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Scheduling Optimization Model for Highway Port Network Tractor and Semitrailer Dispatching Considering Time Window under Unbalanced Demand

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Abstract:

Tractor and semitrailer transportation, as a common organization form of cargo transport, is an effective way to improve road transport efficiency and reduce transport costs. At present, highway port has become an important place for China to carry out tractor and semitrailer transportation. Highway port is not only a site for tractor and semitrailer transportation operations, but also a customer demand point and a trailer pool, so each node in the highway port drop and pull network can be the starting or ending point of tractor and semitrailer transport (depot). Based on the pure network tractor and semitrailer dispatching mode of highway ports, considering that there is unbalanced demand at both operation ends in the tractor and semitrailer transport and there may be multiple tractor and semitrailer demands, this paper aims to achieve the lowest network transport cost and minimum number of tractors. Giving consideration to time window constraints, it establishes a pure network tractor and semitrailer scheduling optimization model, designs an ant colony algorithm and introduces a local search strategy to solve the model. Effectiveness of the model is verified by an example. The research results show that compared with the traditional model, the number of pure network tractor and semitrailer tractors is reduced by 83.5%, the cost is saved by 19.1%, and the tractor and semitrailer ratio is 1:6.06. That is, the use of pure network scheduling optimization will result in better operational performance, thereby reducing costs and increasing profits. The research results provide a certain reference for the pure network tractor and semitrailer vehicle scheduling optimization with balanced demand and multiple demands

***Keywords**: Tractor and semitrailer transportation, Highway port, Scheduling optimization, Unbalanced demand, Pure network tractor and semitrailer, Time window.*

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I. INTRODUCTION

Under the new trend of tractor and semitrailer and large-scale road transport vehicles, tractor and semitrailer transport has become a new direction leading the development of the road transport industry. After years of development, China's tractor and semitrailer transport has made great progress, but compared with developed countries in Europe and the United States, China's tractor and semitrailer transport still exists in primary development stage with a low market share, backward organization and management, and unreasonable superior haul distances and tractor and semitrailer ratios. In 2020, the market size of domestic road freight industry is about 54.85 billion yuan, and the domestic tractor and semitrailer transport industry market size is 1.552 billion yuan, accounting for about 2.83%. In 2020, there were 11,715,400 trucks nationwide, of which 3,108,400 are tractors, 3,346,300 are trailers, and the drop-to-pull ratio is only 1:1.07. tractor and semitrailer transportation has been widely used abroad. According to incomplete statistics, as early as 2006, the ratio of tractors to trailers engaged in freight logistics in developed regions in Europe and the United States reached 1:3; in 2011, in Southeast Asia and other countries with small areas, the ratio of tractors to trailers has reached around 1:7. When it comes to the tractor and semitrailer ratio alone, there is a big difference between China and developed countries, which makes it difficult for tractor and semitrailer transport to give full play to its advantages. Secondly, there are still problems such as backward vehicle scheduling management methods.

At this stage, characteristics of the vehicle types in Chinese enterprises able to be used for tractor and semitrailer transport determine that intercity trunk line transport is the main application field of tractor and semitrailer transport mode. Academia generally believes that the dispatching problem of automobile and train is very complicated, which constitutes an NP problem. At the same time, it brings a huge challenge to the dispatching of tractor and semitrailer transport vehicles on the intercity trunk line.

In view of this, the researcher has conducted extensive research on the tractor + semi-trailer (TSRP) vehicle scheduling problem under the intercity trunk line transport network [1-3], but only assumes that the customer has a specific amount of demand, that is, the tractor and semitrailer vehicle can meet the requirements of goods distribution or garbage collection with only one customer visit. However, in the highway port tractor and semitrailer transport trunk network, tractor and semitrailer transport operations are carried out between highway ports, while highway port is not only a tractor and semitrailer operation site, but also a customer demand point. Different from the need in actual application of general tractor and semitrailer transportation, the demand for drop and pull in highway ports is based on trailers. The demand may be multiple trailers and the demand at both ends of the drop and pull may be unequal. That is, there are multiple tractor and semitrailer transportations between two highway ports with unbalanced demand at both ends of the tractor and semitrailer transport, which increases the complexity in optimizing the tractor and semitrailer transport scheduling. At the same time, based on the author's research on the tractor and semitrailer transportation mode of highway ports, it is believed that the tractor and semitrailer transportation mode suitable for highway ports is pure network tractor and semitrailer. Therefore, in view of the characteristics of pure network tractor and semitrailer transportation in highway ports, this paper considers the complex situation where customers in actual tractor and semitrailer transportation have multiple drop and pull needs and unbalanced demand at both ends of the drop and pull, and establishes a pure network tractor and semitrailer scheduling optimization model considering time windows. Through example calculation, it can provide a reference for the network tractor and semitrailer optimization in actual highway ports.

To this end, the author innovatively considers the network-wide tractor and semitrailer transport mode. Considering that there is unbalanced demand at both operation ends in the tractor and semitrailer transport and there may be multiple tractor and semitrailer demands, this paper aims to achieve the lowest network transport cost and minimum number of tractors. Giving consideration to time window constraints, it establishes a pure network tractor and semitrailer scheduling optimization model, designs a heuristic algorithm to solve the model. Effectiveness of the model is verified by the example of Tiandihui. The paper aims to solve the problem of multiple tractor and semitrailer demands and unbalanced vehicle scheduling at both ends, as well as the optimal tractor and semitrailer ratio problem in highway port pure tractor and semitrailer network considering the time window, and then provide a reference for the highway port tractor and semitrailer vehicle scheduling problem.

II. STATE OF THE ART

Tractor and semitrailer transportation scheduling is a vehicle routing problem (VRP), but because of trailer transport, it is more complicated than general vehicle scheduling problem. In many countries, a variety of vehicle trains (truck plus trailer, truck plus semi-trailer) are allowed to operate, as shown in Fig 1. However, in China, the existing policy restricts the form of tractor and semitrailer transport trains. Trucks with trailers are not allowed to run on Chinese roads, and only tractors and semi-trailers are allowed, as shown in Fig 2. The power part is not allowed to load. Therefore, the research and application of tractor and semitrailer vehicle transport in China is quite different from that in Europe and the United States.

