Integrated Supplier Selection and Distribution in Perishable Food Supply Chain

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Abstract. In this study, we investigate the classical supplier selection and distribution problem in an integrated framework. The combined problem is originated from a local producing tomato sauce producer, whom we have been collaborated with since 2022. The suppler selection strategies are made based not only on each supplier's product price and corresponding product quality, but also on the reliability and lead time of each protentional supplier. We proposed a quantitative framework with a conditional value-at-risk (CVaR) technique in the purpose of assessing the supplier performance. Then the selection and distribution decisions are simultaneously considered in a mixed integer linear programming (MILP) model, with the objective of maximizing the value added to the purchasing portfolio and distribution plans. Our experiments and computational results reveal that the combined approach is more beneficial than separated approaches. Finally, future research topics and managerial insights are provided.

Keywords: CVaR; perishable food supply chain; MILP; supplier selection.

1. Introduction

With the advent of fast social and society development, environmental pollution and ecological disruption are deteriorate in a speed faster than ever before. Customers and enterprises are more concern with the environmental and society issues, which requires a higher criterion for supply chain practitioners. Recently, more and more research attentions have been drawn to combine supply chain design with sustainable development, in order to achieve sustainable development of economic, environment and society. For perishable food supply chain, it is imperative to consider the risks and uncertainty in the supply chain decision making process.

Product price are one of the most important criteria in selecting suppliers, since the decision makers are in the position of pursuing profit maximization. With the consideration of uncertain demand and price discount, literature [1] propose a multi-objective mixed integer stochastic programming model to allocate order quantities among different suppliers. A multi-supplier order allocation problem combining on-time delivery and procurement cost the is studied in literature [2]. An integrated approach of network analytic hierarchy process and MILP is discussed in [3]. An analytical study of simultaneous optimization of supplier selection and order quantity allocation under uncertain demand is discussed in [4]. Among the literatures mentioned above, financial factors have been extensively studied, however, the consideration of supplier reliability, i.e., the risk of losing production quantity, is relatively less. For researches in assessing order risk, i.e., in the newsvendor problem, we refer to literature [5-7], where the conditional value-risk evaluation method originated from financial engineering is introduced to evaluate buyer's risk preference in the saucing management.

Most of the literature in the field of purchasing strategies consider the purchasing decisions with the purpose of maximizing customer satisfaction (i.e., service level), or the minimization of total purchasing expenses. In a highly uncertain environment, nodes, facilities and paths in the network might be interrupted, i.e., insufficient raw material supply, malfunctional manufacture machines or power shutdown. Therefore, the reliability of supplier is vital to the success of purchasing management. The assessments of purchasing portfolios effect under uncerties, deserves a dedicated study. In this study, we examine the method of conditional value at risk (cVaR) to quantitatively estimate the risk and value of service level. We fill the gap of absence of assessing perishable food supply chain uncertainties and a combinatorial optimization of purchasing and distribution. A three-level supply chain consisting of multiple suppliers, a single manufacture and multiple distributors is considered. Suppliers considered in this study, can be either local or international, and sells several raw materials at different prices. The final products are then delivered to different distributors to satisfy their demands. The solution of the proposed problem includes a order allocation plan that determines the suppliers and corresponding order quantity, and the quantity transported to the distributor. The objective is to minimize the total costs while satisfying the demand requirement and service level to the most extend.

2. Risk Analysis Based on CVaR

In this section, we briefly describe the conditional value at risk (CVaR) method to assess the service level of a supply network [7]. CVaR is defined on VaR (Value at Risk), and is used in financial engineering to estimate the investment portfolio, and overcome the drawback of VaR. In this context, we consider the risk and value of a purchasing portfolio, which is defined by VaR at a certain confidence level, considering the uncertainties of the market. Within the context of supply chain management, the value and risk purchasers perceived as the service level, is denoted as the minimum value of the service level within a specific interval of confidence. Note that the service level is valued between 0 and 1. Suppose the random factors $v \in V$, the corresponding probability density function is $\phi(v)$, customer perceived service level w $(0 \le w \le 1)$, and the value function $\pi(w, v)$, we can derive the CVaR as follows. Let ζ be the service level, and value $\pi(w, v)$ is larger or equal to the critical value of ζ with confidence α. The value of VaR ζ_α is the maximum of

$$\{\zeta\colon \int_{\pi(w,v)\ge\zeta}^{\infty} \phi(v) \ge \alpha\}$$

and the service value in the context of CVaR is smaller than

$$\frac{1}{1-\alpha}\int_{\pi(w,v)\le\zeta_\alpha}^{\infty} \pi(w,v)\phi(v)$$

Since the probability function $\phi(v)$ is not trivial to find, we apply an approximation method to simplify the above formula as

$$\zeta - \frac{1}{1-\alpha}\int_{v\in V} (\pi(w,v)-\zeta)^{+}$$

where $(\pi(w,v)-\zeta)^{+} = \max\{(\pi(w,v)-\zeta), 0\}$. Similar methods can also be found in the power industry [8-9].

