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Cost-Response Trade-offs in Transportation Network Design: A Business Optimization Perspective from E-commerce Supply Chains

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Abstract. Against the backdrop of China's rapid e-commerce development, platforms and logistics companies are enhancing customer experience by densifying warehousing and transportation networks and launching multi-tiered services such as same-day and next-day delivery. However, this has led to a significant increase in warehousing, transportation, and last-mile delivery costs. This report, based on a systematic review of supply chain cost-response theory and network design models, and combined with macroeconomic statistics, industry reports, and platform practices such as JD.com, analyses the main contradictions faced by transportation network design under conditions of multiple time-sensitive products coexisting. On the one hand, increased logistics density and service levels are beneficial to supporting e-commerce development and regional economic upgrading; on the other hand, high-density networks and high-time-sensitivity services bring continuous investment and operational pressure. The study points out that e-commerce platforms need to coordinate facility layout, transportation modes, and service levels at the overall network level, and identify the "appropriate service level range" through scenario comparison to achieve a relatively reasonable balance between service improvement and cost control.

Keywords: E-commerce supply chain, transportation network design, cost-response trade-off, multi-delivery, last-mile delivery

1. Introduction

Driven by policy support and improved digital infrastructure, China's e-commerce sector has experienced rapid growth, with online retail sales continuing to rise, becoming a significant force driving economic growth and consumption upgrading [1]. Express delivery and logistics companies are continuously densifying their warehousing and transportation networks, building high-standard warehouses around core cities to shorten delivery distances and improve fulfilment efficiency [2]. Platforms such as JD.com have built up multiple-tiered service such as same-day and next-day delivery through self-built warehousing and distribution systems, enhancing customers' experience but also causing higher warehouse and transportation costs [3]. Research suggests a positive relationship among logistics network density and the development of e-commerce and high-quality

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economic growth, which helps to promote business expansion and regional economic improvement [4].

According to supply chain theory, transportation network design has a trade-off between cost and responsiveness. The supply chain strategy of a company is put at "the cost response frontier". It's more responsive, the transportation and inventory cost are higher, but also it's less responsive to reduce the cost [5,6]. The model developed by Shen and Daskin shows that improved service level leads to increase of marginal cost, which is moderate in terms of service level range, "Moderate service level range" [7]. The theory can provide some ideas for designing the multiple time sensitive products on e-commerce platform.

Tian and Zhang have found that a reasonable division of labor among suppliers' warehouses, regional warehouses, and local warehouses will be able to balance the cost of warehouse rent and transportation expenses but also meet time-sensitivity requirements [8]. Li et al. pointed out that there is a great difference in the cost of various last mile service models under high time sensitivity requirement, and companies have to make trade-off between service level and unit cost [9]. And it means that the planning of transportation network needs to be based on facilities, transportation modes, and service model.

However, there are very few articles on it, the literature is mainly about manufacturing industries or abstract models, and has not had a thorough analysis of multi-time sensitive services + high-density network characteristics of China's e-commerce. While macro level study has verified the interaction between logistics density and e-commerce development, few have presented cost-response curves when the network density and service level are varied from a firm's viewpoint [1,4]. Industry reports also show that even though high-density networks and timely services increase competitiveness, they are uncertain as to whether returns are good or bad [2,3].

According to that, this paper is looking at the Chinese e-commerce supply chain and it has to think about what costs can be reduced for transport. Using the literature review and scenario analysis, an analytical framework for the e-commerce scenario is constructed, finding the "appropriate service level range" at different time sensitive service condition to be identified, and providing some decisions for e-commerce platform in warehouse location selection, network density and service level combination.

2. Manuscript evolution of China's e-commerce supply chain network and trade-offs in service level

Driven by policy support, improved digital infrastructure, and consumption upgrades, China's e-commerce has maintained rapid growth over the past decade, with online retail expanding continuously and becoming a significant force in promoting economic growth and industrial upgrading [1]. Alongside the expansion of e-commerce, the logistics and supply chain networks supporting its operation have also grown significantly: express delivery companies and third-party logistics providers are continuously increasing the density of trunk line transportation and node deployment, building high-standard warehouses and distribution centers around major urban clusters to shorten fulfilment times and improve service stability [2]. Empirical research shows a significant positive correlation between logistics network density and e-commerce development and high-quality economic growth; a more complete supply chain network is a crucial foundation for the continued expansion of e-commerce [4].