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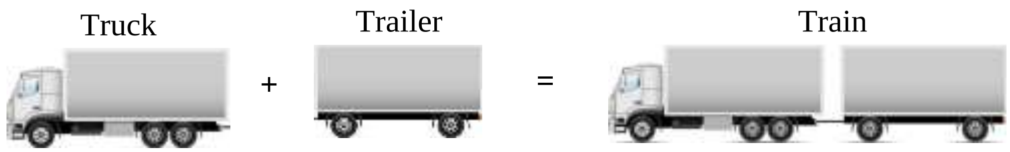

Fig 1: combination vehicle form A

Fig 2: combination vehicle form B

In practical applications, tractor and semitrailer transport is applied to many scenarios. For instance, Semit F first proposed in 1993 to apply tractor and semitrailer transport to the distribution of goods in grocery stores [4], but the time window constraints are not considered, and the designed algorithm also needs to be improved; L De Meulemeester et al. proposed the application of tractor and semitrailer transport to garbage collection and transport for the first time in 1997 [5]. A tractor and semitrailer transport company in Belgium was taken as a background, involving 160 customers. The designed algorithm can generate result within 1 minute, but only domestic and industrial enterprise users are considered, and the users considered have certain limitations. Mikhail et al. applied tractor and semitrailer transportation to warehouses goods distribution to multiple stores in 2014 [6]. Taking into account the problem of soft and hard time windows and the inconsistency of vehicle models, the designed algorithm has achieved relatively satisfactory results.

For the tractor and semitrailer transport scheduling problem, scholars have conducted extensive researches. In view of certain problems in the tractor and semitrailer transport, corresponding mathematical models are established, and heuristic algorithms are designed for solution to provide support for decision-making in tractor and semitrailer transport scheduling. Chao first proposed the Truck and Trailer Routiong Promblem (TTRP) in 2002, fully defined the problem, and designed a tabu search algorithm to effectively solve TTRP[7], but did not consider constraints such as number of vehicles, time window. Subsequently, for TTRP problem, some scholars considered whether there are constraints such as the number of vehicles and time windows, designed various heuristic algorithms based on Chao's research to improve the calculation efficiency and accuracy. In 2016, Isis perfected the TTRP model, introduced the user's ability and constraints of fuzzy requirements into the model, and obtained relatively good calculation results, but the model has room for continuous improvement [8]. Isis then further improved the TTRP model in 2017 and used data mining algorithms to derive a decision tree.

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The decision tree determined the best comparison method according to the characteristics of the TTRP problem to be solved [9], but none of Isis's two models consider the constraints of time windows. E. Bartolini built the CTTRP model, applied heuristic algorithms to solve the example calculations of 30 customers, and obtained relatively good calculation results [10]. However, he did not consider the time window constraints, and did not consider the free combination of trucks and trailers. Considering the constraints of the time window, Parragh et al. proposed the Branch-and-Price algorithm to solve the TTRPTW problem [11], but the proposed pricing scheme is relatively simple. Toffolo et al. also divided the customers into three categories: customers who can only be delivered by trucks, customers who can be delivered by both trucks and car trains, and customers who can only be delivered by car trains. A random partial search algorithm was designed to solve the proposed SB -VRP problem (similar to TTRP problem) [12], but its designed algorithm is complex, with a large number of neighborhoods, etc. which affect its application in other problems. Wang et al. developed an adaptive bat algorithm to solve the TTRP problem, and designed five domain search structures in the local search link. In addition, an adaptive adjustment strategy was desinged to preserve the diversity of particles. Finally, 21 benchmark problems were used to verify the effectiveness of the algorithm in terms of accuracy and efficiency [13], but the constraints of customer time window were not considered. Rotuenbaecher et al. [14] proposed two extended scenarios of the TTRP problem. Mirmohammadsadeghi [15] established a TTRP problem model with stochastic demand constraints, and used the Metetic algorithm to solve the problem. Regnier-Couder et al. [16] designed a simple structural solver that can solve real-time dynamic optimization problems, and evaluated the optimization degree of the scheduling plan prop.

The research of tractor and semi-trailer problem involves two situations: Rollon-rolloff Vehicle Routing Problem (RRVRP) and Tractor and Semi-trailer Routiong Promblem (TSRP). According to the research results of Li et al., the RRVRP problem is a evolution based on VRP style that uses a combination of tractors and semi-trailers, which is one of the three main garbage collection businesses. In the basic RRVRP problem, there is a single station. At the beginning of the day, all tractors are parked at the station, and there is a garbage disposal facility, so loaded trailers are sent here to dump garbage, and empty trailers can also be towed away from here. After the end of the day, all the tractors return to the station, and the trailers stay at the customer node or the garbage disposal facility [17]. Garbage truck has similar operation mode to combination vehicle of truck and semi-trailer. The power part and the cargo part of the garbage truck with detachable compartment respectively correspond to the tractor and semi trailer. Li et al. used the path decomposition algorithm to convert the path into arc requirements, and then proposed the vehicle flow planning model of RRVRP, developed an improved C-W saving algorithm with local search for solution [18], but did not consider the constraints of time window. Considering the practical problems of container transport, Li proposed Generalized RRVRP

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(G-RRVRP) [19], but it is not applicable to situations involving multiple warehouses and open routes. Xue et al. proposed that the result plan can only solve small-scale problems. For large-scale problems, the author developed a maximum and minimum ant colony optimization algorithm to reduce the calculation time. [20] The paper only considers that the empty container needs to be shipped back to the dock after the customer opens the package, but does not consider the issue of container sharing. In this way, it will improve the overall system efficiency, but it will also increase the model construction complexity.

The research on TSRP is mainly based on the research results of VRP and TTRP. In Li Hongqi's study, based on the cyclic tractor and semitrailer mode, all tractors are required to start from the yard and then return to the yard. A two-stage heuristic algorithm was designed. In the first stage, the initial solution is constructed with the driver driving time as the constraint. In the second stage, iterative calculation is performed for solution based on initial solution. The calculation results show that the designed algorithm is effective [21]. TSRP problem is studied from the perspective of how to reduce carbon emissions. Based on this, the intercity trunk line tractor and semitrailer transport with "many-to-many" transport needs is studied. The carbon dioxide emission per kilometer is used as the objective function, and the tractor is required to start from the yard and then return to the yard. Heuristic algorithm was proposed to solve the problem based on economy and neighborhood search [22]. Based on calculation examples, there are about 4 semi-trailers on each tractor route. The examples with better solving effect require greater number of semi-trailers. Immediately afterwards, for the road tractor dispatching involved in the tractor and semitrailer transport process of the intercity trunk line, by taking whole vehicle transport and "many-to-many" transport demand as the basic features, the tractors are also required to start from the yard and then return to the yard, thus constructing an integer programming model of the LTDP problem. Taking into account the continuous working time constraints of the driver and the tractor, with CO2 emissions of freight ton-kilometers as the objective function, tractor scheduling problem in the intercity trunk line transport was proposed, the main solution algorithm flow was desinged based on simulated annealing. Supplemented by optional post-processing operations for the main flow calculation results, the satisfactory solution was further improved. The algorithm was applied to solve practical examples. The calculation results show that the constructed integer programming model and its heuristic solution method are feasible and effective. The mainline tractor and semitrailer transport mode has good energy-saving and emission-reduction effects, and it is determined from a quantitative perspective that the ideal tractor route is a combination of several models with "one line, two points, drop and pull at both ends" [23]. Subsequently, Li Hongqi et al. studied the TSRP problem with time windows. Considering the many-to-many transport demand, heuristic algorithm was proposed for solution based on economy and neighborhood search [24]. Yu Li et al. studied the TSRP problem of multiple yards in the network mode and considered the