3. Problem Definitioin and Statement

3.1 Problem Definition

A three-level supply chain network is considered, which includes several suppliers, one manufacture and multi distributors. The demand volume and type are highly uncertain. Each supplier has a certain product profile, and a limited capacity. The reliability of supplier is characterized as the probability of providing required products as the right time. For the distributor, the unsatisfied demand is penalized as the loosing of customer loyalty. The proposed model the purpose of maximizing the expected value of purchasing while minimizing the total cost of lateness, purchasing and transportation, is presented in the next subsection.

3.2 Problem Notation

The variables and parameters used in this study are presented as follows. We consider a set of products N $(i \in N)$, a set of suppliers S $(s \in S)$, and a set of distributors u $(u \in U)$. Let $v \in V$ denote the stochastic factor, and M is an arbitrary large value. Each supplier $s \in S$ provides product $i \in N$ at price p_{si} and has a capacity Cap_{si}. c'_{si} and c''_{ui} are the unitary transportation cost of product i from supplier s to manufacture and from manufacture to distributor $u \in U$, respectively. f'_{si} and f''_{ui} are the unitary penalty cost of late delivery of product i from supplier s to manufacture and from manufacture to distributor $u \in U$, respectively. The uncertainty of the problem is described by demand fluctuation and lead time uncertainty. Let D_i be the uncertain demand at the manufacture and D'_{ui} the uncertain demand at distributor u. L_{si} is the lead time of product i and supplier s. σ_{si} is the quantitative evaluation rate of product i from supplier s. θ is the unitary tardiness cost of unmet distributors requirement. $\epsilon(v)$ is the perturbation term of stochastic factor v. r defines the risk factor. α is the confidence interval.

We introduce the binary decision variables X_{si}, which is 1 if supplier s is selected to provide product i, and 0 otherwise. Integer variables Y_{si} is the purchasing amounts of products i from supplier s, and Z_{ui} is the quantity for product i transported to distributor u.

3.3 Problem Statement

In this section, we propose a combined optimization problem with the objective of maximizing the value associated with the ordering portfolio and distribution plan, which is the value difference between the value-at-risk and the entire cost of saucing, transportation and lateness penalties.

$$max\, r\left(\zeta - \frac{1}{1-\alpha}\int_{v\in V}(\pi(w,v)-\zeta)^{+}\right) - \sum_{i\in N}\sum_{s\epsilon S}\left(Y_{si}p_{si} + Y_{si}c'_{si} + Z_{ui}c''_{ui}\right) - \sum_{i\in N}\sum_{u\in U} f''_{ui}(Z_{ui} - D'_{ui}, 0)^{+} \quad (1)$$

s.t.

$$w = \frac{\sum_{s\in S} Y_{si}\,\sigma_{si}}{D_i} \quad (2)$$

$$\sum_{s\in S} Y_{si} \geq D_i, \forall\, i \in N \quad (3)$$

$$\sum_{u\in U} Z_{ui} \leq D'_i, \forall\, i \in N, u \in U \quad (4)$$

$$Y_{si} \leq Cap_{si}, \forall\, i \in N, s \in S \quad (5)$$

$$Y_{si} \leq X_{si}M, \forall\, i \in N, s \in S \quad (6)$$

$$\zeta \leq \frac{\sum_{s\in S}\sum_{i\in N} Y_{si}\,\sigma_{si}}{D_i} \quad (7)$$

$$X_{si} \in \{0, 1\}, Y_{si}, Z_{ui} \in R^{+}$$

Constraints (3) guarantee the total purchasing quantity of product i satisfy the demand. Constraints (4) make sure the scheduled delivery quantity of product i will exceed the requirement quantity of distributor u. The capacity constraints of each supplier are respected in constraints (5). In case of supplier i is not selected, the corresponding purchase quantity is 0, which is ensured in constraints (6). Constraints (7) restrict the upper and lower bounds of ζ.

4. Solution Approach and Computational Study

The problem proposed in this study is not trivial to be solved to optimality. We apply the traditional fix-and-optimize algorithm to solve the problem efficiently. Similary solution approaches can be found in literture [10-11].

We test our model on real-world instances generated from a company producing tomato sauce. There 4 suppliers providing 5 products. In the table below, all the parameter values are scaled by a unitary weight. The values of the parameters are presented in Table 1. $\alpha = 0.95$

Table 1. Deterministic parameters

Supplie r	Product	Price	Capacity	Delivery cost	Tardiness cost
1	1	3.2	456	2.1	0.6
	2	3.3	450	2.1	0.6
	3	3.1	610	1.1	0.6
2	3	3.1	213	1.3	0.6
	4	3.4	334	2.2	0.6
3	1	3.2	787	2.1	0.6
	2	3.3	654	2.2	0.6
	3	3.1	546	1.8	0.6
	4	3.4	550	1.9	0.6
4	4	3.4	476	1.9	0.6
	5	3.0	305	2.2	0.6

We apply a random sample method to generate a parameter set based a normal distribution. Table 2. summarizes the corresponding mean value and variance.

