Research on Scheduling Model and Algorithm of Drop-and-hook Transport Vehicles Based on Land-Sea Combined Transport

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Abstract—Background China’s squatting transportation mode has been continuously developed. A single road hoisting transportation can no longer meet the market demand, and a variety of ways to coexist in the transportation mode is constantly emerging. Objective To study how the stern transport vehicles can complete the dispatching task more efficiently under the conditions of land and sea transportation. Methods analyzes the advantages of the sling transport operation under the condition of land and sea transportation, and establishes the scheduling model of the stern transport vehicle based on land and sea transportation. This paper designs a heuristic algorithm to solve the initial solution of the model. Based on this, combined with the application of simulated annealing The algorithm performs the objective function minimization solution. Results The vehicle scheduling model was verified by practical examples, which proved the practicability of the model and algorithm.

1. INTRODUCTION

Drop and pull transportation refers to the transportation in which the tractor pulls the semi-trailer to the freight loading and unloading destination and drops it while pulling another semi-trailer to a new destination as required[1]. With the improvement of China’s road transportation system, the industry of drop and pull transportation is also expanding, with more and more enterprises transforming from the original point-to-point transportation to point-to-points transportation integrating network, circulation, multimodal transportation and other complex systems. Among them, researches on the joint rail and water drop and pull transportation have gradually increased in recent years both at home and abroad.

Foreign studies on the vehicle scheduling of drop and pull transportation started earlier, with Chao being the first to propose the optimized model to calculate paths for drop and pull transportation and develop tabu algorithm for this purpose[2]. Kris Braekers proposed asymmetric multi-vehicle traveling with time windows and designed a two-stage algorithm combining simulated annealing and tabu search[3]. Parragh S N et al. studied the truck and trailer routing with time windows, and proposed an adaptive algorithm for large neighborhood search[4]. Verma studied the combination of drop and pull transportation with railway transportation, and established a multi-objective function model to facilitate vehicle scheduling concerning dangerous goods[5]. Although domestic studies on vehicle scheduling of drop and pull transportation started relatively late, researches on land and sea combined transportation have gradually deepened in recent years due to strong support from the government. Hu Zhihua proposed to carry out drop and pull transportation between two ports, and established a mixed integer
programming model with numerical experiments to prove the effectiveness of the algorithm[6]. Fan Ningning established a tractor scheduling model to improve the loading and unloading capabilities of the Yantai-Dalian railway ferry in terms of drop and pull transportation, and designed a saving algorithm to solve the model, which proved the feasibility of the algorithm[7]. Han Xuemei established a multi-objective model to optimize the land-sea transportation path of containers under the Ro-Ro drop and pull transportation[8]. Yang Zhenhua, considering the situation in which multiple ships are simultaneously carrying out trailer loading and unloading operations, used the mathematical model of tractor operation and scheduling to optimize researches on tractor scheduling under the Ro-Ro drop and pull transportation[9].

This paper aims at combining land and sea transportation to establish a vehicle scheduling model for land-sea combined drop and pull transportation, taking into account the presence of trailers and constraint of time window at the place of departure from the perspective of the operator. A heuristic algorithm was designed to work out the initial solution of the model, based on which a simulated annealing algorithm was applied to minimize the objective function. Finally, the practicability of the model and algorithm was verified in the real scenario.

2. ANALYSIS OF LAND-SEA COMBINED DROP AND PULL TRANSPORTATION

2.1. Characteristics of land-sea combined drop and pull transportation

The land-sea combined transportation is dominated by long-distance sea transportation while land drop and pull transportation serves as a supplement. Specifically, it refers to the transportation in which the trailer arrives at the port via land transportation before getting on Ro-Ro ship to function in drop and pull transportation. The trailer is shipped to the next port by the Ro-Ro ship via water transportation and heads to the final destination headed by tractor via land transportation.