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scheduling of empty trailers, but it was assumed that the number of trailers at each service point remained unchanged, which led to limitations in network scheduling [25]. Yang Guangmin et al. established a container tractor and semitrailer transport scheduling model under a hub-and-spoke network structure, and designed a heuristic algorithm for solution [26, 27]. This solution idea can effectively increase the solving speed. The configuration of the number of trailers is derived through example calculation to guide the practice of enterprises. Yang Zhenhua et al. considered the tractor and semitrailer scheduling problem of tractors capable of towing multiple tonnage trailers, designed a hybrid simulated annealing algorithm for solution, and proposed that the cross-drop and pull of multiple vehicles has cost-saving advantages, but it is not suitable for joint optimization of multi-vehicle task allocation and scheduling based on freight volume [11]. Wen Yongrui et al. used the meta-heuristic algorithm to solve the port container tractor and semitrailer vehicle scheduling model, but the paper only considered the demand between the port and the operating point, and did not consider the demand between different operating points [28]. Hu Zhihua adopted the cyclic tractor and semitrailer mode, took the minimum total operating time as the objective function, and designed a two-stage optimization algorithm to solve the problem, which provided a reference for the tractor and semitrailer transport scheduling of the local logistics network [29]. Subsequently, Hu Zhihua adopted the one-point two-point, tractor and semitrailer mode at both ends to study the mutual drag between container terminals, and designed a two-stage optimization algorithm. A calculation example illustrates the effectiveness of the method [30].

In summary, a large number of current researches are mainly focused on the research of trucks and trailers. It is considered that trucks can continue to meet customer needs after dropping off the trailer, which is more flexible and can meet customer needs of multiple levels. Only a few studies have focused on tractors and semi-trailers in the network, mainly considering the "one-to-one" tractor and semitrailer transport demand. There are many studies on tractor and semitrailer mode based on the "one-line two-point, two-point tractor and semitrailer" and "hub-and-spoke network", which is quite different from the actual tractor and semitrailer transport in the highway port network. At present, in domestic research on tractor and semitrailer transport, most literature focuses on the mode of tractor and semitrailer transport and the dispatching of tractors. However, the research on trailer configuration is very limited. Through literature retrieval, only a few domestic documents have studied the configuration of trailers. The tractor and semitrailer ratio is an important indicator for the level of tractor and semitrailer transport operations. Through investigations, it is learned that companies such as Tiandihui engaged in tractor and semitrailer transport mainly calculate the drop-pull ratio of a customer according to the customer needs by considering the loading time, unloading time and transit time, etc. Calculation of tractor and semitrailer ratio only according to customer needs has a big drawback. That is, single customer has relatively great changes in needs, which will inevitably

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cause the problem of excessively big or small investment in trailers. Therefore, it is urgently needed to study the dispatch optimization and the theory of drop and pull ratio suitable for pure network tractor and semitrailer in view of the characteristics of highway port tractor and semitrailer transportation. Based on the characteristics of tractor and semitrailer transportation in China's highway ports, this paper considers the unbalanced demand at both ends of the tractor and semitrailer transportation, establishes a network drop and pull scheduling optimization model, designs a heuristic algorithm to solve the model and then provide reference for improving the efficiency of drop and pull scheduling in highway port network.

III. MODEL ESTABLISHMENT

3.1 Model Assumptions

According to the characteristics of tractor and semitrailer transportation in the highway port network, the following assumptions are made:

(1) All tractors and trailers in the network belong to standard models, and the models are consistent;

(2) There are enough trailers in each highway port in the network. This assumption can be achieved by the integration of social resources among highway port tractor and semitrailer transport companies;

(3) The tractor operation time in drop and pull is not considered, and the number of trailers is sufficient, so there is no need for the tractor to wait for the loading and unloading of the trailer;

(4) The distance and time of traveling back and forth between the two highway ports are the same;

(5) The demand for tractor and semitrailer is generated every day in the network, and there are fluctuations in daily demand. The enterprise can arrange scheduling according to the actual daily demand. Due to the long distance between some nodes, the tractor and semitrailer transportation may not be completed within one day. Hence, it is assumed that the drop and pull task not completed in the previous day does not affect the subsequent scheduling;

(6) There are no accidents delaying the road transport during the transport.

3.2 Symbol Description

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N : Represents the collection of all highway ports, $N = \{1, 2, \cdots, n\}$;

i, j, l : Indicates the number of the highway port, $i, j, l \in N$;

K : Represents the collection of tractors, $K = \{1, 2, \cdots, k\}$ and K also represents the total number of tractors required by the road network;

k : Indicates the number of the tractor, $k \in K$;

d_{ij} : Indicates the distance between highway ports i, j, unit: km;

q_{ij} : Represents the demand for tractor and semitrailer transportation from the highway port to j, which is expressed by the number of tractor and semitrailer transportation times. Since demand is not necessarily balanced, q_{ij} may not be equal to q_{ji};

C_{ij} , c_{ij} : Respectively represent the cost of towing, re-hanging and idle loading of the tractor, unit: yuan/km;

$c^{'}$: Indicates the waiting cost for the towing vehicle to arrive at the task location in advance (unit, yuan/h)

: Indicates the fixed cost of tractor usage per unit time, including vehicle depreciation, employee salaries, etc. Unit: yuan;

T : Indicates the continuous working time of tractors. It is stipulated that the continuous working hours of all tractors are equal every day;

v_1, v_2 : Indicates the speed at which the tractor is towed, re-hanged and idle loaded, unit: km/h;

k_1, k_2 : Respectively indicate the state of tractor towing, re-hanging and idle loading, $k \in K$;

$$x_{ijk1} = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix}, \quad x_{ijk2} = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix}$$

