Time-window-based Scheduling Strategy and Optimization for Maximizing the Income of Drop and Pull Transport

Linlong Xu1,*, Zheyong Qiu2, Zibo Kang1, Xiaojuan Ma3, Huilin Xiong3 and Lei Yang3

1Zhuoyue Honors College, Hangzhou Dianzi University, Hangzhou Zhejiang 310018, China
2School of Science, Hangzhou Dianzi University, Hangzhou Zhejiang 310018, China
3School of Computer Science and Technology, Hangzhou Dianzi University, Hangzhou Zhejiang 310018, China

*Corresponding author

Abstract. As an intensive and efficient way of transportation, drop and pull transport has become the mainstream transportation organization of foreign developed countries and regions. Based on the freight demand vector and aging of a given initial state, this paper established a goal planning and scheduling model based on the maximization of time window revenue to get the most efficient deployment plan under the condition of high customer satisfaction. The genetic algorithm based on task urgency was used to solve this model to obtain the optimal allocation scheme of total income. Finally, the number of algorithm iterations was analyzed, which proved the effectiveness of the algorithm performance. Through the sensitivity analysis of the number of tractors, this paper gave suggestions for more efficient tractor configuration.

Keywords: Drop and pull transport; Goal planning; Genetic algorithm; Sensitivity analysis.

1. Introduction

Drop and pull transport refers to the way in which the tractor transports the trailer to its destination and then tows other trailers full of goods to return to the original place or to a new location. It is a concentrated expression of standardization, networking and scale of the road freight industry, which is characterized by intensive and efficient[1]. In recent years, it has become the mainstream transportation organization of foreign developed countries and regions[2]. China started relatively late because the Ministry of Transport issued the "Notice on Promoting the Development of Suspended Transportation" until 2009[3]. After that, drop and pull transport was only highly valued. However, this transportation still exhibits the characteristics of “small, scattered and weak”, which are mainly characterized by low level of hang-up operation, immature operation mode and uneven regional development in China[4]. Consequently, it is of great practical value and significance to research the core issue of this transportation, namely the vehicle scheduling problem.

In recent years, in the optimization of transportation scheduling, a large number of scholars at home and abroad have combined in-depth research with different mathematical algorithms. Chao I M[5] established the truck and trailer routing optimization model earlier and used the tabu search to solve. Caris A[6] proposed the optimization problem of the transportation scheduling with time window constraints, and designed the corresponding two-stage heuristic algorithm to solve the problem. Li H[7] proposed the problem of the transportation route planning between the trailer and the semi-trailer, and solved it by a two-stage genetic algorithm based on simulated annealing algorithm. Imai[8] and
Gendreau[9] proposed a heuristic algorithm based on Lagrangian relaxation and a tabu search algorithm, which is to study the joint scheduling optimization problem of loading and unloading operations and container trucks. Zhang G[10] solved the truck and trailer routing problem with flexible tasks by dividing the day into five decision periods and designing a two-stage approximation optimization algorithm. Seyedmehdi[11] added stochastic demand and time windows to traditional TTRP, and introduced meme-heuristic algorithm for multi-crossing, mutation and local search.

Although the above papers have carried out different research on the problem of drop and pull transport, most of them only solve this problem in theory. The actual business operation time, high traffic rate, low order completion rate, customer order response time requirements, add new operating points and other practical issues are not considered in them. Therefore, based on the previous researches, this paper studies the dynamic scheduling problem of actual freight companies in the transportation.

2. Problem Description and Modeling

The problem of the transportation scheduling strategy studied in this paper is realized by dynamic scheduling method, taking into account the number of tractors, cost limit, order cancellation, order response time, order arrival time parameters, head change rate, empty rate and completion rate as evaluation standards. Given the initial state and the day-to-day freight demand vector and aging, this paper assigns a blending scheme to the task based on its initial state for a single-purpose provisioning task. The overall transportation plan consists of a number of individual deployment tasks. Through the genetic algorithm to find the task allocation order that makes the total return optimal, which can get the best overall distribution plan.

Based on the above description, the following assumptions are given:

- Regardless of the state, the tractor always runs at the same speed, and the cost calculation coefficient remains the same.
- The tractor will run at most one trailer at a time.
- The picking/tapping time of the tractor at all visited customer points is consistent and determined.
- The specifications of the carriage and the tractor are the same and match.
- All transportation tasks are based on container FCL as a unit.
- If there is a spare trailer in a certain place, the goods are already installed when the front of the tractor arrives, and the front of the tractor does not have to wait for the loading time.

