Research on transportation scheduling algorithm for special fuel of high frequency task

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Keywords: Space Launch, Special Fuel Transportation, High Frequency task ,Scheduling Algorithm

Abstract. Special fuel transportation scheduling is an important part of the space launch. Because of the lack of fuel transport train and limited production capacity of manufacturers having become the main limiting factors for special fuel transportation scheduling in space launch, it is very necessary to research the method of special fuel transportation scheduling. This paper has a description of transportation scheduling for special fuel of high frequency task in detail, establishes a mathematical model and an effective scheduling algorithm, which can satisfy the needs of special fuel transportation scheduling for special fuel of high frequency task.The strategy of transportation scheduling can make it possible to complete a large number of special fuel transportation scheduling tasks with less transport trains. At the same time, it meets the goal constraints in cost and task balance.

Introduction

In recent years, the number of space missions is increasing rapidly with the development and prosperity of our country's space industry. Compared to the previous year, the launch plan has been doubled in number and become more and more unbalanced in terms of time, which makes the contradiction between the demand of high frequency task and special fuel transportation scheduling more prominent. In a short time, the development of the number of special fuel transport trains and the manufacturer's production capacity can't match the rapid growth rate of launch plan. Under the existing conditions and environments, it is necessary to use the limited transportation and production resources to make the transportation scheduling for special fuel smooth and safe, in order that the designated space launch mission plan can be completed successfully.

The transportation scheduling for special fuel of high frequency task is an important factor in the space launch field .[1] At the present stage, with the increasing of space launch tasks, the demand for special fuel transportation scheduling has increased either[2,3], which makes the factors in production and transportation scheduling gradually becoming the main constraints in the process of the special fuel transportation scheduling.[4] However, the research on the transportation scheduling for special fuel is still in the stage of manual scheduling, the foreign and domestic experts have not research it deeply.[5,6] Therefore, the research has a high theoretical value and practical significance.

The description and model establishment of special fuel transportation scheduling

Description. When the special fuel transport vehicles N_k perform transport scheduling task i， we can determine the replenishment number of fuel of base S_{bt}, the manufacturer F_j and fuel replenishment time T_{ik}, according to the required amount of fuel R_{bt} and launch time T_{bt}.Then we choose available vehicles N_k, which can meet the conditions of the transportation process. According to the transport route, it takes N_k several days to arrive manufacturer F_i from initial base B_0. After refueling fully in manufacturer F_i, vehicles N_k will go to the launch site B_k for unloading, which makes the transport scheduling task i completed. Therefore the individual process of special fuel transportation scheduling can be summarized as follows: initial base B_0 →manufacturer F_i →launch site B_k.

The entire process of special fuel transportation scheduling is the aggregation of the individual process. We should use dependency rule to make a base supplementary plan SP_b=(S_{b1}， T_{b1})(S_{b2}， T_{b2})…(S_{bt}， T_{bt}, according to the entire launch plan RP_b=(R_{b1}， T_{b1})(R_{b2}， T_{b2})…(R_{bt}， T_{bt}).Then we can calculate the transportation scheduling plan VP_k=(B^k_1 , T^k_{BF1} , F^k_1 , T^k_{FS1} , T^k_{FF1} , B^k_2 , T^k_{BS2})(B^k_2， T^k_{BF2}， F^k_2， T^k_{FS2}， T^k_{FF2}， B^k_3， T^k_{BS3})… (B^k_j， T^k_{BFj}， F^k_j， T^k_{FSj}， T^k_{FFj}， B^k_{j+1}， T^k_{BSj+1})for each N_k, while the T^k_{BFj},T^k_{FSj},T^k_{FFj} and T^k_{BSj+1} stands for the time of N_k leaving the base,arriving the manufacture, leaving the manufacture and arriving the launch site. Therefore the entire process of special fuel transportation scheduling can be summarized as follows: initial base B_0 →manufacturer F_i →launch site (base) B_i →manufacturer F_{i+1} →launch site (base) B_{i+1} →repairing(if necessary) →・・・・→manufacturer F_j→launch site (base) B_j.

Different types of transportation group differ in carrying capacity and repair time, so it will take different refueling tasks. However, the number of current special fuel transport vehicle is limited. There are only four vehicles can be used, which have two different types. In the case of the increasing in the number of launch missions and the limited transport ability, how to establish a set of scheduling mechanism which can meet the development of special fuel transportation scheduling problems in the future for a period of time, has very important significance to complete transportation scheduling algorithm for special fuel of high frequency task.

