Research on the Optimization of Integrated Schedule and Transport Plan of E-Commerce Goods

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Abstract. Based on the line-haul freight transport of a certain e-commerce company, this paper studies the cargo scheduling schemes between different supply centres and demand centres with different transport modes. Taking the minimum transport cost as the objective function, time window and supply-demand balance as constraints, considering the various types of goods, this paper establishes the decision-making optimization model for e-commerce goods line-haul transportation, and calculates the cargo scheduling schemes in different scenarios by LINGO 18.0. The paper finds out that highway is still the main mode of transporting e-commerce goods at present; with the continuous improvement of high-speed rail freight transportation, railway shows great potentials to carry e-commerce goods; at the same time, air transport is irreplaceable for transporting time-sensitive products and high value-added products.

1. Introduction
China's e-commerce transaction scale has made rapid progress from 7.85 trillion in 2012 to 34.81 trillion in 2019. But the development of logistics at the same time is relatively weak. In recent years, the coordinated development of various transport modes has added new impetus to the transportation market. Thus, e-commerce logistics scheduling optimization has become one of the hot research areas.

At present, e-commerce logistics scheduling optimization mainly aims at three aspects of cost control: logistics time cost, logistics economic cost and logistics environmental cost. Andreas R. et al. studied the operation scheme of multimodal transport under the constraints of time window with the least carbon emission and the lowest economic cost[1]. Zhang J. et al. introduced the concept of matching degree to describe the relation between logistics demand and capacity in terms of time cost, economic cost and load capacity. Taking the optimal matching degree as the objective function, an optimization model with capacity and resources as constraints was established[2]. Guo X.F. et al. studied the processing capacity of the distribution centre (DC) and the needs of consumers for delivery time. With the goal of minimum logistics cost and maximum logistics service capacity, a three-level supply chain system was established[3]. Liu S. et al. established an optimization model with the objective of minimizing the total multimodal freight cost under the limit of carbon emissions, considering not only the transport cost but refrigeration and cargo damage cost[4]. Ghezavati V.R. et al. studied the problem of minimizing time cost and transportation cost in reverse logistics scenario[5].

Based on the current research, this paper studies minimum transport cost under different scenarios with multiple transport modes to form a better schedule plan for various goods between different DCs.
2. Problem Statement
The research on integrated transporting and scheduling of e-commerce goods is based on the line-haul freight transportation, which aims to solve the allocation volume of different types of goods transferred from the supply centre to the demand centre and their corresponding transportation modes. Highway, railway (high-speed rail freight) and air transportation can be used on each line.

In order to meet time requirements of freight scheduling between two centres, a single mode of transportation is limited and restricted by the running speed, which is difficult to satisfy the needs of company operation and management. Therefore, other modes of transportation with higher speed should be adopted. However, the sensitivity to timeliness of different goods is not the same. If the faster transportation mode is appointed to all kinds of cargos between two points, it will dramatically increase the freight cost of the enterprise. Therefore, it is necessary to select the corresponding transportation mode according to the time requirements of different goods between distribution centres. The freight transport network structure formed between the distribution centres is shown in Figure 1.

![Figure 1. Integrated network structure of e-commerce freight.](image)

3. Model Building
3.1. Assumption
To establish the model, the paper makes the following assumptions on the research scenario:

- Cargo category: e-commerce common goods are not time-sensitive. Therefore, they have no needs for cold chain transportation and special refrigerated packaging. However, fresh cold chain cargos are easy to rot and perish, thus they have high timeliness requirements and need special packaging and equipment.
- Pricing method: the pricing quotation method adopted in this paper, volume rate ($/m^3$), is one of the common billing methods of less than truck load (LTL) transportation rate in the market.
- The distance between different distribution centres is measured by Euclidean distance.
- In the process of goods freight, different modes of transport keep the constant running speed.
- The differences in loading and unloading time of various transportation modes are reflected on the average running speed of different modes.
- The freight scheduling scheme between distribution centres can finally achieve the balance of supply and demand needs.

3.2. Model
In this paper, a cost optimal decision model with time window constraints and volume constraints based on different types of goods and various modes of transportation is established to achieve a better scheduling and transporting plan. The notations are set as follows: $O_{ij}/H_{ij}/L_{ij}$ is 0/1 decision variable, representing the transportation mode selected for a certain kind of cargo $N$ between two points. $P_{ij}, G_{ij}, W_{ij}$ is the price quotation of different transportation modes from point $i$ to point $j$. $Q_{ij}$ is the transportation volume of cargo $N$ from point $i$ to point $j$. $D_j$ is the total demand for cargo $N$ at point $j$. $C_i$ is the inventory volume of cargo $N$ at point $i$. $f_{ij}$ is the Euclidean distance from point $i$ to point $j$. $t_{ij}$ is the speed of road/railway/air transportation mode. $S_i$ is the road departure time of cargo $N$ at point $i$. $A_j$ is the
railway departure time of cargo \( N \) at point \( i \). \( B_i \) is the air departure time of cargo \( N \) at point \( i \). \( T_j \) is the required arrival time of cargo \( N \) at point \( j \). \( Y \) is the loading time at each point. The objective function of the model is set as follows:

\[
\text{Min} F = \sum_i \sum_j \sum_n Q_{ij}^n \times O_{ij}^n \times P_{ij} + \sum_i \sum_j \sum_n Q_{ij}^n \times H_{ij}^n \times G_{ij} + \sum_i \sum_j \sum_n Q_{ij}^n \times L_{ij}^n \times W_{ij} \quad (1)
\]

It aims to optimize the minimal cost of freight transportation and consists of three parts. \( \sum_i \sum_j \sum_n Q_{ij}^n \times O_{ij}^n \times P_{ij} \) is the total cost of road transportation. \( \sum_i \sum_j \sum_n Q_{ij}^n \times H_{ij}^n \times G_{ij} \) is the total cost of rail transportation. \( \sum_i \sum_j \sum_n Q_{ij}^n \times L_{ij}^n \times W_{ij} \) is the total cost of air transportation.

The constraints of the model are as follows:

\[
O_{ij}^n = \begin{cases} 1 & (\text{Highway selected for cargo } N) \\ 0 & (\text{Highway not selected for cargo } N) \end{cases} \quad (2)
\]

\[
H_{ij}^n = \begin{cases} 1 & (\text{Railway selected for cargo } N) \\ 0 & (\text{Railway not selected for cargo } N) \end{cases} \quad (3)
\]

\[
L_{ij}^n = \begin{cases} 1 & (\text{Aviation selected for cargo } N) \\ 0 & (\text{Aviation not selected for cargo } N) \end{cases} \quad (4)
\]

\[
O_{ij}^n + H_{ij}^n + L_{ij}^n = 1 \quad (\sum_n Q_{ij}^n > 0) \quad (5)
\]

\[
\sum_i Q_{ij}^n = D_{ij}^n \quad (6)
\]

\[
Q_{ij}^n \leq C_{ij}^n \quad (7)
\]

\[
P_{ij} = \begin{cases} P_{ij} \times 0.8 & (\sum_n Q_{ij}^n > 5) \\ P_{ij} \times 1.0 & (\sum_n Q_{ij}^n \leq 5) \end{cases} \quad (8)
\]

\[
G_{ij} = \begin{cases} G_{ij} \times 0.9 & (\sum_n Q_{ij}^n > 5) \\ G_{ij} \times 1.0 & (\sum_n Q_{ij}^n \leq 5) \end{cases} \quad (9)
\]

\[
W_{ij} = \begin{cases} W_{ij} \times 0.8 & (\sum_n Q_{ij}^n > 5) \\ W_{ij} \times 1.0 & (\sum_n Q_{ij}^n \leq 5) \end{cases} \quad (10)
\]

\[
O_{ij} \times f_{ij} / f_{ij}^H + H_{ij} \times f_{ij} / f_{ij}^H + L_{ij} \times f_{ij} / f_{ij}^H + S_{ij}^n \times Q_{ij}^n + A_{ij}^n \times H_{ij}^n + B_{ij}^n \times L_{ij}^n + Y < T_{ij}^n - Y 
\]

Equation (2) to (5) ensure that a certain type of cargo \( N \) is carried by one mode of transportation between two centres. If highway is selected for cargo \( N \), then \( O_{ij}^n = 1 \), otherwise \( O_{ij}^n = 0 \). If railway is selected for cargo \( N \), then \( H_{ij}^n = 1 \), otherwise \( H_{ij}^n = 0 \). If air is selected for cargo \( N \), then \( L_{ij}^n = 1 \), otherwise \( L_{ij}^n = 0 \). Equation (6) ensures that demand of centre \( j \) for different types of goods can be satisfied by other supply centres. Equation (7) ensures that the delivery volume of different types of goods in supply centre \( i \) is less than its own inventory. Equation (8) to (10) describes the price quotation discount of different transportation modes in the case of carrying large volume. According to the total amounts of the goods, the corresponding discounts of different transportation modes are given as follows: taking 5 cubic meters as the discount starting point, the discount coefficient of railway (high-speed rail) transportation is 0.7, that of highway transportation is 0.8, and that of air transportation is 0.9. For cold chain transportation, the discount coefficient of railway transportation is 0.8. Equation (13) is the time window constraint for different types of goods. In this paper, a hard time window constraint is used.

4. Experimental Analysis

The model in this paper is solved by LINGO 18.0. In LINGO, it usually needs four steps to code and solve the complex model, including defining set segment, defining target segment, defining constraint
segment and defining data segment. According to the characteristics of this model, we can quickly get the optimal solution by calling related function in LINGO.