The land-sea combined drop and pull transportation is more efficient. Take the 12.5-meter semi-trailer as an example. It takes an average of 6 hours to load, unload and sort out goods in traditional transportation, but less than 3 hours in drop and pull transportation. The land-sea combined drop and pull transportation is more energy-saving, as evidenced by pollution control (freight volume per kilometer) in which the cost of marine transportation, railway transportation and road transportation is about 1:3:14, indicating that the land-sea combined transportation is much more environment-friendly and energy-saving than pure road transportation. The land-sea combined drop and pull transportation is more economical. Take Shandong Peninsula and Liaodong Peninsula as an example. The sea transportation saves distance of more than 1200 kilometers on average compared with road transportation, and is much cheaper than the latter. The land-sea combined drop and pull transportation is safer. Compared with traditional land-sea combined roll-on roll-off transportation, the drop and pull transportation doesn't need the trailer to cross the sea with the ship, therefore avoiding potential safety hazards of fire in the cargo tank in the cabin, thus making maritime transportation safer.

2.2. Problems in land-sea combined drop and pull transportation

This paper studied the land-sea combined drop and pull transportation while taking into account the presence of trailers at the place of departure and the service time window to determine the optimal drop and pull transportation of maximized cost efficiency for enterprises.

Step 1: The place of departure sends an application of transportation and reports whether there is a trailer. The drop and pull transportation center accepts the application and reserves parking space in the cabin in advance. The drop and pull transportation center sends trailers or semi-trailers to pick up goods at the place of departure based on its needs. After arriving at the place of departure, it loads and sorts out the goods, while the fully loaded semi-trailers are sent to the designated parking space in the cabin of the port of origin or to the storage yard of the port of origin, and then transported by the port trailers to the designated parking space in the cabin before the trailers return to the drop and pull transportation center or the storage yard of the port of origin. Step 2: Sea transportation from the port of departure to the port of destination. Step 3: After the ship arrives at the port of destination, the drop and pull
transportation center or the port will send trailers to pick up the semi-trailers in the cabin and transport them to the place of receipt. As shown in Figure 1.

![Diagram of Drop and Pull Transportation in Land-sea Combined Transportation](image)

Figure 1. Diagram of Drop and Pull Transportation in Land-sea Combined Transportation

### 3. MODEL CONSTRUCTION

#### 3.1. Hypothesis

1. One trailer corresponds to one task;
2. All tractors and trailers are of uniform size;
3. Exclude the time when the tractor loads and unloads the trailer;
4. In the maritime transportation, liner transportation will be organized according to various operations in the port and weather conditions.

#### 3.2. Define variables:

- **L**: Port of Departure
- **D**: Port of Destination
- **W**: Set of tasks, \( W = \{1, 2, \ldots, W\} \);
- **A**: Set of each drop and pull transportation center;
- **I**: Set of task delivery points, \( i \in I = \{1, 2, \ldots, I\} \);
- **J**: Set of task delivery points, \( j \in J = \{1, 2, \ldots, J\} \);
- **d_{ai}**: Distance between the drop and pull transportation center \( a \) and the delivery point \( i \);
- **d_{di}**: Distance between the delivery point \( i \) and the port of departure \( L \);
- **d_{dj}**: Distance between the port of destination \( D \) and the point of receipt \( j \);
- **C_0**: Cost of trailer;
- **C_1**: Cost of tractor empty run per unit distance;
- **C_2**: Cost of trailer empty run per unit distance;
- **C_3**: Cost of trailer per unit distance;
- **X_i, Y_i**: when \( X_i = 1, Y_i = 0 \), it means there are trailers at the delivery point of \( i \); when \( X_i = 0, Y_i = 1 \), it means there is no trailer at the delivery point of \( i \);
- **M**: A high penalty value indicates the impracticability of the plan;
- **t_0**: the time needed for loading goods;
- **p_w**: The earliest delivery time of task \( w \) at the delivery point;
- **q_w**: The latest delivery time of task \( w \) at the delivery point;
- **[p_i, q_i]**: The time window of task \( w \) at the delivery point \( i \);
- **m_j**: The earliest time of receipt of task \( w \) at the delivery point \( j \);
- **n_j**: The latest time of receipt of task \( w \) at the delivery point \( j \);
- **[m_j, n_j]**: The time window of task \( w \) at the delivery point \( j \);
- **t_{ai}**: The time needed to travel from the drop and pull transportation center \( a \) to the delivery point \( i \);
$t_{ij}^a$: Time of departure from the drop and pull transportation center $a$ for the tractor;