In view of such background, China's e-commerce supply chain is showing a platform-dominated structural feature. Large integrated platforms combine online transactions, warehousing, trunk transportation, and last-mile delivery to make a high-precision supply chain system. Companies

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such as JD.com operates many warehouses and forward nodes throughout the country via self-built warehousing and distribution networks, providing various types of service including same day and next day delivery in major cities, and regarding fulfillment capability as a key competitiveness characteristic of them [3]. In this way, platform will have system optimization in forecasting, inventory management and transportation organization but at the same time it will increase the complexity of network planning, facilities selection and matching transport mode.

From a spatial standpoint, China's e-commerce supply chain is changing from a "single centralized warehouse plus nationwide distribution" model to a multi-tier network of "national backbone warehouses + regional warehouses + city forward warehouses." Savills states that due to the rise of e-commerce and new retail, it has become very important for high-quality warehousing to be close to consumers' markets [2]. Warehouses and distribution centers cluster around the core urban clusters for shorter transportation distance between "last mile" and the central points of the system. Backbone warehouses, meanwhile, take cross-regional stock preparation and long-term inventory management responsibilities. Improves response time, but spreads more over many nodes causing a larger investment and operating expense.

For the existence of products with different timing and prices, it becomes a standard practice. Platforms and express delivery companies generally provide services like same day delivery, next day delivery and economy delivery to guide customers in their choice of service [3]. Therefore, e-commerce supply chain has to carry orders of different service levels within the same network, coordinated resource allocation based on time window control and route design. The model of "service level-cost trade-off" introduced by Shen and Daskin show that service improvement brings rise in marginal cost, and there is moderate service level range [7]. In the e-commerce context, how to establish reasonable network density and route combination for various service levels has become an important problem. In terms of service structure, the coexistence of products with different timing and price level has been a normal phenomenon. Platforms and express delivery companies generally provide various forms of services such as same-day delivery, next-day delivery, and economy delivery, guiding customers' choices according to different pricing models [3]. Therefore, the e-commerce supply chain has to have orders flowing from different service level at the same time within a same network, coordinated by time window management and route design. Shen and Daskin [7] have shown that the service cost is proportional to the marginal cost of improving the quality of service, and the range of reasonable network density and route combination has been established.

Last mile delivery is the most challenging link in the e-commerce supply chain. A large number of orders are distributed in the high-density urban area, which leads to a high delivery frequency and increased route complexity, making it difficult for traditional cost-effective route optimization to achieve both short delivery time and high service level. Shuaibu et al. stated that the last-mile delivery needs to make multi-objective trade-off among cost, on time rate and customer satisfaction [10]. In China's e-commerce environment, high frequency, small batch orders and promotion fluctuation make the system uncertainty more complicated.

Overall, China's e-commerce supply chain is characterized by "increased network density, richer service levels, and increased pressure on the last mile." On the one hand, denser warehousing and transportation networks and multi-delivery service systems bring competitive advantages and regional economic effects to platforms [1,4]. On the other hand, infrastructure investment, inventory holding, and last-mile delivery costs are rising simultaneously, and companies face continuous trade-offs in network design and service strategies.

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3. E-commerce logistics networks under multi-time-efficiency competition: cost-response trade-offs and multi-objective conflicts at the last mile

3.1. First cost – the tension between cutting-edge response and a multi-time-sensitive product portfolio

From the perspective of supply chain management theory, transportation network design first faces the fundamental trade-off between cost and responsiveness. Classic textbooks suggest that a company's supply chain strategy can be placed on a "cost-response frontier." High responsiveness implies higher transportation, inventory, and facility costs, while pursuing low costs often comes at the cost of declining service levels [5,6]. In the Chinese e-commerce context, this frontier relationship is further amplified by the coexistence of multiple time-sensitive products: platforms simultaneously offer same-day delivery, next-day delivery, and economy delivery services, effectively operating multiple "sub-frontiers" with different service levels on the same physical network. Without systematic analysis, it is easy to create an imbalance between investment and service.

