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A study on sharing logistics network design considering demand uncertainty

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Abstract. The evolution of e-retailing is driving a rise in logistics costs and risk of late delivery. Collaborative logistics has become the key to help businesses eliminate inefficiencies, improve responsiveness to market changes, and reduce overall supply chain costs by adjusting transportation capacity efficiently. In this study, we propose a stochastic mixed integer linear programming model that incorporates shipper's transportation operations via truck sharing service. The model supports strategic network design decisions in uncertain market environments by optimizing the number of trucks under uncertain demand. Through several case studies on a small-scale truck sharing network, we show the influence of demand uncertainty on the network performance in terms of the on-time delivery ratio and the gross profit margin ratio. We also show the influence of the sharing platform features such as the transaction price and the number of available trucks, on shippers as well as a platformer in terms of the turnover of trucks.

Keywords: Supply chain logistics, Network design, Sharing logistics

1 Introduction

The growth of e-retailing market leads to the increase in freight and the shortage of trucks, and enterprises are facing a rise in logistics costs and risk of late delivery. Collaboration in logistics is even more critical to cope with uncertainty in their operation environment and to respond quickly to market changes. Vertical collaboration refers to the integration of organizations from different level of a supply chain. In contrast, horizontal collaboration refers to a collaboration between organizations from different supply chain at same level [1,2]. As a part of horizontal collaborative logistics, truck sharing business has grown rapidly in some areas. Truck sharing enables users to react to demand by adjusting transportation capacity efficiently as well as to reduce the costs that come with ownership of trucks [3]. To address distribution network design that incorporates truck sharing, some contributions focus on the number of trucks for strategic planning and others consider routing and truck allocation for operational planning [4-7]. However, very few of them focuses on characteristics in sharing platform operations, such as pricing and geographical reach. Furthermore, several literatures apply stochastic programming to network design to capture demand uncertainty, but assume

demand for only a single item [8-11]. In other words, little literature exists that addresses logistics network design considering multiple independent uncertain demand.

In this paper, we propose an optimization model for the network design with truck sharing based on a stochastic programming. Through several numerical experiments, we evaluate the impact of truck sharing on the network performance in terms of cost and on-time delivery ratio. Also, we evaluate the effect of demand uncertainty on the optimal number of own trucks and on the expected profit of the platformer. Further, we show how the transaction price influences the number of shared trucks and promotes the truck sharing.

2 Problem description

In this paper, we study transportation operations of multiple shippers who deliver items from their location to a warehouse by using trucks which they own or borrow through a sharing platform or lease from the outside of a platform. The objective is to minimize the fixed cost of own trucks and expected logistics cost by using a combination of these trucks depending on demand. On the platform a truck owner can lend its own trucks to others who need to satisfy demand when they are not in use. A percentage transaction fee is deducted from daily rental rate, and a lender keeps the remaining plus mileage charge. Thought the platformer also has a constant number of trucks, shippers may have to lease trucks from a leasing company due to a shortage of trucks available for rent. A borrower picks a truck up and returns it at the owner's location. Platformer-provided trucks are located at a dedicated parking spot. Leased trucks are located at the lessee's location.

3 Stochastic collaborative network model

3.1 Notation

The notation introduced in the network design model is shown in Table 1.

Table 1. Sets, parameters and decision variables.

Sets	
S	Set of shippers
V	Set of truck owners
W	Set of scenarios
Parameters	
$D_{s\omega}$	Daily demand for shipper s's item in scenario ω
P_s	Gross profit of shipper s's item
Fix^C	Subscription charge for truck sharing
Fix^V	Daily maintenance cost for truck

Fix^S	Daily rate to borrow truck on platform
Fix^R	Daily rate to lease truck from leasing company
Var^V	Freight cost per kilometer
Var^M	Mileage charge per kilometer
Var^F	Handling cost of one product
α	Percentage fee per transaction on platform
Cap^V	Loading capacity of truck
L_s^F	Distance from shipper s to warehouse
L_{sv}	Distance from shipper s to truck owner v
L_s^P	Distance from shipper s to dedicated parking spot
L^P	Distance from warehouse to dedicated parking spot
Q_p	Number of platformer-owned trucks
π_ω	Probability of scenario ω
m_s	Binary parameter to indicate if shipper s uses platform
Decision variables	
$x_{sv\omega}$	Percentage of demand for shipper s's item delivered to warehouse using v's own trucks in scenario ω
$x'_{s\omega}$	Percentage of demand for shipper s's item delivered to warehouse using leased trucks in scenario ω
$x''_{s\omega}$	Percentage of demand for shipper s's item delivered to warehouse using platformer-owned trucks in scenario ω
$z_{sv\omega}$	Number of v's own trucks used by shipper s in scenario ω
$z'_{s\omega}$	Number of leased trucks used by shipper s in scenario ω
$z''_{s\omega}$	Number of platformer-owned trucks used by shipper s in scenario ω
q_v	Number of v's own trucks