$t_{ij}^f$: The time of departure for task $w$ with $i$ as the delivery point and $j$ as the point of receipt;

$t_{ij}^r$: Time of arrival at the delivery point for task $w$ with $i$ as the delivery point and $j$ as the point of receipt;

$t_{LD}$: Duration of sea transportation from the port of departure $L$ to the port of destination $D$;

$t_{ij}$: Duration of travel from the port of destination $D$ to the point of receipt $j$;

$t_{ij}$: Duration of travel from the delivery point $i$ to the port of departure $L$;

$\dot{\theta}$: Cost of penalty per unit time;

$P(t_{ij}^a)$: Time cost penalty function of the delivery point for moving up or delaying schedule;

$P(t_{ij}^f)$: Time cost penalty function of the receipt point for moving up or delaying schedule;

$B$ : Set of lines from the port of departure $L$ to the port of destination $D$, $b \in B = \{1, 2, \ldots, B\}$

$H_{ijb}$ : $H_{ijb} = 1$ means that the delivery point is set at $i$ and the receipt point is set at $j$, with line $b$ arranged for the task, or $H_{ijb} = 0$;

$t_{ij}$: the point of time at which the delivery point is set at $i$ and the receipt point is set at $j$, with line $b$ arranged for the task;

Objective function:

$$Z = \min \left( \sum_{a} \sum_{i=1}^{I} \left( C_{ai} d_{ai} X_{ai} + C_{ai} d_{ai} Y_{ai} \right) + \sum_{i=1}^{I} C_{ai} Y_{ai} \right)$$

Constraints:

$$\sum_{i=1}^{I} X_{ai} + \sum_{i=1}^{I} Y_{ai} = I$$

$$\sum_{b=1}^{B} b H_{ijb} = B$$

$$t_{ij}^a = t_{ij}^f + t_{LD} + t_{ij}$$

$$t_{ij}^f = \begin{cases} t_{ij}^a + t_{ai}, & X_{ai} = 1, Y_{ai} = 0 \\ t_{ij}^a + t_{ai} + t_{ij}, & X_{ai} = 0, Y_{ai} = 1 \end{cases}$$

$$P(t_{ij}^a) = \begin{cases} 0, & p_i \leq t_{ij}^a \leq q_i \\ \dot{\theta}, & p_i - 1 \leq t_{ij}^a < p_i; q_i < t_{ij}^a \leq q_i + 1 \\ 2\dot{\theta}, & p_i - 2 \leq t_{ij}^a < p_i - 1; q_i + 1 < t_{ij}^a \leq q_i + 2 \\ M, & t_{ij}^a < p_i - 2; t_{ij}^a > q_i + 2 \end{cases}$$

$$P(t_{ij}^f) = \begin{cases} 0, & m_j \leq t_{ij}^f \leq m_j + n_j \\ \dot{\theta}, & m_j - 1 \leq t_{ij}^f < m_j; n_j < t_{ij}^f \leq n_j + 1 \\ 2\dot{\theta}, & m_j - 2 \leq t_{ij}^f < m_j - 1; n_j + 1 < t_{ij}^f \leq n_j + 2 \\ M, & t_{ij}^f < m_j - 2; t_{ij}^f > n_j + 2 \end{cases}$$

In the equations, the total number of trailers at each delivery point equals the total number of delivery points; each task is delivered by one corresponding liner; the timetable at the receipt point is based on the liner, duration of sea transportation, port of departure and port of destination; the presence of trailers at the delivery point means the time of delivery is the sum of departure at the drop and pull...
transportation center and the time duration from the center to the delivery point; the absence of trailers at the delivery point means that the time of delivery is based on the departure at the drop and pull transportation center, the time duration from the center to the delivery point, and the loading duration.