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x_{ijk1}, x_{ijk2} = 1,means that the tractor k is loaded or unloaded from the highway point i to j
x_{ijk1}, x_{ijk2} = 0, means other circumstances

a_{ijk_1}, a_{ijk_2} : Respectively indicate the number of trips of the tractor from the highway port to i the highway port j by heavy loading and idle loading;

$Q=\{q_{ij}^m \mid m=1,2,\cdots,M; i, j \in S_n\}$ indicates the set of tasks that need to be dropped and pulled between the nodes of the transport depot, in which, q_{ij}^m represents the transport starting and ending point $i \to j$ in the m th drop and pull task and the transport volume (unit, vehicle);

$T=\{t_m^1, t_m^2 \mid m=1,2,\cdots,M\}$ represents the time window of each task, in which, t_m^1 represents the lower time limit of m th drop and pull task, and t_m^2 represents the upper time limit of the m th drop and pull task;

t_{ik}^m : Represents the time for the tractor k to arrive at the transport starting point i in the drop and pull task;

$J(x)$ is a step function, when $x>0$, the value is, and when $x \le 0$,the value is 0.

3.3 Mathematical Model

According to the actual operation of the highway port network, tractor and semitrailer transport companies pursue the minimum operating cost throughout the entire network, thus meeting the demand while investing the least number of tractors.

(1) Goal 1: Network operating costs are composed of re-hanging driving costs, idle loading costs, and fixed costs. The re-hanging driving cost is $Z_{重}=\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_1} d_{ij} C_{ij} x_{ijk_1}$; the idle loading cost is: $Z_{空}=\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_2} d_{ij} c_{ij} x_{ijk_2}$; the fixed cost of using vehicles on the day is: $Z_{固}=Kc$; the penalty cost is: $Z_{惩}=\sum_{m=1}^{M}\sum_{i=1}^{n}\sum_{k\in K} c' \cdot J(t_{\mathrm{m}}^1 - t_{ik}^m)$,the target is minimum network operating cost, which is expressed as:

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$$\min Z_1 = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_1} d_{ij} C_{ij} x_{ijk_1} + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_2} d_{ij} c_{ij} x_{ijk_2} + Kc + \sum_{m=1}^{M}\sum_{i=1}^{n}\sum_{k\in K} c^{'} \cdot J(t_{\mathrm{m}}^{1} - t_{ik}^{m}) \tag{1}$$

(2) Goal 2: The number of tractors put into use is minimum, which is expressed as:

$$\min Z_2 = K \tag{2}$$

(3) Constraint: The tractor and semitrailer demand is met:

$$\sum_{k\in K} a_{ijk_1} x_{ijk_1} = q_{ij} \tag{3}$$

Continuous working time limit of the tractor:

$$\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ijk_1}}{v_1} + \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ijk2}}{v_2} + \sum_{m=1}^{M}\sum_{i=1}^{n} J(t_{\mathrm{m}}^{1} - t_{ik}^{m}) \le T \tag{4}$$

Hard time window constraint:

$$t_{ik}^{m} + J(t_{m}^{1} - t_{ik}^{m}) + \frac{d_{ij}}{V} x_{ijk} \le t_{m+1}^{2} \tag{5}$$

The network tractor and semitrailer scheduling problem with unbalanced demand is a dual-objective problem. Goal 1 pursues the minimum network operation cost. Since the tractor and semitrailer demand must be met, under this goal, we mainly need weigh between the idle loading cost of the tractor and the fixed cost. The fixed cost Kc of tractors is directly proportional to the number of tractors K put into use. If the idle loading cost of tractors is greater than the fixed cost, then the tractor investment will be increased and the overall operating cost will be reduced, which is in contradiction with Goal 2. If the idle loading cost of tractors is smaller than the fixed cost, then the tractor will be arranged to run under idle loading without increasing the number of tractors, which is consistent with Goal 2. At this time, only non-inferior solutions meeting the goals 1 and 2 can be solved. The tractor and semitrailer demand of the entire network is $\sum_{i=1}^{n}\sum_{j=1}^{n} q_{ij}$. If each tractor and semitrailer demand is arranged to be completed by

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a tractor, it is obvious that $0 \le K \le \sum_{i=1}^{n}\sum_{j=1}^{n} q_{ij}$. Then, goal 2 can become a constraint condition of target 1.

From the above, the network tractor and semitrailer scheduling model with unbalanced demand changes to:

$$\min Z_1 = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_1} d_{ij} C_{ij} x_{ijk_1} + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k\in K} a_{ijk_2} d_{ij} c_{ij} x_{ijk_2} + Kc + \sum_{m=1}^{M}\sum_{i=1}^{n}\sum_{k\in K} c' \cdot J(t_{\mathrm{m}}^{1} - t_{ik}^{m}) \tag{6}$$

$$\text{S.T.:} \quad \sum_{k\in K} a_{ijk_1} x_{ijk_1} = q_{ij} \tag{7}$$

$$\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ijk_1}}{v_1} + \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ijk2}}{v_2} + \sum_{m=1}^{M}\sum_{i=1}^{n} J(t_{\mathrm{m}}^{1} - t_{ik}^{m}) \le T \tag{8}$$

$$0 \le K \le \sum_{i=1}^{n}\sum_{j=1}^{n} q_{ij} \tag{9}$$

$$t_{ik}^{m} + J(t_{m}^{1} - t_{ik}^{m}) + \frac{d_{ij}}{V} x_{ijk} \le t_{m+1}^{2} \tag{10}$$

3.4 Algorithm Design Based on ACO

The use of ant colony algorithm to solve the optimal ratio of tractor and semitrailer transportation tractors and trailers involves several algorithm design core issues such as the construction of solution space structure diagrams, the processing of constraint conditions, the design of pheromone related rules, the design of selection strategies, the design of local search strategies, and how to terminate the algorithm. The key issues mentioned above are described below:

3.4.1 Solution space structure diagram construction

According to the characteristics of the optimal ratio model of the tractor and semitrailer transport tractor and trailer, the solution space representation scheme is designed as shown in Figure 3:

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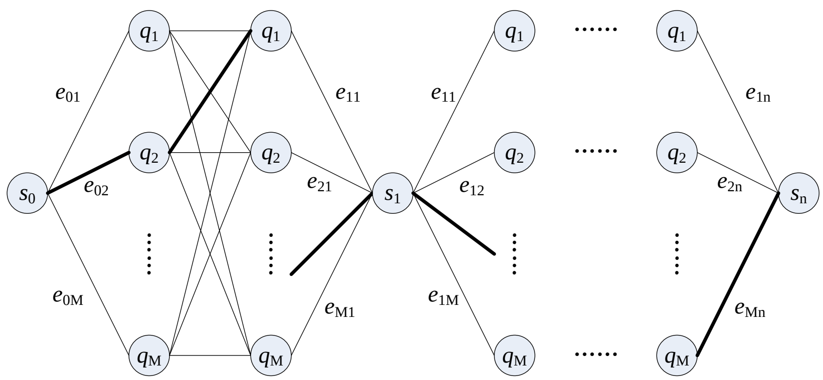

Fig 3: the solution construction diagram about the optimal ratio of tractors and trailers

Fig 3 shows the solution construction diagram about the optimal ratio of tractor and trailer. Where, q_i represents the i th task in the set Q of drop and pull tasks; the solid line e_{ij} indicates that the tractor completes one drop and pull task q_i and then another drop and pull task q_j, and its weight is the cost for the tractor to travel from the final station s_i^2 of the task q_i to the starting station s_j^1 of the task q_j; the dotted line $e_{ij}^{'}$ is the auxiliary edge, which is used to connect q_i and q_j, and its weight is to ensure that a feasible solution can be found in each iteration, and its weight is M; The meaning of multiple s in the figure is that when a tractor completes a certain tractor and semitrailer transport task, it cannot continue to the next task point due to the constraints of time window and running time, and it can be parked at the highway port s_1. At the same time, the tractor number in use +1.

The process of ants constructing the solution in Fig 3 is the process in which ants start from the highway port s_0, traverse all tasks q_i and then stay at s_1. The route the ants walk constitutes a feasible solution for the arrival-departure track application plan. The thick solid line in Fig 3 is the walking route of the ant in the solution construction process, which represents a feasible solution F. Therefore, the feasible solution F to the problem of the optimal ratio of tractor and trailer can be expressed as the set of ants passing through the real edges. For example, the route $s_0 \rightarrow q_2 \rightarrow q_5 \rightarrow q_8 \rightarrow q_6 \rightarrow s_1$ means that the first tractor departs from the storage station s_0 and stops at s_1 after completing the traction tasks q_2, q_5, q_8, q_6.

3.4.2 Constraint handling

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When the ants move from task q_i to task q_j in Fig 3, they need to satisfy the constraint conditions in the model from Equation 7 to Equation 10. N_i^k is the set of candidate tasks of the k th ant on the node q_i. The set is calculated based on the ant's selection of $1,2,\cdots,i-1$ continuous tractor and semitrailer task, constraint conditions 7∼10, and cost matrix C. When $N_i^k=\varnothing$, it means that there is no continuous tractor and semitrailer task that satisfies the constraint condition after the task q_i is started, then $N_i^k=\{s_0\}$. Through N_i^k , it can be guaranteed that the structural solution meets the constraint condition.

3.4.3 Pheromone related rule design

Pheromone τ_{ij} refers to the degree of expectation that the task q_i is followed by the task q_j. Ants use pheromone as a medium for communication, which exerts huge impact on algorithm performance. The better the solution searched by the ant, the stronger the pheromone left by the ant on the edge it passes. Therefore, in the tractor scheduling problem, the value of the pheromone should be inversely proportional to the value of the objective function of the solution. According to the idea of the minimum and maximum ant system, only when iterative optimal ant constructs the optimal solution of this iteration or global optimal ant constructs the global optimal solution can the ant be allowed to release pheromone. To avoid iteration stagnation, the value of pheromone is limited to an interval $[\tau_{\min},\tau_{\max}]$. After all the ants have constructed the path, the algorithm will update the pheromone on each side of the solution structure graph according to the performance of the solution.

1) Pheromone initialization

To expand the search range of the ants in the solution space at the beginning of the iteration, all the pheromone on the real edges of the solution construction graph are initialized to $\tau_{\max}$, namely $\tau_{ij}(0)=\tau_{\max}$. All the virtual edges in the figure are auxiliary edges and do not have a decision-making effect, so there is no pheromone on the virtual edges.

2) Pheromone update principle

The pheromone update strategy is one key step in the ant colony algorithm. If the information is updated too fast, the algorithm will fall into a local optimum or even stagnate. If the information is updated too slowly, the convergence speed will be slow and the optimal route cannot be searched. The pheromone update principle adopted by the algorithm is that after each

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iteration, the pheromone is updated by the global optimal ant or the optimal ant of this iteration, and the value of the pheromone is limited to the interval $[\tau_{\min}, \tau_{\max}]$. In the solution construction process, no local pheromone update is performed.

The principle of pheromone update is

$$\tau_{ij}(t+1) = \rho\tau_{ij}(t) + \Delta\tau_{ij} \tag{11}$$

Where, ρ is the volatilization coefficient of the pheromone; t is the number of iterations; $\Delta\tau_{ij}$ is the pheromone increase after this iteration. Where, $\rho < 1$, its value can be changed along with the solution process, and a smaller value can be used at the beginning of the solution ρ, in the hope that the algorithm will search for more paths at the beginning.

Assume that Z^* is the objective function value of the theoretically optimal solution, according to the idea of MMAS, the calculation of $\Delta\tau_{ij}$ is as follows:

$$\Delta\tau_{ij} = \begin{cases} Z^*/Z & e_{ij} \in S \\ 0 & e_{ij} \notin S_0 \end{cases} \tag{12}$$

After the pheromone $\tau_{ij}(t+1)$ is calculated, it must be judged whether its value is within the interval $[\tau_{\min}, \tau_{\max}]$. Therefore, the update principle of the pheromone in this algorithm is as follows:

$$\tau_{ij}(t+1) = \begin{cases} \tau_{\max} & \tau_{ij}(t+1) > \tau_{\max} \\ \tau_{\min} & \tau_{ij}(t+1) < \tau_{\min} \\ \tau_{ij}(t+1) & else \end{cases} \tag{13}$$

3) Determination of $\tau_{\max}$ and $\tau_{\min}$

In this paper, the upper bound value $\tau_{\max}$ of pheromone and the lower bound value $\tau_{\min}$ of pheromone are experimentally determined

.