Suppose there are S cities in the transportation network G. Hi is known to indicate the number of trailers in the i-th city. Si is the number of tasks in the city S. Qi is the single benefit of the i-th task. M represents the sum of the tasks in all cities. C1 represents the fixed cost of a tractor for one day. C2 represents the fixed cost of a trailer for one day. C3 represents the driving cost coefficient of tractor. C4 represents the driving cost coefficient of trailer. d represents the distance between the task node i and task node j. tmf represents the end time of the task m. tms represents the start time of the task m. tmn represents the duration of the task m. tms represents the total time of the transportation plan [hours], from the first task to the end of the last task. lb represents the loading time, for the non-empty tractor problem is specified as 0.5 hours. ub represents the unloading time, for the non-empty tractor problem is specified as 0.4 hours. [ETi, LTi] represents the time window required by task i. tk, n, s represents the start time of the nth transport task of the tractor k. tk, n, f represents the end of the nth transport task of the tractor k. Introduce the decision variables as:

\[ x_{skij} = \begin{cases} 1, & \text{Tractor } k \text{ towed out from center } S \text{ is dragged from task node } i \text{ to } j \\ 0, & \text{otherwise} \end{cases} \]

\[ y_{ik} = \begin{cases} 1, & \text{Tractor } k \text{ hangs the heavy trailer at the task node } i \\ 0, & \text{Tractor } k \text{ does not hang the heavy trailer at the task node } i \end{cases} \]

Therefore, the mathematical model of the problem can be described as:
\[
\begin{align*}
\max\{\sum_{j=1}^{M} j \cdot Q_j - & \left[ \sum_{i=0}^{S} (K_i \cdot C_1 \cdot \frac{t_{i,all}}{24} + H_i \cdot C_3 \cdot \frac{t_{i,all}}{24}) + \sum_{s=1}^{S} \sum_{k=1}^{K} \sum_{j=0}^{S_m} (d_{ij} \cdot x_{skij} \cdot C_2 + d_{ij} \cdot y_{skij} \cdot C_4) \right. \\
& \left. + \sum_{j=1}^{S_n} x_{0jk} + \sum_{j=1}^{S_n} y_{0jk} = 1, \right. \\
& t_{mf} = t_{ms} + t_m + t_a + t_b, \\
& t_{k, n+1, s} \geq t_{j, n, f}, \\
& ET_i \leq t_{mf} \leq LT_i, \\
& x_{skij} \cdot y_{lk} = 1 \text{ or } 0. 
\end{align*}
\] (1)

s.t.
\[
\begin{align*}
\sum_{s=1}^{S} \sum_{k=1}^{K} \sum_{j=0}^{S_m} x_{skij} & \leq K_i, \\
\sum_{j=1}^{S_n} x_{0jk} + \sum_{j=1}^{S_n} y_{0jk} & = 1, \\
t_{mf} & = t_{ms} + t_m + t_a + t_b, \\
t_{k, n+1, s} & \geq t_{j, n, f}, \\
ET_i & \leq t_{mf} \leq LT_i, \\
x_{skij} \cdot y_{lk} & = 1 \text{ or } 0. 
\end{align*}
\] (2-7)

In the model, formula (1) represents the objective function, which means profit maximization. The first half represents the income, and the second half represents the cost, which includes the fixed cost and the variable cost. Formula (2) stipulates the number of tractors from the city i no more than the current total number of tractors in the city i. Formula (3) stipulates the tractor that is driven from the city may be a heavy trailer to complete its own transportation task, or an empty trailer. Formula (4) stipulates the end time of a task is the sum of the start time and duration of the task. Formula (5) stipulates the tractor k should start the next task after completing a task. Formula (6) stipulates the service time that the tractor must arrive at the station within the window. Formula (7) is the decision variable.

3. Genetic Algorithm Based on Task Urgency

3.1. Algorithm Overview

The genetic algorithm can give an approximate optimal solution within the constraints of the optimization problem. In this paper, the order sequence is used as a gene. First, calculate the linear weighted sum of the two task time windows of the earliest order receiving time and the latest arrival time, and sort from small to large, then change the weight to get multiple initial solutions. Second, multi-generational inheritance is carried out, and the parent is given a new order by cross-mutation operation, and together with the parent individual. After that, a new population is formed. For each permutation, a feasible arrangement is generated, and the parameters such as the head change rate, the empty trailer rate, and the completion rate are calculated. Then an index is obtained from the three parameters, and finally the excellent individual is selected as the next genetic father. Among them, the specific order arrangement mainly includes two types of local front and shunting from different places. By querying the number of tractors in each city at each time point, scheduling is performed to meet the sufficient requirements of the time window and the front of the vehicle. And the number of tractors in each city at a future time point is updated when arrangement is recorded at the same time.

3.2. Generate Initial Population

Considering the large amount of tasks and the order of tasks, in order to make the genetic algorithm more efficient, this paper establishes a time window based urgency evaluation mechanism to assist in generating a relatively good population in the initial population generation.