4. ALGORITHM DESIGN

4.1. Principles behind the algorithm design
This paper aims at minimizing the cost by optimizing the route of goods delivery by the tractor while ensuring the time window at the delivery and receipt points as well as task-fulfilling. Based on the model established by this paper, the problem is categorized as N-P, which means it is not likely to obtain the global optimal solution via common approaches. Simulated annealing algorithm, as an effective solution to N-P problems, can be used to solve different nonlinear problems and optimize nondifferentiable or even discontinuous functions, thus making it possible to obtain global optimal solutions[10]. To be specific, the algorithm design should firstly determine how to code the solution and obtain the initial solution by heuristic algorithm before getting a new solution via neighborhood exchange and the optimal solution corresponding to the minimum value of the objective function by simulated annealing algorithm.

4.2. Design simulated annealing algorithm

Generation of initial solution:
1. Number all the tasks \( w, w \in W = \{1, 2, \ldots, W\} \);
2. Rank the time windows of tasks from morning till night in time sequence, and rank the liners’ departure time \( b \) from morning till night in time sequence;
3. Distribute tasks \( w \) to the drop and pull transportation center \( a \);
4. Determine if the factors including the departure time at the drop and pull transportation center \( t_{ij} \), the time duration \( t_{ai} \) from the drop and pull transportation center \( a \) to the delivery point \( i \), and \( t_{ij} \) the sum duration of loading\( t_0 \) are consistent with the time window \([p, q]\) of tasks \( w \) at the delivery point \( i \);
5. If Condition 3 is satisfied, add the time duration \( t_{ai} \) of task \( w \) from the delivery point \( i \) to the port of departure \( L \) into \( t_{ij} \) to determine if it is less than or equal to the departure time \( t_{ijb} \) of liner \( b \). If Condition 3 is not satisfied, then \( a = a + 1 \), and return to Condition 3;
6. If Condition 4 is satisfied, add the time duration \( t_{LD} \) of task \( w \) from the port of departure \( L \) to the port of destination \( D \) and the time duration \( t_{Dj} \) from the port of destination \( D \) to the receipt point \( j \) into \( t_{ijb} \) to determine if it is consistent with the time window \([m, n]\) of receipt point \( j \). If Condition 4 is not satisfied, then \( b = b + 1 \), and return to Condition 4;
7. If Condition 5 is satisfied, then determine if task \( w \) is a null set. If Condition 5 is not satisfied, then \( w = w + 1 \), and return to Condition 3.
8. If Condition 6 is not satisfied and \( w \) is a null set, then it is terminated.

Simulated annealing algorithm:
1. Set the initial temperature \( T = T_0 \), and adjust it based on the cooling function \( T = \beta T \), \( \beta \) is the number between \((0,1)\).
2. Calculate the objective function \( f(x_i) \) of the initial solution \( x_i \), the objective function \( f(x_2) \) of the new feasible solution \( x_2 \), and \( \Delta = f(x_2) - f(x_i) \).
3. If \( \Delta \leq 0 \), then the new solution is acceptable. Replace \( x_i \) with \( x_j \), namely \( x_i = x_j \). If \( \Delta > 0 \) and 
\[
\exp\left(-\frac{df}{T}\right) > \text{rand} ,
\]
with \( \text{rand} \) being a random number evenly distributed in the interval of \((0,1)\), then the new solution is also deemed as acceptable. Replace \( x_i \) with \( x_j \), namely \( x_i = x_j \); otherwise keep the current solution of \( x_i \).

4. When the temperature \( T \) is less than the predetermined temperature, the iteration is terminated, and the current solution is the optimal solution; otherwise the iteration will continue.

