw_i}}F(x)dx$$

$$\frac{\partial G_i(v,Q_i)}{\partial v}=1-\frac{1}{1-\eta}F\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-\frac{v}{pw_i}\right]=0$$

$$v^*=pw_i[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-F^{-1}(1-\eta)]$$

3)When $v\geq pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\right]$,

$$G_i(v,Q_i)=v$$

$$\frac{\partial G_i(v,Q_i)}{\partial v}=1>0$$

To sum up ,

$$v^*=\begin{cases}pw_i[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-F^{-1}(1-\eta)], & F^{-1}(1-\eta)\leq\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right.}\\ 0, & F^{-1}(1-\eta)>\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\end{cases}$$

So,

$$CVaR_\eta\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^+\}$$

$$=\begin{cases}pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-F^{-1}(1-\eta)\right]+\frac{pw_i}{1-\eta}\int_0^{F^{-1}(1-\eta)}F(x)dx, & F^{-1}(1-\eta)\leq\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\\ \frac{pw_i}{1-\eta}\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx}F(x)dx, & F^{-1}(1-\eta)>\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\end{cases}\quad(26)$$

From equation (20) and equation (22), namely, equation (26), we can get:：

$$P-CVaR_{\eta}\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^{+}\}$$

$$=\begin{cases}\frac{\eta-\theta}{\eta}\left\{pw_i\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx-F^{-1}(1-\eta)\right]+\frac{pw_i}{1-\eta}\int_0^{F^{-1}(1-\eta)}F(x)dx\right\}+\frac{\theta}{\eta}pw_i\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx}F(x)dx, & F^{-1}(1-\eta)\le\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\\ \frac{\eta-\theta}{\eta}\frac{pw_i}{1-\eta}\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx}F(x)dx+\frac{\theta pw_i}{\eta}\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx}F(x)dx, & F^{-1}(1-\eta)>\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\end{cases} \quad (27)$$

$$\frac{\partial P-CVaR_{\eta}\{[E[\pi_i(Q_i)]-\pi_i(Q_i)]^{+}\}}{\partial Q_i}$$

$$=\begin{cases}\frac{pw_i}{\eta}\bar{F}\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i\right]\left\{(\eta-\theta)+\theta F\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\right]\right\}, & F^{-1}(1-\eta)\le\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\\ \frac{1-\theta}{1-\eta}pw_i\bar{F}\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i\right]F\left[\left(1-\frac{1}{r_iQ_i}\right)Q_i-\int_0^{\left(1-\frac{1}{r_iQ_i}\right)Q_i}F(x)dx\right]>0, & F^{-1}(1-\eta)>\left(\frac{1}{r_iQ_i}+s_i\right)Q_i-\int_0^{\left(\frac{1}{r_iQ_i}+s_i\right)Q_i}F(x)dx\end{cases} \quad (28)$$

Jammernegg et al. [14] proved the $F^{-1}(1-\eta)\le\left(\frac{1}{r_iQ_i}+s_i\right)Q_i-\int_0^{\left(\frac{1}{r_iQ_i}+s_i\right)Q_i}F(x)dx$ equivalence to $\eta<\theta$,and vice versa.

Therefore, the supplier's S_i optimal supply quantity meets the following requirements：

$$\begin{cases}F\left[\left(1-\frac{1}{r_iQ_i^{***}}\right)Q_i^{***}-\int_0^{\left(1-\frac{1}{r_iQ_i^{***}}\right)Q_i^{***}}F(x)dx\right]=\frac{\theta-\eta}{\eta}, & \eta\le\theta,\\ Q_i^{***}=0, & \eta>\theta\end{cases} \quad (29)$$

As can be seen from equation (29), when only the loss that fails to reach the expected profit is considered, the optimal supply quantity of risk-averse suppliers S_i has nothing to do with the wholesale price and revenue sharing factor.In other words, in this case, the decision of the assembler will not affect the decision of the supplier S_i, only the risk aversion level of the supplier S_i will affect its own supply quantity.When $\eta>\theta$, the optimal order quantity of the supplier S_i was zero. No matter how much the supplier S_i supplied, the profit of the supplier would not reach the expected profit, and the more the quantity supplied, the more the part that did not reach the expected profit suffered, that is, the farther it was from the expected profit.At that time $\eta\le\theta$,, the larger η, the supplier S_i, the more risk aversion, less supply; The higher the coefficient θ, the less the supplier pays attention to the part of excess VaR_{η} loss, indicating that the more the supplier S_i likes risk, the greater the supply. To sum up, the more circumvention of supplier S_i risk, the smaller the supply.

VI. A NUMERICAL EXAMPLE

table1

	p	r_1	r_2	c_0	c_1	c_2	t_1	t_2	$Q_c{}^*$	$\pi(Q_c{}^*)$	$Q_d{}^*$	$\pi(Q_d{}^*)$
①	40	0.1	0.05	5	4	3	2	1	2408	26965	1445	23679
②	40	0.1	0.05	7	4	3	2	1	2100	22460	1341	20189
③	40	0.1	0.05	7	5	3	2	1	1962	20420	1221	18080
④	40	0.1	0.05	7	5	4	2	1	1833	18502	940	14790
⑤	40	0.1	0.05	7	5	4	3	1	1833	18492	920	14780
⑥	40	0.1	0.05	7	5	4	3	2	1833	18472	920	14760
⑦	40	0.2	0.05	7	5	4	3	2	1833	18512	920	14800
⑧	40	0.2	0.1	7	5	4	3	2	1833	18572	920	14860