3.2 Model formulation

Our objective is to minimize the total network cost of multiple shippers by making decisions on the number of owning and operating trucks. The first term of Eq. (1) represents the scenario-dependent cost of borrowing trucks on the platform, leasing trucks from the leasing company, delivering items to the warehouse, handling items at the warehouse, mileage charge and demand opportunity loss. The second and the third term represent the scenario-independent fixed cost of owning trucks and using the platform, respectively.

$$\text{Min} \quad \sum_{\omega} \pi_{\omega} \Bigg\{ Fix^{S} \left(\alpha \sum_{s} \sum_{v} z_{sv\omega} + \sum_{s} z''_{s\omega} \right) + Fix^{R} \sum_{s} z'_{s\omega}$$

$$+Var^{V} \sum_{s} \left(\sum_{v} (L_s^F + L_{sv} + L_v^F) z_{sv\omega} + 2L_s^F z'_{s\omega} + (L_s^F + L_s^P + L^P) z''_{s\omega} \right)$$

$$+Var^{F} \sum_{s} \sum_{v} D_{s\omega} (x_{sv\omega} + x'_{s\omega} + x''_{s\omega}) + Var^{M} \sum_{s} (L_s^F + L_s^P + L^P) z''_{s\omega}$$

$$+ \sum_{s} P_s D_{s\omega} \left(1 - \sum_{v} x_{sv\omega} - x'_{s\omega} - x''_{s\omega} \right) \Bigg\} + Fix^{V} \sum_{v} q_v + Fix^{C} \sum_{s} m_S \qquad (1)$$

Subject to

$$\sum_{v} x_{sv\omega} + x'_{s\omega} + x''_{s\omega} \leq 1, \qquad \forall s, \forall \omega \qquad (2)$$

$$\sum_{s} z_{sv\omega} \leq q_v, \qquad \forall v, \forall \omega \qquad (3)$$

$$\sum_{s} z''_{s\omega} \leq Q_p, \qquad \forall \omega \qquad (4)$$

$$1 + Cap^{V} (z_{sv\omega} - 1) \leq D_{s\omega} x_{sv\omega} \leq Cap^{V} z_{sv\omega}, \qquad \forall s, \forall v, \forall \omega \qquad (5)$$

$$1 + Cap^{V} (z'_{s\omega} - 1) \leq D_{s\omega} x'_{sv\omega} \leq Cap^{V} z'_{s\omega}, \qquad \forall s, \forall \omega \qquad (6)$$

$$1 + Cap^{V} (z''_{s\omega} - 1) \leq D_{s\omega} x''_{sv\omega} \leq Cap^{V} z''_{s\omega}, \qquad \forall s, \forall \omega \qquad (7)$$

$$m_s \leq \sum_{\omega} \left(\sum_{v} z_{sv\omega} + \sum_{s'} z_{s's\omega} \right), \qquad \forall s \neq v, s' \in S \backslash s \qquad (8)$$

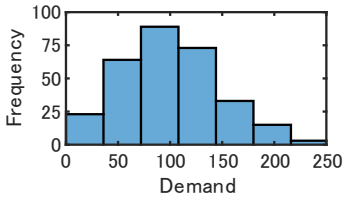
Constraints (2) ensure that the total number of items delivered from shipper s to warehouse does not exceed its demand. Constraints (3) ensure that the total number of v's own trucks used to deliver items does not exceed the number of that trucks q_v. Constraints (4) ensure that the total number of platformer-provided trucks used to deliver items does not exceed the number of that trucks Q_p. Constraints (5), (6) and (7) limit the number of trucks, considering the number of delivered items and the loading capacity of trucks. Constraints (8) ensure that a shipper lends or barrows a minimum of one truck in at least one scenario.

4 Numerical experiment

This section elaborates on benefits of using sharing service under uncertain demand environment. Also, we show how the transaction price and the number of platformer-owned trucks have impact on the decision of owning and borrowing trucks and contribute to cost savings. Gurobi Optimizer V.9.1 was used to solve the stochastic problem.

4.1 Scenario generation

The random numbers are generated following Pearson distribution characterized by average, standard deviation, and skewness, and partitioned into 7 small sets based on percentiles, as depicted in Fig. 1. We randomly select one set from all and define this combination with probabilities as a demand profile. The demand profiles of each item are combined into a demand scenario of a network. In following experiments, we consider the distribution network of 3 shippers whose items have the same demand profile.