5. CASE STUDIES

5.1. Data and parameters

It is known that the Ro-Ro routes in Bohai Sea include Yantai-Lvshun, Penglai-Lvshun, Dongying-Lvshun and Weihai-Dalian. The liners operate at a speed of about 16-18 nautical miles/hour, where the median value is 17 nautical miles/hour. The whole hour or half hour is taken when calculating the voyage time. Parameters of each route are shown in Table 1 and Table 2.

| Sailing                        | Voyage (times/day) | Voyage (n mile) | Voyage time (hour) | Trailer toll fee (yuan/vehicle) |
|-------------------------------|-------------------|-----------------|-------------------|--------------------------------|
| Dongying→Lushun               | 2                 | 122             | 7.5               | 1370                           |
| Penglai→Lushun                | 2                 | 65              | 4                 | 730                            |
| Yantai→Lushun                 | 3                 | 86              | 5                 | 100                            |
| Weihai→Dalian                 | 2                 | 93              | 5.5               | 1040                           |

Table 2. Liner Schedule and Maximum Trailer Load

| Sailing                       | Ship number | Sailing time | Arrival time | Maximum number of trailers |
|-------------------------------|-------------|--------------|--------------|----------------------------|
| Dongying→Lushun               | 1           | 10:30        | 18:00        | 144                         |
|                               | 2           | 20:00        | 3:30         | 97                          |
| Penglai→Lushun                | 1           | 14:30        | 18:30        | 124                         |
|                               | 2           | 22:30        | 2:30         | 127                         |
| Yantai→Lushun                 | 1           | 5:10         | 10:10        | 156                         |
|                               | 2           | 14:10        | 18:10        | 156                         |
|                               | 3           | 22:10        | 3:10         | 156                         |
| Weihai→Dalian                 | 1           | 21:30        | 3:00         | 101                         |
|                               | 2           | 10:30        | 4:00         | 130                         |

Take a drop and pull transportation company as an example. There is a total of 32 transportation tasks, that is, \( A=32 \), and the number of tasks at each customer point is a random integer between 1 and 10. The information of the receipt point, delivery point and task load are shown in Table 3.

| Shipping point | Receiving point | Task volume | Task number |
|----------------|-----------------|-------------|-------------|
| Shandong       | Shenyang        | 6           | 1-6         |
| Jinan          | Dandong         | 7           | 7-13        |
| Tai’an         | Anshan          | 9           | 14-22       |
| Handan         | Fushun          | 3           | 23-25       |
| Shijiazhuang   | Jinzhou         | 5           | 26-30       |
| Beijing        | Liaoayang       | 2           | 31-32       |
The full-load fuel consumption of tractors transported between cities is generally 35-45 liters/100 kilometers, which depends on the driver's experience and type of vehicle. The median value of 40 liters/100 kilometers is adopted in the paper to derive the value of $C_{ij}^{1}$, $C_{ij}^{2}$. The tractor runs at 80km/h, and the distance between places and the running duration of tractor is shown in Table 4, with $M$ representing a larger value. The time window corresponding to each task is shown in Table 5, which is preset at 48 hours and counted between 0-48 hours. The acceptable time window for each task is the required time window plus or minus 4 hours.

Table 4.  Road Distance between Customer Points and Running Duration of the Tractor (kilometers/hour)

| City       | Yantai | Weihai | Penglai | Dongying | Dalian | Lushun |
|------------|--------|--------|---------|----------|--------|--------|
| Qingdao    | 230/2.9| 272/3.4| 277/3.5 | 275/3.4 | M/M    | M/M    |
| Jinan      | 454/5.7| 515/6.4| 412/5.1 | 224/2.8 | M/M    | M/M    |
| Taian      | 523/6.5| 584/7.3| 463/5.8 | 275/3.4 | M/M    | M/M    |
| Handan     | 691/8.6| 752/9.4| 648/8.1 | 460/5.8 | M/M    | M/M    |
| Shijiazhuang| 738/9.2| 799/10.0| 696/8.7 | 445/5.6 | M/M    | M/M    |
| Beijing    | 746/9.3| 807/10.1| 682/8.5 | 407/5.1 | M/M    | M/M    |
| Shenyang   | M/M   | M/M   | M/M   | M/M    | 391/4.9| 425/5.3|
| Dandong    | M/M   | M/M   | M/M   | M/M    | 307/3.8| 340/4.3|
| Anshan     | M/M   | M/M   | M/M   | M/M    | 300/3.8| 334/4.2|
| Fushun     | M/M   | M/M   | M/M   | M/M    | 445/5.6| 478/6.0|
| Jinzhou    | M/M   | M/M   | M/M   | M/M    | 379/4.7| 413/5.2|
| Liaoyang   | M/M   | M/M   | M/M   | M/M    | 326/4.1| 360/4.5|