3.4.4 Selection strategy design

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When the k th ant is at the task node q_i, it is possible to use a probabilistic $p_{ij}^k(t)$ decision rule to select the next task node q_j. $p_{ij}^k(t)$ is a function of pheromone τ_{ij} and heuristic information η_{ij}, which represents the probability of task node q_i being followed by the task node q_j.

$$p_{ij}^k(t)=\begin{cases}\dfrac{\alpha\cdot\tau_{ij}+\beta\cdot\eta_{ij}}{\sum\limits_{j\in N_i^k}(\alpha\cdot\tau_{ij}+\beta\cdot\eta_{ij})} & j\in N_i^k\\ 0 & j\notin N_i^k\end{cases} \tag{14}$$

Where, η_{ij} is the heuristic information, which refers to the heuristic expectation degree of the task node q_i followed by the task node q_j. This paper stipulates that $\eta_{ij}=1/c_{ij}$, $0\le\alpha,\beta\le 1$ is used to indicate the role of pheromone τ_{ij} and heuristic information η_{ij} in constructing the solution. In the initial stage of the search, the pheromone is initialized to an initial value, which does not have any guiding effect on the ant's behaviour and will cause the algorithm to construct a path of very low quality. The main function of heuristic information is to avoid this situation. It makes the ants tend to construct a good path from the beginning. When $N_i^k\ne\varnothing$, the ant k chooses the next task node at the task node q_i according to the probability $p_{ij}^k(t)$ in a way similar to the roulette in the evolutionary algorithm. When $N_i^k=\varnothing$, that is, when the task q_i is completed, the tractor chooses the tractor storage station s_0 with a probability of $p_{i0}^k(t)=1$.

3.4.5 Local search strategy design

In the ant colony optimization algorithm, the solution is constructed probabilistically by the ant colony, and its effect is relatively not very good. Therefore, in practical applications, ant colony algorithm is always combined with neighborhood search algorithms such as descent search, simulated annealing, and tabu search. On the one hand, the neighborhood local search algorithm can further improve the solution to the problem generated by each ant construction. On the other hand, because the ant colony is guided by the pheromone trace when constructing the solution, the ant can construct a good initial solution for the neighborhood search algorithm.

After the ants find the initial solution through the solution construction, it introduces a local search strategy to adjust the use plan of the arrival-departure track that is obviously inappropriate in the initial solution. This paper adopts the 2-opt method. That is, two random tasks out of the

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sequence of the solution generated in each iteration are exchanged in pairs.

3.4.6 Algorithm termination criteria

The algorithm terminates when at least one of the following conditions is met:

1) The algorithm has found the optimal solution, that is, the objective function of the current solution $f = f^*$, which means all the tractor and semitrailer tasks are arranged with the optimal tractor and semitrailer plan;

2) The algorithm has fallen into a stagnant state, no better solution can be found, and all the tractor and semitrailer tasks are arranged with the best tractor and semitrailer plan;

3) The number of iterations executed by the algorithm reaches the maximum.

Based on the analysis of the key elements in the above algorithm, the specific implementation flow chart for solving the optimal ratio of tractor and semitrailer transportation tractors and trailers based on MMAS is shown in Fig 4:

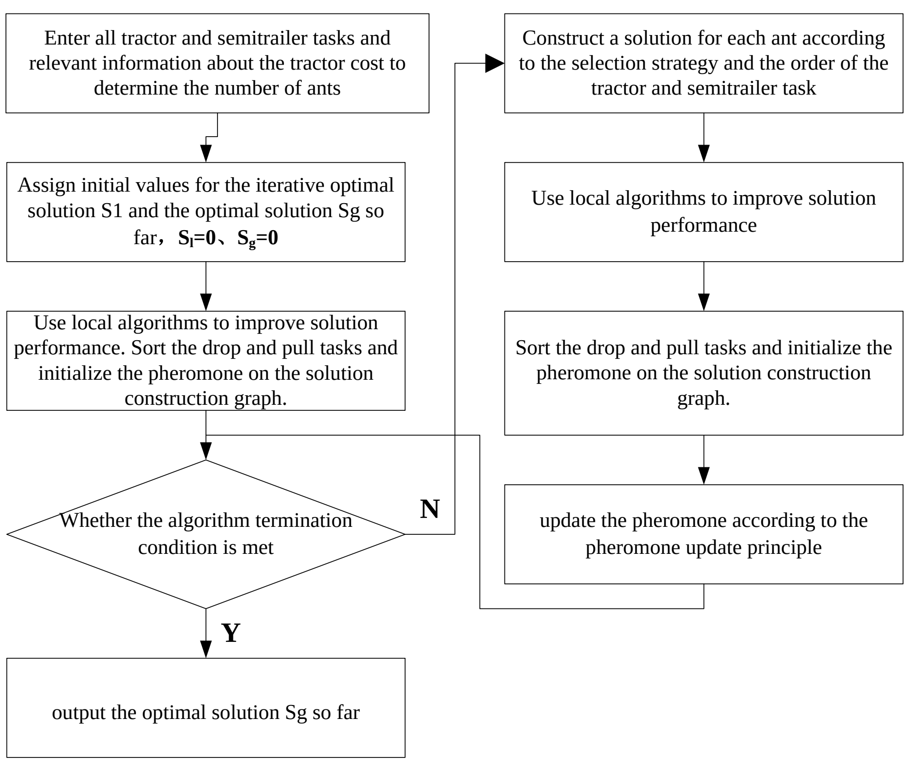

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Fig 4: schematic diagram of the algorithm for the ratio of tractor and semitrailer transport tractors and tractor and semitrailer vehicles based on MMAS

IV. EXAMPLE ANALYSIS AND DISCUSSION

Logistics enterprise L relies on Tiandihui Highway Port and has tractor and semitrailer transport points in 30 cities. How to arrange vehicle scheduling in the tractor and semitrailer network to minimize the overall network cost is a technical problem that business managers hope to solve.

Assume that the cost of rehanging and idle loading of the tractor is , $c_{ij} = 0.4元/km$. The speed of tractor in rehanging and idle loading is $v_1 = 50km/h, v_2 = 70km/h$, the fixed cost per day is c=500元, the continuous working time per day is T=16小时, and the waiting cost is C '=1.5 YUAN/hour, d_{ij} can be found according to Google Map, as shown in Table I. Regarding q_{ij} value, use the randint function in Matlab 2010a software to generate tractor and semitrailer transportation tasks between 30 customer points in [30]. All tractor and semitrailer transportation tasks are integers, as shown in Table II.