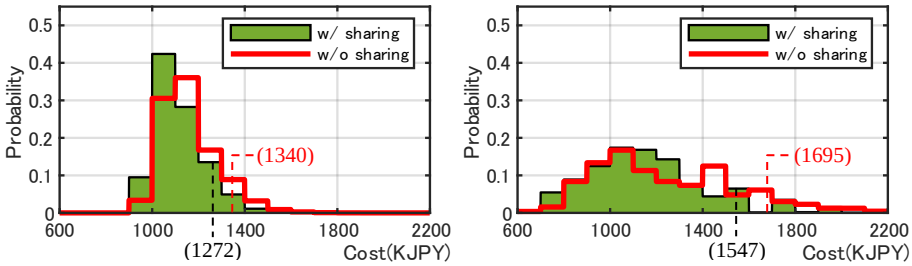
Demand profile

Probability	0.08	0.23	0.30	0.23	0.12	0.04	0.01
Demand (max)	37	74	111	148	185	222	259
Demand (min)	0	36	75	112	149	186	223

Fig. 1. Example of a demand profile

4.2 Results

The demand distribution is assumed to follow Pearson distribution with the average of 100 and the skewness of 0.5. It represents that low-demand scenarios occur with high probability. Fig. 2 illustrates the cost distributions of the optimized network with and without truck sharing in different level of demand uncertainty. The figures in parentheses refer to 90th percentile cost. Those results indicate that shippers using truck sharing can deliver items at a lower cost compared to those who do so independently. While the 90th percentile cost difference at the low uncertainty level is 5.1%, that at the high uncertainty level is 9.7%. Truck sharing provides cost reduction more effectively in a high uncertainty environment.



(a) Low uncertainty level (b) High uncertainty level

Fig. 2. Cost distributions of a network with and without truck sharing

To evaluate the effect of the demand uncertainty and the transaction price, we introduce on-time delivery ratio γ and operation profit margin ratio δ as performance indicators. μ denotes the gross profit margin ratio of an item before subtracting logistics cost, and we set $\mu = 0.2$. The numerator represents the logistics cost, and the denominator represents the revenue in Eq. (10), where E and E^{Loss} denote the objective function value and the demand opportunity loss calculated with the optimal solution, respectively.

$$\gamma = \sum_{\omega} \pi_{\omega} \varphi_{\omega} \tag{9}$$

$$\delta = \mu - \frac{E - E^{Loss}}{\sum_s \frac{P_s}{\mu} \sum_{\omega} \pi_{\omega} D_{s\omega} \varphi_{s\omega}} \tag{10}$$

$$\varphi_{s\omega} = \sum_{v} x_{sv\omega} + x'_{s\omega} + x''_{s\omega} \tag{11}$$

$$E^{Loss} = \sum_{s} P_s \sum_{\omega} \pi_{\omega} D_{s\omega} (1 - \varphi_{s\omega}) \tag{12}$$

Fig. 3 illustrates how the on-time delivery ratio, the gross profit margin ratio and the turnover of the platformer-owned trucks change across the deviation of demand at different transaction prices. In this experiment, we set the number of platformer-owned trucks $Q_p = 12$ and rate of leased trucks $Fix^R = 30$. The on-time delivery ratio is over 99% across the different deviations and prices. While the gross profit margin ratio reduces due to the increasing number of borrowed and leased trucks, the turnover of the platformer-owned trucks increases as the deviation increases. Although the increase in the transaction price leads to lower profit margin ratio, using truck sharing is consistently beneficial for shippers.

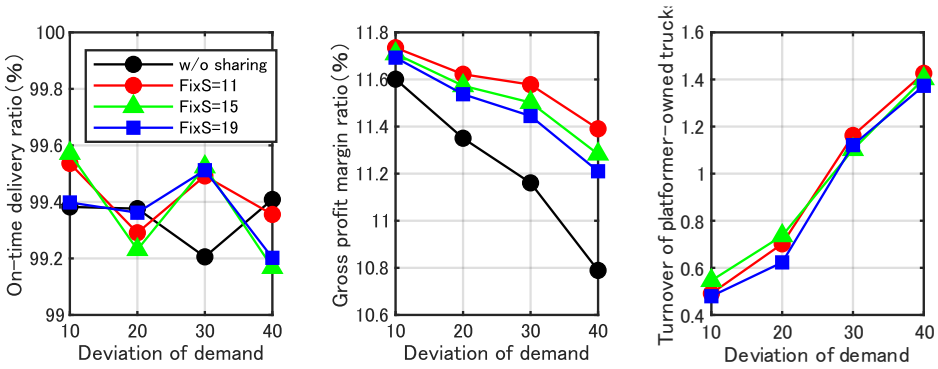


Fig. 3. Sensitive analysis of different deviations and prices

Fig. 4 illustrates how the gross profit margin ratio and the turnover of the platformer-owned trucks change at different Q_p. In this experiment, we set the transaction price $Fix^S = 11$. Large number of Q_p leads to high gross profit margin ratio for larger deviation of demand due to a low cost of borrowing trucks. In contrast, the turnover is low for smaller deviation since there is a small change in the number of required trucks. Q_p and the transaction price together with other parameters such as fees and mileage charges, need to be adjusted to improve the robustness to demand fluctuations.