- Consider the aging requirements. After the customer's aging requirements \([ET, LT]\), we should prioritize the tasks with earlier aging requirements when determining the task deployment order, so as to meet the requirements of more customers and make more benefits. That is, the task deployment order should be subject to the \(ET\) from small to large.
Consider the length of the task. For some tasks with very long completion time, in order to reduce the fixed cost of the vehicle, shorten the total task completion time, and ensure the parallel execution of multiple short-time tasks and long-term tasks, we should also consider it first. That is, the task deployment order should obey the task completion time \( t_m \) from large to small. Based on the above two factors, we give the definition of urgency \( e_i \) as follows:

\[
\frac{1}{e_i} = \alpha \cdot ET_i + (1 - \alpha) \cdot t_m
\]  

(8)

The urgency coefficient \( \alpha \) represents the influence weight of two factors, \( \alpha \in [0,1] \). After determining \( \alpha \), all task urgency can be sorted to get a task-provisioning sequence as an initial population. Since \( \alpha \) will have a significant impact on the task completion order, we can't assign values randomly. Hence, we take \( \alpha \) from 0 to 1 by 0.1, that is, initially generate 100 populations according to different urgency coefficients.

4. Project Select and Rejection Feedback

4.1. Cost-based Project Rejection

Before task assignment, we select some tasks that are less profitable than cost to remove them, so as to ensure no loss. Define the unit income \( A_i \) for task \( i \) as:

\[
A_i = \frac{Q_i}{d_i}
\]  

(9)

Regardless of the fixed cost, \( A_i \) is compared with the variable total cost \( C_{v2} + C_{v4} \) of the tractor and trailer. If the unit income is lower than the unit cost, the task is rejected and the customer is promptly answered.

4.2. Item Rejection Based on Time Window

The customer has given the required timeliness \([ET_i, LT_i]\). This paper evaluates the customer's timeliness requirements in the case of known in-transit aging and loading and unloading time of the existing route. If the customer's timeliness cannot be met, it will be rejected in time to ensure the tasks that are taken over will arrive on time and achieve good customer satisfaction.

5. Algorithm Steps

The genetic algorithm has little dependence on the solution problem. The Darwin evolution mechanism is used to reflect the complex situation. The requirements of models are simple, robust and easy to implement. Especially for large complex nonlinear function models, genetic algorithms have advantages over other traditional methods. It can generally find multiple sets of satisfactory solutions, and the solution with the largest total income is the best solution.

![Algorithm flowchart](image)

**Figure 1.** Algorithm flowchart.

The basic steps of the algorithm are:

Step 1. Generate initial population based on a time window based urgency evaluation mechanism;

Step 2. Calculate the fitness of each population by using the transportation cost in the line as the fitness evaluation index;

Step 3. According to the fitness, the individuals with high fitness are selected. The individuals with low fitness are selected, and the individuals with low fitness are eliminated.

Step 4. Generate a new individual according to the 2-point crossover operator;

Step 5. Generate a new individual according to the mutation operator with a mutation probability of 10% and the variation method of segmentation replacement.
Step 6. Generate a new generation of populations from crossovers and mutations, then return to step 2. And iterate over and generate the optimal solution.

6. Solution Results and Analysis

6.1. Solution Results
In order to facilitate the subsequent description, the city is numbered as follows. According to the initial number of fronts and the number of tractors, it is found that most of the moving tractors are almost unused and are in an idle state. And too many idle vehicles will result in excessive fixed costs and losses. Therefore, this paper proposes to reduce vehicle idle or multiple tasks. In this model, to reduce vehicle idleness, for example, 0 to 4 tractors are randomly generated for use in each city. And a sensitivity test will be performed later to find the best vehicle configuration.