Shen and Daskin's integrated network design model shows that improving service levels leads to increasing marginal costs, and there exists a "moderate service level range" within which customer satisfaction and company costs can reach a relative equilibrium [7]. Applying this to the e-commerce context, when platforms nationwide push for higher delivery time commitments and force many orders to the forefront of "high response" channels, marginal revenue may not cover marginal costs, especially in categories with low average order value and high competition. This tension between "theoretical frontiers" and "real-world product combinations" is the first contradiction currently facing e-commerce transportation network design: companies are unwilling to lose their competitive advantage in delivery time, yet they cannot sustain the cost pressure brought by consistently high delivery times in the long term.

3.2. Corporate decision-making dilemmas from the perspective of logistics density and high-quality development

Macro-level research generally agrees that higher logistics network density contributes to e-commerce development and high-quality economic growth. The UNIDO China E-commerce Development Report points out that e-commerce expansion has created unprecedented demand for logistics infrastructure, while a well-developed network, in turn, supports the continued expansion of e-commerce [1]. Zeng et al. further demonstrate through inter-provincial panel empirical analysis that there is a significant positive relationship between logistics density and e-commerce development and high-quality economic development; high-density networks are considered an important condition for promoting regional economic upgrading [4]. From this perspective, increasing warehousing and nodes, and improving network density, seems to be the "correct" development path.

However, from the perspective of enterprise micro-decision-making, this "macro-correctness" does not automatically translate into "individual rationality." For platforms and logistics companies, each additional warehousing facility or transit node means long-term capital investment and operating costs, and the resulting demand growth and brand premium are not immediately apparent. For leading platforms, high-density networks offer implicit benefits such as strategic entry barriers and ecosystem control; however, for small and medium-sized platforms and regional enterprises, the benefits are limited, yet they must bear the same real investment pressure. This creates a second

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contradiction: at the macro level, network encryption is encouraged to promote high-quality development, while at the micro level, enterprises face a dilemma between "expanding the network" and "preserving profits" in specific projects.

3.3. Uncertainty of return on investment for high-density networks and time-sensitive services

From an industry and market research perspective, China's e-commerce supply chain is clearly evolving towards a "closer to the demand side." A Savills [2] report points out that driven by e-commerce and new retail, demand for high-standard warehousing around first tier and core second-tier cities remains strong, with numerous new projects being built in areas close to consumer markets to shorten delivery distances and times [2]. Meanwhile, platforms like JD.com, through self-built or deep involvement in warehousing and distribution networks, operate numerous warehouses nationwide, achieving same-day or next-day delivery services in major cities, regarding fulfilment capabilities as a key competitive advantage [3].

However, this combination of high-density networks and high-efficiency services inevitably involves multi-dimensional investments in land, construction, automated equipment, manpower, and information systems, with a long payback period. Reports and annual reports often only present cross-sectional data on total costs and fulfilment indicators, making it difficult to accurately break down the true marginal benefits of each facility expansion in the long term. Furthermore, high-density networks amplify fixed costs to some extent, increasing operating leverage and risk exposure for companies during periods of demand fluctuation and intensified competition. This creates a third contradiction: on the one hand, companies gain market share by encrypting networks and improving timeliness; on the other hand, they must face the uncertainty of long-term investment returns that is difficult to quantify and lack an analytical framework that can clearly characterize "how fast is appropriate and how encrypted is suitable".

3.4. The "last mile" faces multiple conflicts and accumulated operational pressures

Compared to trunk transportation and warehousing layout, "last-mile" delivery more directly reflects the cost-response tension. A large number of orders are concentrated in high-density urban area, the delivery frequency and route is constantly improving, and it has become more obvious that there is a conflict between revenue per order and last mile delivery cost. Shuaibu et al. shows that last mile delivery optimization usually takes multiple objectives at once, such as cost reduction, on time delivery improvement and customer satisfaction enhancement, frequently having conflict among these goals [10]. In e-commerce environment, to meet extremely short delivery time, companies should use more frequent deliveries, more flexible vehicle scheduling and also bring in crowdsourced or instant delivery mode, increase unit delivery cost and operational uncertainties while improve service response rate.

Promotional activities and new marketing methods such as live-streaming e-commerce further exacerbate the volatility of the last-mile system. During peak promotional periods, order volume surges dramatically in a short time, often requiring companies to temporarily increase manpower and transportation capacity, creating "peak redundancy capacity"; however, during off-peak periods, this redundancy capacity translates into idle resources and additional costs. For platforms, focusing solely on short-term market share and user experience can easily lead to an "unlimited pandering" strategy in last-mile services, neglecting the shape of the long-term cost-response curve and systemic constraints. This constitutes the fourth contradiction: the last mile carries the direct

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perception of customer experience, yet it is often the part where cost-response conflicts are most acute and operational pressures are most likely to accumulate.