4.1. Common Goods Transport

4.1.1. Transport scenario. The distribution centres of J Company in Chengdu, Wuhan, Xi’an and Jinan plan to transfer three types of goods to the distribution centres in Beijing, Shanghai and Guangzhou. It is necessary to calculate the volume of different goods to be transported on each line and select the corresponding transportation mode for different goods on each line.

For the e-commerce common goods, three types of standard products are selected, including office products, electrical products and footwear products. These three types of products are not sensitive to time and do not need cold chain transportation and packaging. Specific optimization examples are analysed as follows. Known parameters include:

**Table 1. Supply of three types of e-commerce common goods.**

|          | Office Products | Electronical Products | Footwear Products |
|----------|-----------------|----------------------|-------------------|
| Chengdu  | 120             | 60                   | 80                |
| Wuhan    | 60              | 100                  | 70                |
| Xi’an    | 30              | 92                   | 80                |
| Jinan    | 75              | 65                   | 55                |

**Table 2. Demand of three types of e-commerce common goods.**

|          | Office Products | Electronical Products | Footwear Products |
|----------|-----------------|----------------------|-------------------|
| Beijing  | 95              | 95                   | 95                |
| Shanghai | 85              | 92                   | 135               |
| Guangzhou| 105             | 130                  | 55                |

**Table 3. Price of road/rail/air transport mode.**

|          | Beijing | Shanghai | Guangzhou |
|----------|---------|----------|-----------|
| Chengdu  | 270/300/706 | 250/290/703 | 230/265/465 |
| Wuhan    | 210/235/500 | 190/245/325 | 205/240/505 |
| Xi’an    | 240/260/656 | 230/290/711 | 260/300/720 |
| Jinan    | 150/185/355 | 270/285/360 | 220/300/660 |

**Table 4. Timetable for delivering office/electrical/footwear products.**

|          | Highway | Railway | Air |
|----------|---------|---------|-----|
| Chengdu  | 1D06/1D12/1D17 | 1D08/1D06/1D10 | 1D08/1D08/1D06 |
| Wuhan    | 1D10/1D12/1D14 | 1D09/1D08/1D05 | 1D09/1D13/1D12 |
| Xi’an    | 1D14/1D10/1D10 | 1D12/1D14/1D03 | 1D10/1D13/1D09 |
| Jinan    | 1D16/1D18/1D18 | 1D17/1D13/1D14 | 1D12/1D16/1D20 |

**Table 5. Timeliness requirements of demand centres.**

|          | Highway | Railway | Air |
|----------|---------|---------|-----|
| Beijing  | 2D10    | 2D14    | 2D13 |
| Shanghai | 2D11    | 3D02    | 2D21 |
| Guangzhou| 2D13    | 2D21    | 2D16 |
4.1.2. Scenario results. Under this Scenario, the minimum transportation cost is ¥ 144668. The specific cargo volume allocation plan and corresponding transport mode selection results are shown in Table 6. to Table 8.

Table 6. Volume allocation and corresponding transport mode of office products.

|         | Beijing | Shanghai | Guangzhou |
|---------|---------|----------|-----------|
| Chengdu | 0       | 15(Road) | 105(Road) |
| Wuhan   | 0       | 60(Road) | 0         |
| Xi’an   | 20(Rail)| 10(Road) | 0         |
| Jinan   | 75(Road)| 0        | 0         |

Table 7. Volume allocation and corresponding transport mode of electrical products.

|         | Beijing | Shanghai | Guangzhou |
|---------|---------|----------|-----------|
| Chengdu | 0       | 0        | 60(Road)  |
| Wuhan   | 0       | 30(Road) | 70(Road)  |
| Xi’an   | 30(Rail)| 62(Road) | 0         |
| Jinan   | 65(Road)| 0        | 0         |

Table 8. Volume allocation and corresponding transport mode of footwear products.

|         | Beijing | Shanghai | Guangzhou |
|---------|---------|----------|-----------|
| Chengdu | 0       | 25(Road) | 55(Road)  |
| Wuhan   | 0       | 70(Road) | 0         |
| Xi’an   | 40(Rail)| 40(Road) | 0         |
| Jinan   | 55(Road)| 0        | 0         |

4.2. Cold Chain Goods Transport

4.2.1. Transport scenario. For the cold chain goods, we select primary agricultural (PA) products, meat products and processed food (PF) products. Due to the characteristics that they are easy to rot and perish, these three types of products need special packaging operations and cold chain transportation, which may result in higher freight costs and stricter time requirements than common products. Among them, primary agricultural products include vegetables, fruits, flowers, etc. Meat products include meat, poultry, eggs, aquatic products, etc. Processed food products include instant frozen food, packaged cooked food, ice cream, dairy products, etc. Specific optimization examples are analysed as follows. Known parameters include:

Table 9. Supply of three types of cold chain goods.

|         | PA Products | Meat Products | PF Products |
|---------|-------------|---------------|-------------|
| Chengdu | 60          | 40            | 60          |
| Wuhan   | 80          | 80            | 60          |
| Xi’an   | 60          | 60            | 40          |
| Jinan   | 40          | 30            | 40          |

Table 10. Demand of three types of cold chain goods.

|         | PA Products | Meat Products | PF Products |
|---------|-------------|---------------|-------------|
| Beijing | 90          | 80            | 60          |
| Shanghai| 80          | 60            | 70          |
| Guangzhou | 60      | 60            | 60          |
Table 11. Price of road/rail/air transport mode.

|         | Beijing   | Shanghai  | Guangzhou |
|---------|-----------|-----------|-----------|
| Chengdu | 405/420/847 | 375/406/840 | 345/370/558 |
| Wuhan   | 315/320/600 | 285/340/390 | 305/336/606 |
| Xi’an   | 360/364/780 | 345/406/850 | 390/420/860 |
| Jinan   | 225/255/422 | 405/395/432 | 330/420/792 |

Table 12. Timetable for delivering PA/meat/PF products.

|         | Highway | Railway | Air  |
|---------|---------|---------|------|
| Chengdu | 1D10/1D09/1D10 | 1D11/1D10/1D08 | 1D07/1D08/1D09 |
| Wuhan   | 1D10/1D10/1D10 | 1D07/1D11/1D09 | 1D10/1D10/1D08 |
| Xi’an   | 1D09/1D08/1D12 | 1D12/1D12/1D13 | 1D11/1D08/1D10 |
| Jinan   | 1D08/1D09/1D13 | 1D10/1D10/1D15 | 1D16/1D14/1D15 |

Table 13. Timeliness requirements of demand centres.

|         | Highway | Railway | Air  |
|---------|---------|---------|------|
| Beijing | 2D10    | 2D00    | 1D18 |
| Shanghai| 2D08    | 2D02    | 1D20 |
| Guangzhou| 2D06    | 2D04    | 1D22 |

4.2.2. Scenario results. Under this Scenario, the minimum transportation cost is ¥ 166664. The specific cargo volume allocation plan and corresponding transport mode selection results are shown in Table 14. to Table 16.

Table 14. Volume allocation and corresponding transport mode of PA products.

| (m³) | Beijing | Shanghai | Guangzhou |
|------|---------|----------|-----------|
| Chengdu | 0       | 0        | 60(Road)  |
| Wuhan | 50(Road) | 30(Road) | 0         |
| Xi’an | 0        | 50(Road) | 0         |
| Jinan | 40(Road) | 0        | 0         |

Table 15. Volume allocation and corresponding transport mode of meat products.

| (m³) | Beijing | Shanghai | Guangzhou |
|------|---------|----------|-----------|
| Chengdu | 0       | 0        | 40(Road)  |
| Wuhan | 50(Road) | 30(Road) | 0         |
| Xi’an | 0        | 30(Road) | 0         |
| Jinan | 30(Road) | 0        | 0         |

Table 16. Volume allocation and corresponding transport mode of PF products.

| (m³) | Beijing | Shanghai | Guangzhou |
|------|---------|----------|-----------|
| Chengdu | 60(Rail)| 0        | 0         |
| Wuhan | 0        | 40(Road) | 20(Road)  |
| Xi’an | 0        | 0        | 40(Rail)  |
| Jinan | 0        | 30(Air)  | 0         |
4.3. Results Analysis

By comparing the final transporting schemes under the e-commerce common goods scenario with cold chain products scenario, the following analysis can be obtained:

- Highway is the main mode for e-commerce freight transport. Though the running speed of highway is relatively slow, it can still meet the time requirements of most line-haul freight products which aims to fill the inventory in advance. Because of the low transportation cost and price of highway, it occupies a large share in the e-commerce freight market.
- High speed rail freight transport has great potentials and can be developed into one of the mainstream transport modes in the future for e-commerce goods. With the further improvement of railway freight reform, high-speed rail will make up a larger market share and show a better performance.
- Air transportation is irreplaceable for products with more stringent time requirements. Due to the highest speed and better freight service of air transport mode, air transportation is still the indispensable mode for high value-added products and time-sensitive products.

5. Conclusions

In this paper, we study the minimum freight cost problem based on different products and transportation modes, realizing the volume allocation and modes selection for different types of goods between different centres. An optimal transporting and scheduling model is established with time window constraints and supply-demand balance constraints. Combined with the actual operation data from an e-commerce company, both common goods scenario and cold chain goods scenario are studied. It is proved that highway is the main mode for e-commerce freight, high speed rail has great potentials to be better developed and air transport is irreplaceable for certain types of products.

6. References

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