table2

	p	w_0	c_0	η	θ	r_1	r_2	Q_1^{***}	Q_2^{***}	π_0
①	40	0.4	5	0.85	0.75	0.1	0.2	0	0	0
②	40	0.4	5	0.85	0.78	0.1	0.2	0	0	0
③	40	0.4	5	0.85	0.8	0.1	0.2	0	0	0
④	40	0.4	5	0.85	0.9	0.1	0.2	135	130	1364
⑤	40	0.4	5	0.85	0.92	0.1	0.2	190	185	1902
⑥	40	0.4	5	0.85	0.95	0.1	0.2	277	272	2709

table3

	p	w_0	c_0	η	θ	r_1	r_2	Q_1^{***}	Q_2^{***}	π_0
①	40	0.4	5	0.7	0.95	0.1	0.2	1171	1166	8307
②	40	0.4	5	0.8	0.95	0.1	0.2	475	470	4352
③	40	0.4	5	0.9	0.95	0.1	0.2	127	122	1284
④	40	0.4	5	0.95	0.95	0.1	0.2	0	0	0
⑤	40	0.4	5	0.96	0.95	0.1	0.2	0	0	0
⑥	40	0.4	5	0.97	0.95	0.1	0.2	0	0	0

Table 1 shows that members of the entire supply chain are risk neutral.In table 1, Q_d^* and π（Q_d^*） respectively refer to the optimal assembly quantity of assemblers under decentralized decision-making and the income of the entire supply chain under decentralized decision-making.According to table 1, the optimal assembly quantity of assemblers under centralized decision-making is larger than that of assemblers under decentralized decision-making, and the income of the whole supply chain under centralized decision-making is larger than that under decentralized decision-making.As you can see ①②③④, it is known that, when the assembly cost of assembler or the production cost of supplier increases, the assembly quantity of assembler under centralized decision-making, the income of the whole supply chain and the assembly quantity of assembler under decentralized decision-making, the income of the whole supply chain will decrease.As you can see ④⑤⑥, When the cost of dealing with defective products increases, the assembly quantity under centralized decision-making and decentralized decision-making stays the same, but the income of the whole supply chain decreases under centralized decision-making and decentralized decision-making.As you can see ⑥⑦⑧, Whenr_1 orr_2 increases, that is, when the quality of parts improves, the assembly quantity under centralized decision-making and decentralized decision-making will not change, but the income of the whole supply chain under centralized decision-making and decentralized decision-making will increase.

Table 2 and table 3 study the optimal supply quantity of suppliers based on risk aversion and the income of assemblers based on P-CVaR model.π_0 is the income of the assembler.According to table 2, when $\eta \geq \theta$, the optimal supply quantity of supplier S_1 and S_2 is zero, and the income of assembler is zero.When $\eta < \theta$ and θ increases, the supply quantity of supplier S_1 and S_2 increases, the assembly quantity of assembler increases, and the income increases accordingly.When Θ is larger, the supplier does not pay attention to the part of excess VaR_η loss, and the supplier prefers risk and supplies more. At this time, the profit of the assembler increases, that is to say, the more the supplier prefers risk, the better it is for the assembler.According to table 3, when $\eta \geq \theta$, the optimal supply quantity of supplier S_1 and S_2 is zero, and the income of assembler is zero.When $\eta < \theta$, η increases, supplier S_1 and S_2 reduce their supply quantity, assembler's assembly quantity decreases, and the income decreases accordingly.When η is larger, the supplierS_1 is more risk-averse and the supply quantity is smaller, then the income of the assembler decreases, that is to say, the more risk the supplier avoids, the more unfavorable it is to the assembler.To sum up, the more the supplier avoids risks, the smaller the supply quantity is, the less the assembler gains, and the more unfavorable it is to the assembler.

VII. CONCLUSION

This paper studies the assembly system under the random condition of final product demand.The n parts considered are defective, and the acceptance rate is a function of the output.In this paper, the qualification rate is set as $(1-\frac{1}{r_i Q_i})$.In the assembly system, unassembled parts will be wasted. In order to maximize revenue, equation $\frac{c_1}{w_1}=\frac{c_2}{w_2}=\cdots=\frac{c_n}{w_n}\geq\frac{c_0}{\omega_0}$ is obtained in the revenue sharing contract.Revenue sharing contracts alone do not harmonize the supply chain.On the basis of the revenue sharing contract, we put forward the "revenue sharing + subscription subsidy" contract which can make the supply chain realize coordination.It is found that the optimal assembly quantity of assemblers under centralized decision-making is larger than that under decentralized decision-making, and the income of the whole supply chain under centralized decision-making is larger than that under decentralized decision-making.When the assembly cost of assemblers or the production cost of suppliers increases, the assembly quantity of assemblers under centralized decision-making, the income of the whole supply chain, the assembly quantity of assemblers under decentralized decision-making and the income of the whole supply chain will decrease.When the processing cost of defective products or parts quality decreases, the assembly quantity under centralized and decentralized decision-making will not change, but the income of the whole supply chain will decrease under centralized and decentralized decision-making.

This paper also discusses the optimal delivery quantity of parts suppliers when they are risk averse.In this paper, it propose a new P-CVaR model.Based on M-CVaR, this model only considers the part of loss where the supplier's profit does not reach the expected profit.The research shows that the optimal supply quantity of risk-averse suppliers based on P-CVaR model has nothing to do with the decision of assemblers, but only with their risk aversion degree, and the more risk-averse they are, the less supply quantity they have, and the more unfavorable it is for assemblers.

In this paper, the acceptance rate of n parts is assumed to be a function of production volume, but in real life, the acceptance rate may be random, or the acceptance rate can be controlled through investment.In the future research, we can also assume that the qualification rate of n parts is a random variable, or assume that the qualification rate is controllable, and study the properties of the assembly system under these circumstances.

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