| City Number | Tractors | Trailers | Improved Tractors | City Number | Tractors | Trailers | Improved Tractors | City Number | Tractors | Trailers | Improved Tractors | City Number | Tractors | Trailers | Improved Tractors |
|-------------|----------|----------|-------------------|-------------|----------|----------|-------------------|-------------|----------|----------|-------------------|-------------|----------|----------|-------------------|
| 1           | 2        | 3        | 1                 | 4           | 2        | 3        | 1                 | 5           | 2        | 1        | 4                 | 6           | 2        | 1        | 4                 |
| 2           | 0        | 0        | 1                 | 3           | 2        | 3        | 1                 | 6           | 2        | 2        | 3                 | 7           | 2        | 2        | 3                 |
| 3           | 56        | 98       | 4                 | 2           | 3        | 1                 | 7           | 2        | 2        | 3                 | 8           | 2        | 2        | 3                 |
| 4           | 0        | 0        | 1                 | 3           | 2        | 3        | 1                 | 8           | 2        | 2        | 3                 | 9           | 2        | 2        | 3                 |
| 5           | 28        | 48       | 1                 | 3           | 2        | 3        | 1                 | 9           | 2        | 2        | 3                 | 10          | 2        | 2        | 3                 |
| 6           | 2         | 4        | 2                 | 3           | 2        | 3        | 1                 | 11          | 2        | 2        | 3                 | 11          | 2        | 2        | 3                 |
| 7           | 0         | 0        | 1                 | 3           | 2        | 3        | 1                 | 12          | 2        | 2        | 3                 | 12          | 2        | 2        | 3                 |
| 8           | 0         | 0        | 1                 | 3           | 2        | 3        | 1                 | 13          | 2        | 2        | 3                 | 13          | 2        | 2        | 3                 |
| 9           | 4         | 7        | 3                 | 3           | 2        | 3        | 1                 | 14          | 2        | 2        | 3                 | 14          | 2        | 2        | 3                 |
| 10          | 2         | 4        | 2                 | 3           | 2        | 3        | 1                 | 15          | 2        | 2        | 3                 | 15          | 2        | 2        | 3                 |
| 11          | 0         | 0        | 1                 | 3           | 2        | 3        | 1                 | 16          | 2        | 2        | 3                 | 16          | 2        | 2        | 3                 |
| 12          | 11        | 18       | 2                 | 3           | 2        | 3        | 1                 | 17          | 2        | 2        | 3                 | 17          | 2        | 2        | 3                 |
| 13          | 13        | 18       | 2                 | 3           | 2        | 3        | 1                 | 18          | 2        | 2        | 3                 | 18          | 2        | 2        | 3                 |
| 14          | 2         | 4        | 2                 | 3           | 2        | 3        | 1                 | 19          | 6        | 10       | 2                 | 19          | 6        | 10       | 2                 |
| 15          | 0         | 0        | 1                 | 3           | 2        | 3        | 1                 | 20          | 13       | 23       | 2                 | 20          | 13       | 23       | 2                 |
| 16          | 4         | 7        | 2                 | 3           | 2        | 3        | 1                 | 21          | 0        | 0        | 1                 | 21          | 0        | 0        | 1                 |
| 17          | 6         | 10       | 2                 | 3           | 2        | 3        | 1                 | 22          | 0        | 0        | 1                 | 22          | 0        | 0        | 1                 |
| 18          | 8         | 12       | 2                 | 3           | 2        | 3        | 1                 | 23          | 0        | 0        | 1                 | 23          | 0        | 0        | 1                 |
| **Total**   | **425**   | **723**  | **89**            |              |          |          |                 |              |          |          | **85**           |              |          |          |                  |

Based on the above improvements, the first day after the iteration is as follows:

| Original total income[yuan] | Improved total income[yuan] |
|-----------------------------|-----------------------------|
| 63537.21                    | 151760.47                   |

6.2. Algorithm Performance Analysis
The convergence of the algorithm can be analyzed from the running time and the calculation accuracy. According to the principle ‘The more iterations, the longer the algorithm runs and the higher the precision. However, after the number of iterations reaches a certain scale, the precision is the monotonic decreasing function of the iteration number, and the running time is the monotonically increasing function of the iteration number’, combined with the figure 2 of the change in the number of iterations over the first day:
Figure 2. The first day's income varies with the number of iterations.

Figure 3. Sensitivity analysis.

It can be seen that with the increase of genetic algebra, the optimal individual fitness decreases rapidly and gradually stabilizes. It means that the algorithm has great convergence. In addition, as long as the population size and genetic algebra are appropriate, the genetic algorithm of this paper can always obtain an approximate optimal solution, which indicates that the algorithm is effective and feasible.

6.3. Sensitivity Analysis on Tractor Configuration

In order to analyze the impact of each tractor, it is assumed that the number of tractors in each place increases by different proportions and the range of tractors [0, 2] is changed to [0, 3], [0, 4], [0, 5], when other parameters are unchanged. Then four examples are constructed. The calculation results are shown in the figure 3.

It can be seen that as the number of tractors increases, the peak is reached at [0, 3] and then decreased. It can be seen that an appropriate increase in the number of tractors is more beneficial to the total income, but it cannot be increased too much.

7. Summary

Based on the known freight demand and time-dependent demand, this paper establishes a time window-based income maximization trailer scheduling model, which strives to obtain the most effective deployment plan under the condition of high customer satisfaction. Both the screening and rejection of the actual project are considered, as well as the overall transportation plan. In this paper, a genetic algorithm based on task urgency is used to iteratively obtain the optimal allocation scheme of total income. And the analysis of genetic algebras for many times proves the reliability and rationality of the algorithm. At the same time, through the sensitivity analysis of the number of tractors, this paper gives the recommendations for the number of tractors and arrangements with larger income. However, this paper does not consider the punitive measures under the circumstances of delays, etc. Consequently, the follow-up work can continue to conduct in-depth research from this aspect.
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