TABLE I. Distance between highway ports (unit, km)

1	Beijing	0	1218	680	120	290	1080	600	690	945	1010	1100	1000	1220	1360	1750
2	Herbin	1218	0	540	1200	1500	2300	1710	1800	2000	2120	2160	2090	2280	2460	2890
3	Shenyang	680	540	0	660	960	1760	1170	1260	1170	1590	1330	1550	1450	1630	2340
4	Tianjin	120	1200	660	0	314	1108	525	609	818	930	976	902	1095	1280	1680
5	Shijiazhuang	290	1500	960	314	0	816	402	586	846	964	1011	949	1165	1311	1570
6	Xian	1080	2300	1760	1108	816	0	661	832	1131	1128	1303	1147	1411	1489	1511
7	Heze	600	1710	1170	525	402	661	0	274	594	600	759	598	869	1000	1200
8	Xuzhou	690	1800	1260	609	586	832	274	0	323	356	513	340	611	742	1070
9	Ynacheng	945	2000	1170	818	846	1131	594	323	0	276	217	174	349	493	967
10	Nanjing	1010	2120	1590	930	964	1128	600	356	276	0	257	105	312	427	788
11	Nantong	1100	2160	1330	976	1011	1303	759	513	217	257	0	166	131	314	815
12	Yangzhou	1000	2090	1550	902	949	1147	598	340	174	105	166	0	283	414	857
13	Shanghai	1220	2280	1450	1095	1165	1411	869	611	349	312	131	283	0	217	738
14	Ningbo	1360	2460	1630	1280	1311	1489	1000	742	493	427	314	414	217	0	613
15	Nanping	1750	2890	2340	1680	1570	1511	1200	1070	967	788	815	857	738	613	0

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16	Fuzhou	1870	2930	2450	1780	1685	1668	1315	1185	1036	904	860	939	784	587	168
17	Shenzhen	1260	3350	2660	2130	1963	1746	1654	1549	1632	1357	1503	1467	1439	1352	763
18	Quanhzou	1970	3100	2560	1900	1791	1687	1422	1293	1178	1072	1023	1102	947	750	280
19	Guangzhou	2110	3310	2640	2010	1850	1638	1604	1526	1624	1349	1495	1459	1431	1343	781
20	Liuzhou	2110	3300	2760	2100	1848	1531	1580	1654	1772	1529	1739	1606	1675	1587	1147
21	Wuxi	1110	2200	1380	1020	1005	1300	743	485	234	180	123	157	141	266	770
22	Changsha	1470	2690	2120	1480	1204	992	962	1010	1128	885	1113	962	1063	993	711
23	Chnagzhou	1120	2190	1640	1000	987	1261	703	446	213	140	136	117	184	311	763
24	Chongqing	1780	2980	2440	1780	1500	696	1321	1466	1652	1400	1635	1486	1709	1764	1616
25	Chengdu	1820	3040	2500	1820	1532	717	1374	1573	1880	1658	1895	1744	1964	2030	1902
26	Wuhan	1170	2360	1820	1150	902	745	630	655	796	544	782	629	828	906	769
27	Yichang	1300	2450	1950	1280	1033	650	764	909	1095	843	1080	929	1149	1230	1083
28	Hefei	1030	2130	1440	940	902	978	534	329	444	167	405	253	470	570	760
29	Luoyang	800	2140	1470	800	522	366	318	517	824	747	940	789	1030	1166	1326
30	Kuitun	3050	4230	3720	3170	3148	2829	3471	3671	3971	3899	4111	3960	4248	4303	4331

TABLE II. Demand for drop and pull between highway ports (unit: car)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	km	Biejing	Herbin	Shenyang	Tianjin	Shijiazhunag	Xian	Heze	Xuzhou	Yancheng	Nanjing	Nantong	Yangzhou	Shanghai	Ningbo	Nanping
1	Beijing	0	7	8	0	1	4	6	2	0	1	0	3	0	9	8
2	Herbin	9	0	2	0	10	0	3	3	2	7	7	4	6	9	4
3	Shenyang	1	3	0	5	0	9	8	5	8	5	0	0	9	8	0
4	Tianjin	10	0	7	0	8	10	2	2	0	8	0	10	7	2	2
5	Shijiazhuang	6	1	9	10	0	5	7	9	10	7	5	1	2	6	1
6	Xian	1	9	10	1	9	0	2	2	8	9	1	1	4	0	3
7	Heze	3	7	6	6	0	3	0	2	5	9	8	4	5	4	4
8	Xuzhou	6	3	1	5	4	9	6	0	6	3	8	2	10	3	5
9	Yancheng	10	10	1	0	2	4	8	2	0	7	7	5	1	1	5
10	Nanjing	10	0	2	3	8	1	0	4	5	0	1	3	9	1	9
11	Nantong	1	4	9	1	4	8	10	3	10	0	0	10	7	4	5

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12	Yangzhou	10	4	2	8	10	4	8	10	6	8	5	0	4	1	10
13	Shanghai	10	8	8	3	2	2	5	4	5	5	10	0	0	6	7
14	Ningbo	5	8	2	5	2	4	4	2	2	5	7	8	4	0	10
15	Nanping	8	2	10	1	1	1	4	9	5	9	8	2	5	7	0
16	Fuzhou	1	5	3	6	1	1	3	10	6	6	4	4	1	7	7
17	Shenzhen	4	4	2	2	9	10	5	4	7	6	4	6	6	7	3
18	Quanzhou	10	7	2	7	6	10	5	1	4	9	9	10	2	0	7
19	Guangzhou	8	7	6	7	6	6	8	2	4	8	0	4	4	0	7
20	Liuzhou	10	8	5	8	1	0	8	4	10	6	1	10	6	3	0
21	Wuxi	7	3	3	4	9	2	7	6	0	2	1	3	2	5	2
22	Changsha	0	7	9	0	6	3	4	2	9	2	4	7	3	7	2
23	Changzhou	9	7	6	2	3	9	8	6	10	9	9	7	6	4	7
24	Chongqing	10	1	6	10	5	0	5	7	8	0	8	5	2	9	9
25	Chengdu	7	1	10	1	4	0	3	2	1	5	0	7	9	7	3
26	Wuhan	8	5	3	9	0	1	10	1	2	1	4	7	10	10	8
27	Yichang	8	10	8	5	2	7	9	3	3	10	5	1	8	5	7
28	Hefei	4	3	8	10	1	8	6	3	7	7	4	1	3	3	0
29	Luoyang	7	6	4	0	2	7	6	4	1	5	7	10	6	1	6
30	Kuitun	1	2	6	4	2	4	6	5	7	5	6	1	1	6	4

Set the parameters according to the above known conditions and assumptions, and substitute them into the ant colony algorithm program for operation. Perform multiple calculations, and take the optimal quality value as the result.