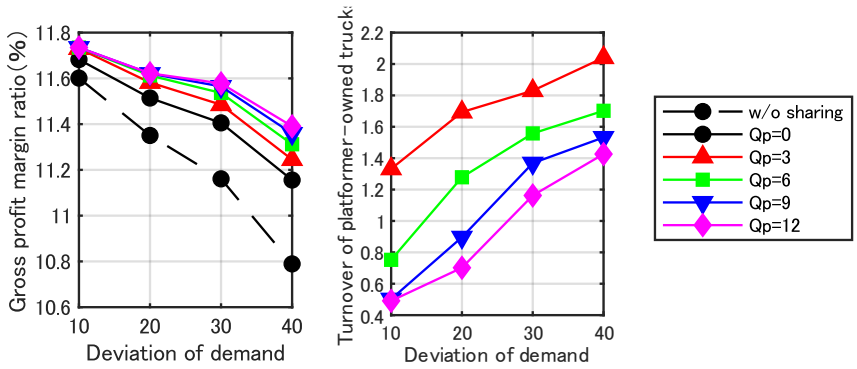


Fig. 4. Sensitive analysis of different number of platformer-owned trucks

5 Conclusion

In this paper, we proposed an optimization model for the network design with truck sharing based on a stochastic programming and perform analysis on several numerical experiments. Our results showed that the benefit of truck sharing increases irrespective of the transaction price and the number of platformer-owned trucks as the deviation of demand increases. However, several extensions for this model that consider, for instance, the area size and the number of shipper locations are suggested to better account for generalized sharing platform. Other sources of uncertainty, such as transportation lead time uncertainty, also need to be considered in terms of a platform management. Further, a heuristic method is required to solve the problem within practical time, since our stochastic approach may not address a large-scale network due to the increasing number of scenarios.

References

1. Bahinipati, B. K., Deshmukh, S.: Vertical collaboration in the semiconductor industry: A decision framework for supply chain relationships. Computers & Industrial Engineering 62(2), 504-526 (2012).
2. Bahinipati, B. K., Kanda, A., Deshmukh, S.: Horizontal collaboration in semiconductor manufacturing industry supply chain: An evaluation of collaboration intensity index. Computers & Industrial Engineering 57(3), 880-895 (2009).
3. Yu, K., Cadeaus, J., Song, H.: Flexibility and quality in logistics and relationships. Industrial Marketing Management 62, 211-225 (2017).
4. Wang, Y., Peng, S., Xu, C., Assogba, K., Wang, H., Xu, M., Wang, Y.: Two-echelon logistics delivery and pickup network optimization based on integrated cooperation and transportation fleet sharing. Expert Systems With Applications 113, 44-65 (2018).
5. Zhang, W., Chen, Z., Zhang, S., Wang, W., Yang, S., Cai, Y.: Composite multi-objective optimization on a new collaborative vehicle routing problem with carriers and depots. Journal of Cleaner Production 274, 1225593 (2020).
6. Cleophas, C., Cottrill, C., Ehmke, J. F., Tierney, K.: Collaborative urban transportation: Recent advances in theory and practice. European Journal of Operational Research 273, 801-816 (2019).
7. Wang, Y., Zhang, J., Assoba, K., Liu, Y., Xu, M., Wang, Y.: Collaboration and transportation resource sharing in multiple centers vehicle routing optimization with delivery and pickup. Knowledge-Based Systems 160, 296-310 (2018).
8. Muroz-Villamizar, A., Montoya-Torres, J. R., Vega-Mejia, C. A.: Non-collaborative versus collaborative last-mile delivery in urban systems with stochastic demands. Procedia CIRP 30, 263-268 (2015).
9. Tolooie, A., Maity, M., Sinha, A.: A two-stage stochastic mixed-integer program for reliable supply chain network design under uncertain disruptions and demand. Computers & Industrial Engineering 148, 106722 (2020)
10. Snoeck, A., Winkenbach, M.: The value of physical distribution flexibility in serving dense and uncertain urban markets. Transportation Research Part A 136, 151-177 (2020)
11. Crainic, T. G., Errico, F., Rei, W., Ricciardi, N.: Modeling demand uncertainty in two-tier city logistics tactical planning. Transport. Sci. 50(2), 559-578 (2016).