Table 5.  Time Window of Each Task (hours)

| Task number | Request delivery time window | Accept delivery time window | Request time window | Time window for receiving goods |
|-------------|-------------------------------|-----------------------------|---------------------|---------------------------------|
| 1-2         | [7,8]                         | [3,12]                      | [22,23]                     | [18,27]                         |
| 3           | [9,10]                        | [5,14]                      | [21,22]                     | [17,26]                         |
| 4-6         | [18,19]                       | [14,23]                     | [33,34]                     | [29,38]                         |
| 7-8         | [16,17]                       | [12,21]                     | [28,29]                     | [24,33]                         |
| 9-10        | [17,18]                       | [13,22]                     | [32,33]                     | [28,37]                         |
| 11          | [6,7]                         | [2,11]                      | [24,25]                     | [20,29]                         |
| 12-13       | [4,5]                         | [0,9]                       | [21,22]                     | [17,26]                         |
| 14-16       | [4,5]                         | [0,9]                       | [18,19]                     | [14,23]                         |
| 17-18       | [5,6]                         | [1,10]                      | [21,22]                     | [17,26]                         |
| 19-21       | [17,18]                       | [13,22]                     | [33,34]                     | [29,38]                         |
| 22          | [9,10]                        | [5,14]                      | [29,30]                     | [25,34]                         |
| 23-25       | [10,11]                       | [6,15]                      | [32,33]                     | [28,37]                         |
| 26-29       | [14,15]                       | [10,14]                     | [35,36]                     | [31,40]                         |
| 30          | [12,13]                       | [8,17]                      | [31,32]                     | [27,36]                         |
| 31-32       | [13,14]                       | [9,18]                      | [30,31]                     | [26,35]                         |
5.2. Solution algorithm
The simulated annealing algorithm and python programming are adopted, and the core content of the programming code is shown in Figure 2. Iterate the case freight route, and the result is shown in Figure 3.

![Figure 2. Core Content of Simulated Annealing Algorithm](image)

![Figure 3. Iterative Results of Simulated Annealing Algorithm](image)

The transportation route of each trailer is shown in Table 6. According to the iterative results, the optimal value tends to stabilize after nearly 380 iterations. The time cost should be considered as important the transportation cost, which is set at $\omega_1 = 0.5$ and $\omega_2 = 0.5$ in the objective function. The transportation cost is calculated at $\sum C = 121579$ and time cost $\sum Y(T) = 12800$, based on which the objective function is given by:

$$
\min Z = \omega_1 \sum C + \omega_2 \sum Y(T) = 0.5 \times 101579 + 0.5 \times 12080 = 56830
$$

| Task number | Shipping point | Shift | Receiving point |
|-------------|----------------|-------|-----------------|
| 1-2         | Qingdao        | Weihai - Dalian 10:30 | Shenyang |
| 3           |                | Weihai - Dalian 10:30  |      |
6. CONCLUSION

The land-sea combined Ro-Ro multimodal transportation will become an efficient solution to energy conservation and emission reduction under rational cargo organization as well as dispatching and management of vehicle and vessel. This paper takes several routes operated in Bohai Sea as an example to establish the scheduling and dispatching model of Ro-Ro multimodal drop and pull transportation, and used the simulated annealing algorithm to solve the model. The dispatching of vehicles in land-sea combined Ro-Ro drop and pull transportation is related to multiple enterprises in the industries of land transportation, port, sea transportation.

Factors like maritime environment would even further complicate the NP problem of vehicle dispatching. Different targets and application environments are confronted with different scheduling problems, which need to be analyzed based on the specific scheduling tasks. For transportation enterprises and ports, efficient dispatching can effectively reduce transportation costs and increase profits. At the social and national level, it can also reduce pollution caused by transportation and promote energy conservation and emission reduction while promoting the development of multimodal transport in China.

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