For the 4220 tasks in the case, the system randomly obtains the serial number of the assigned vehicle and the optimal running time and route. For the same tractor, the order of task execution can be determined by comparing the starting time of the task. The tractor starts from the highway port of the city where it is located, and traverses the tasks belonging to itself in the table according to the task starting time, and then stays at the highway port.

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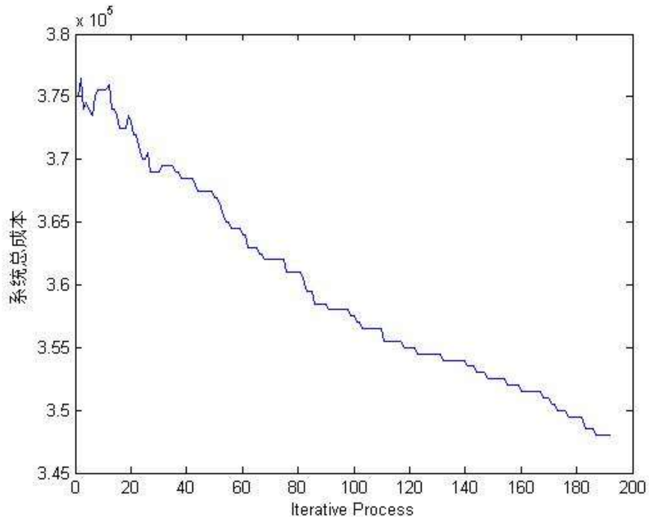

Fig 5: iterative curve of total system cost

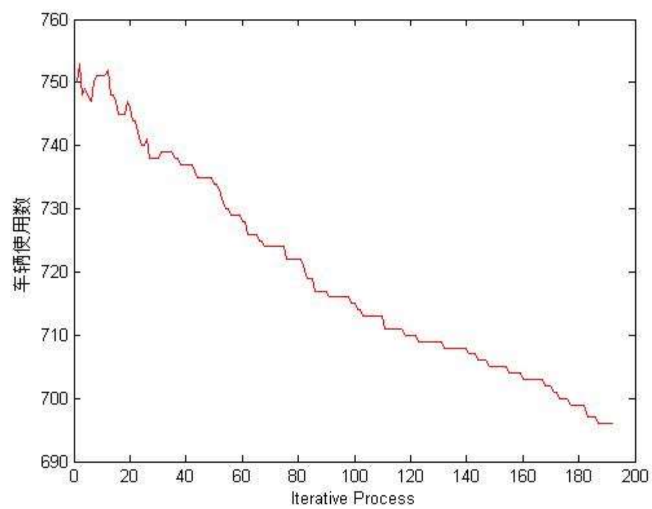

Fig 6: iterative curve of tractor usage number

Fig 5 is the result of operation of the ant colony algorithm, which shows changes of algorithm fitness value, i.e. the overall operating cost of the system, as the iteration algebra increases. Fig 6 shows the changes in the number of tractors used in the entire system during the iteration. It can be seen from the figure that the fitness value first changes drastically within a certain evolutionary algebra, and finally reaches stability and remains so until all evolutionary algebras are completed. A sufficiently large evolutionary algebra can ensure that the optimal individual fitness value is found and iterated to the optimal extreme value. The final running results are shown in Table III below.

TABLE III. Running results

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Vehicle number	Execution task number
Vehicle information	The number of tractors is 696, the number of trailers is 4220, and the number of tractors: trailer (towing ratio) is 1:6.06.
Total cost	5284036.5

It can be seen from Table IV that the towing ratio of the company calculated by the design model is 1:6.06, which is much higher than domestic towing ratio of 1:07 in 2020, reaching the level of developed countries. It shows that the use of pure network scheduling optimization will result in better operational performance, which can maximally optimize the cooperate operation, reduce costs and increase efficiency; at the same time, due to the relatively high purchase cost of vehicles, the determination of the optimal ratio can also avoid idle fixed assets and financial burden due to enterprise's blindness in purchasing vehicles.

TABLE IV. Comparison of calculation results

	Traditional mode	Pure network
Tractor K (vehicle)	4220	696
Fixed cost (yuan)	2110000	1126940
Total cost	6533293	5284036.5
Reduction ratio of the number of tractors (%)	83.5%	
Total cost reduction ratio (%)	19.1%	

It can be seen from Table 4 that the pure network tractor and semitrailer method uses fewer tractors at a lower cost than the traditional method. Compared with traditional tractor and semitrailer tractors, the number of pure network tractor and semitrailer tractors is reduced by 83.5%, and the cost is reduced by 19.1%. Compared with the traditional method, in the pure network tractor and semitrailer, the tractor is allowed to tow multiple trailer tasks when possible, so the number of tractors used will inevitably be reduced. Moreover, when the increased cost due to idle loading of tractors is smaller than the fixed cost saved due to the reduction in the number of tractors, the two types of network tractor and semitrailer transportations show a downward trend in costs.

V. CONCLUSION

In order to explore the optimization of "Tractor + Trailer" (TSRP) tractor and semitrailer transport scheduling in the network state, based on the characteristics of highway ports, this paper considers the uneven demand, the existence of multiple demand and time windows, takes the lowest transport cost and minimum number of used tractors as the goal, establishes a

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dual-objective optimization model for network drop and pull scheduling, and designs a heuristic algorithm for solution. The following conclusions are drawn:

(1) Compared with traditional transport methods, the optimization of pure network tractor and semitrailer transport in the network can reduce the number of tractors used and lower the overall transport cost.

(2) Based on the pure network tractor and semitrailer transport mode, the towing ratio is relatively high. Therefore, the enterprise will have better operational performance, thereby reducing costs and increasing profits.

(3) Innovation and original contribution of the paper

At present, in domestic research on tractor and semitrailer transport, most literature focuses on the mode of tractor and semitrailer transport and the dispatching of tractors. However, the research on trailer configuration is very limited. Through literature retrieval, only a few domestic documents have studied the configuration of trailers. The tractor and semitrailer ratio is an important indicator for the level of tractor and semitrailer transport operations. The author's research not only enriches the theory of tractor and semitrailer ratio of the whole network, but also provides guidance for enterprises to improve their actual operation level. This paper fully considers the unbalanced demand at both ends of the actual tractor and semitrailer transport and possible multiple demands. Based on the pure network-wide vehicle scheduling optimization, the study can approach to the actual application scenario, which will help tractor and semitrailer transport companies to increase economic benefits.

This paper assumes that all highway ports have sufficient trailers, that is, no empty trailers are dispatched, and the existence of multiple tractors and trailer models is not considered, which is still different from the actual operation. Therefore, considering these details on the basis of this paper will be the direction of future research.

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