4. Recommended optimization path-cost- and response-oriented

4.1. Restructuring multi-time-sensitive product portfolios around the "appropriate service level range"

Supply chain cost-response frontier theory suggests that higher responsiveness implies higher transportation, inventory, and facility costs, while extreme cost reduction sacrifices service levels [5,6]. Shen and Daskin's integrated design model indicate that improving service levels has increasing marginal costs, and there exists a "moderate service level range" where customer satisfaction and cost are relatively balanced [7]. In the context of Chinese e-commerce, if platforms indiscriminately push many orders towards same-day or next-day delivery, they are prone to falling into the dilemma of "high service, low revenue".

Specifically, platforms can stratify users' time sensitivity based on historical order data and category characteristics: maintaining high timeliness for high-value, time-sensitive orders, and guiding price-sensitive orders to choose lower service levels through economy or standard shipments. The front end can strengthen the "moderate rather than extreme" timeliness selection through differentiated shipping costs and default options, and regularly evaluate the contribution of each timeliness product in combination with internal cost data, gradually shrinking the ultra-high timeliness commitment with low profitability and high cost, so that the overall product structure is closer to the theoretical "moderate range".

4.2. Determine network density and infrastructure layout through scenario analysis

UNIDO report and studies by Zeng et al. show that there is a significant positive relationship between logistics network density and e-commerce development and high-quality economic development, high-density networks support regional economic upgrading [1,4]. But for an individual enterprise, it is a long-term capital investment and operation cost. Savills also points out that the cost of building high-standard warehouses near consumer markets is increasing, and site selection decision-making has become more sensitive [2].

Therefore, it is necessary to conduct multiple scenario calculations before expanding the network: set different number and locations of facilities for the same demand distribution, compare the change in total costs and average delivery times, find out the suitable level of network density of the enterprise, that is, determine the range of "appropriate network density" for the enterprise's positioning. Operatively, piloting new nodes through leasing, shared warehousing, or collaboration with other entities can be started before. If order volume and revenue have been determined, a decision can be made about heavy assets. By applying the method of "first calculate, then expand", businesses can adapt to the increase in logistics density at the same time avoid one-time expansion, focus resources on nodes with higher cost-response rate.

4.3. Layered restructuring of last-mile services to alleviate multi-objective conflicts

Shuaibu and others pointed out that, as a last-mile service, it is usually pursued in multiple goals, to minimize cost, increase on time delivery, enhance customer satisfaction, there are significant conflict among those three goals [10]. China has a lot of orders when there are high numbers of

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people out at night. In order to meet short delivery goals, platforms can raise delivery frequency and capacity allocation, even adopt crowd sourcing models. And thus it is more difficult to increase unit delivery cost and operational uncertainty. To deal with it, companies can adopt tiered strategy at last mile: "concentration of high-delivery orders plus cost optimizing of normal orders." In high density core area, use self operated teams or key partners for same day and next day delivery orders, and combine this with facilities such as self pick up points and parcel lockers to reduce the distance between delivery. In areas of scattered demands or high demand sensitivity, concentrate on economy package and schedule delivery, extend the delivery time to get benefits from cost. Also, make use of past history data to predict peak and off-peak period, adjust shift and route based on changes, increase number of delivery workers, decrease number of empty run and duplicate delivery. This strategy still maintains the appeal of a high timeliness for core customers but at the same time changes the cost response structure of the final stages.

5. Conclusions

According to a review of supply chain cost-response theory and network design model, and combined with the development trends of China's e-commerce, this paper summaries some important contradictions in the design of logistics infrastructure: the cost-response frontier is shifted to high costs for the sake of the superposition of many products; There is a contradiction between the demand for large-scale logistics density and the constraint of micro-level investment from enterprise enterprises; The return on investment of high-density networks and high-time-sensitivity services are unclear; And the multi-objective conflict is present in the last mile segment. According to this premise, the paper provides some recommendations like reconstructing the combination of multiple time-sensitive products around the "appropriate service level range", prudently determine network density through scenario calculation, hierarchically reconstruct last mile services, and establish a dynamic evaluation mechanism. Those suggest may have some theory and practical value to understand the cost-response tradeoff of the e commerce supply chain.

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