Table 2. Mean and variance of stochastic parameter distribution

	Quality satisfyction rate	Tardiness
Mean	0.96	1
Variance	0.1	0.2

The subproblem in each iteration is a deterministic mixed linear integer problem and is solved by commercial softwires, i.e., Cplex. The computation results are given in the following.

$\zeta = 1.745033$

$$Y = \begin{bmatrix} 120 & 445 & 330 & 400 & 100 \\ 101 & 70 & 450 & 0 & 0 \\ 770 & 0 & 100 & 330 & 180 \end{bmatrix}; \text{X=} \begin{bmatrix} 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 \end{bmatrix}.$$

We can observe from the results that the order can be satisfied while the risk is at a low level.

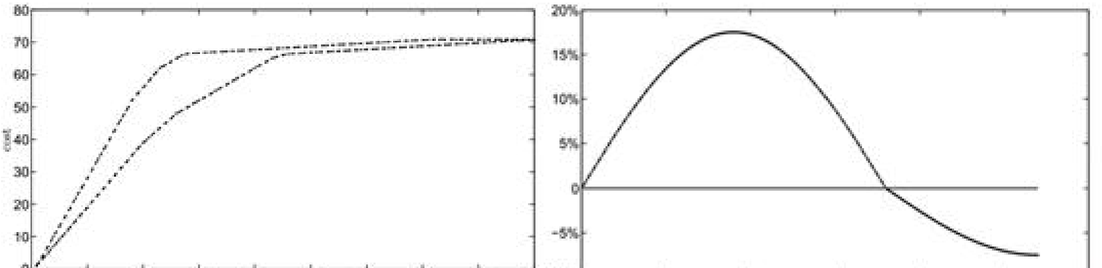

Figure 1. The changes of the objective as the changes of demand

We can observe that, in the case of sufficient capacity, all the target value and the mean value of demand increase at the same time, as shown in the left part of Figure 1. The profit (solid line) for stable demand profile is slightly large in the case of small mean value of demand. For the case of fluctuated demand trend (solid line), the benefit is less influenced. In case of insufficient capacity, the objective first increases then decrease as the demand increases. The reason is that the loss of unsatisfied demand excesses the demand.

5. Conclusion

In this study, we propose an integrated optimization model to solve the supplier selection and distribution problem. In the uncertain environment, the evaluation of unsatisfied demand is vital to the success of the business. We combine an operational level objective, i.e., the cost, with the tactical level targets, i.e., service level, to better evaluate the purchasing decisions. We also propose a CVaR criteria to further examine the supply performance, by adjusting the demand portfolio parameters. A multi-dimension evaluation of the suppliers, including reliability, lead time, quality is also considered. Since the difficulties in solving the problem, we adapt the traditional fix-and-optimize algorithm to tackle the issue of large-sized instances. The algorithm is coded in C++ with a Cplex solver to release the solution of subproblems in the iteration. The computational results indicate that our solution approach is efficient in finding good quality solutions.

References

[1] Guan Zhi-min, Zhou Bao-gang, MA Qin-hai. Research on vendor selection & order quantity allocation problem under multi-product purchases [J]. computer integrated manufacturing systems, 2005, 11 (11): 1626-1632.

[2] Kawtummachai R, Hop N V. Order allocation in a multiple-supplier environment[J]. International Journal of Production Economics, 2005, 93-94(1):231-238.

[3] Ozden Ustun, Ezgi Aktar Demirtas. An integrated multi-objective decision-making process for multi-period lot-sizing with supplier selection [J]. Omega, 2008, 36(4):509-521.

[4] Jiang Qiwei, Qin Jin. Optimization Model and Algorithm of Supplier Selection and Order Quantity Allocation Problem under Uncertain Demand[J]. Systems Engineering, 2010, 28(10):97-102.

[5] Zhou Yan-ju, Qiu Wan-hua, Wang Zong-run. Optomal Ordering Model for Multi-Products with CVaR Constraints [J]. Chinese Journal of management science, 2006,14(5):62-67

[6] Zhou Y J, Chen X H, Wang Z R. Optimal ordering quantities for multi-products with stochastic demand: Return-CVaR model[J]. International Journal of Production Economics, 2008, 112(2):782-795.

[7] Wang Li hua. CVaR criteria for retailer's ordering decision making based on loss aversion [J]. Statistics and Decision making, 2016 (19): 45-48.

[8] Rockafellar R T, Uryasev S. Optimization of Conditional Value-At-Risk[J]. Journal of Risk, 1999, 29(1):1071–1074.

[9] Yang Jiajia, HeYang, Zhou Bo, etc. A CVaR-based Coal Inventory Optimization Model for Coal-fired Power Plants in Electricity Market Environment[J]. Automation of Electric Power Systems, 2014, 38(4):51-59.

[10] Wei, W, L. Guimaraes, P. Amorim, B. Almada-Lobo. Tactical production and distribution planning with dependency issues on the production process. OMEGA. 2017, 67: 99-114.

[11] Chun Cheng, Yossiri Adulyasak, Louis-Martin Rousseau (2021) Robust Facility Location Under Disruptions. INFORMS Journal on Optimization 3(3):298-314.