Model. On the basis of the investigation, expert discussion and guarantee to complete the task the optimization goal of transportation scheduling problems can be identified as the following three aspects: 1.Minimum the transportation cost, 2.Equalize the transportation scheduling, 3.Try to keep the vehicles staying at base.

$$Min\ f_1 = \sum_{k=1}^{K} \sum_{j=1}^{JK} \left(L_k(B_j, F_j) * C_{k1} + L_k(B_j, F_{j+1}) * C_{k2} \right)$$
(1)

In formula 1, f_1 is the total cost for the annual plan of all transportation group.C_{k1} and C_{k2} stand for the per unit transportation cost of no-load and full-load. K is the total number of vehicles， and Jk is the amount number of times for vehicle k. $L_k(B_j, F_j)$ and $L_k(B_j, F_{j+1})$ stand for the distance from base to manufacture and from manufacture to base,when the vehicle k performs transport task j.

$$Min\ f_2 = Max_{k\in K} \sum_{j=1}^{J} \left(L_k(B_j, F_j) + L_k(B_j, F_{j+1}) \right) - Min_{k\in K} \sum_{j=1}^{J} \left(L_k(B_j, F_j) + L_k(B_j, F_{j+1}) \right) \tag{2}$$

In formula 2, f_2 is the difference between the longest transport distance and the shortest transport distance.

$$Min\ f_3 = Max \sum_{k=1}^{K} \sum_{j=2}^{J-1} \left(T^k_{BF_j} - T^k_{BS_j} \right) \tag{3}$$

In formula 3, f_3 is the total time of vehicles staying at base after each scheduling task.

According to the task requirements and characteristics of transportation vehicles, the constraint conditions of the special fuel transport scheduling model are as follows: 1.Constraint in the fuel storage of base, 2.Constraint in transport time of the vehicles, 3.Constraint in load time in the manufacturer, 4.Constraint in regular maintenance of the vehicles.

$$1.\begin{cases} Q_{bt} - R_{bt} + S_{bt} \succ 2 * R_{bt+1} + Q_{bb} \\ Q_{bt} - R_{bt} + S_{bt} < Q_{b\max} \\ S_{bt} = \sum_{k=1}^{K} n_{tk} * Q_k, n_{tk} \in N \end{cases} \tag{4}$$

In formula 4, Q_{bt}, Q_k, Q_{bb} and $Q_{b\max}$ respectively stands for the storage rate of the base before the launch, the carrying capacity of vehicles, the minimum and maximum inventory of the base.

$$2.\begin{cases} T_{FS_j}^k - T_{BF_j}^k \succ TT_{BF} \\ T_{BF_{j+1}}^k - T_{BF_j}^k \succ TT_{FB} \end{cases} \tag{5}$$

In formula 5, TT_{BF} and TT_{FB} are the time of the vehicles spent from the base to manufacturer and from the manufacturer to base. In this article, one day is used to indicate a unit of time.

$$3.\left\{ T_{FF_j}^k \succ T_{FS_j}^k + VLT^k \right. \tag{6}$$

In formula 6, VLT^k is the loading time of the vehicles in the manufacturer.

$$4.\left\{ T_{BF}^k = T_{BF}^k + G\left(T_{BF}\right) \right. \tag{7}$$

In formula 7, when T_{BF}^k > $TG(x)$ that the $TG(x)$ stangs for the maintenance time interval, G=$TTG(x)$, $x=\{a,b,c\}$, a, b and c stands for simple maintenance, complete maintenance and thorough maintenance respectively.

Scheduling Algorithm

In special fuel transportation scheduling problem, the input variable is the launch plan RP_b which is mentioned above,and the output variable is the scheduling planVP_k and the maintenance plan(If necessary).

In special fuel transportation scheduling problem, the solutions are almost infeasible when we use the heuristic algorithm to solve it, whose reason is that the constraints of the problem are large and complex. Therefore, in this paper,we will use randomized procedure to get the feasible solutions and the annual scheduling plan. So the algorithm flow can be defined as follows:

Step1: Initialize the data, for initialization, and formulate special fuel supplement plan according to the launch plan;

Step2: Read the set of special fuel supplement plan, and determine whether the set is empty: yes-output of the scheduling scheme, no-turn to step3;

Step3: Read the set of special fuel supplement plan, choose the available manufacturer. Then choose the available vehicles according to the time, location, and quantity of the refueling task , manufacturer and the location of the vehicles, and determine whether the set of available vehicles is empty: yes- turn to step1,no- turn to step4;

step4: According to refueling time in the base, arrange the time of leaving the base, arriving the manufacture, leaving the manufacture and arriving the launch site appropriately. Then update the location of the vehicle and turn to step2.

This algorithm will take the the objectives and constraints into consideration in every step, such as choose manufacturer , dispatch vehicles and arrange the time.

After we get some solutions, if we want to propose a satisfactory annual transportation scheduling plan, we should make a comprehensive evaluation of three optimization objectives.

In this paper, we will use the weighted method to evaluate the annual transportation scheduling plan. So, the objective function is normalized, and the original function is divided by the maximum value of the function, and the new objective function f_i' is obtained. The weighted coefficient λ_i of each objective function is determined by the decision makers, and the total objective function value of the final scheduling plan K is:

$$f_{\mathrm{k}} = \sum_{i=1}^{3} f_{i\mathrm{k}}' * \lambda_i \tag{8}$$

In all of the solutions generated by using the randomized procedure, several plans with high weighted objective function values will be selected, in order to help the decision makers to make the best decision.

Experiment

In this section, we will use the scheduling algorithm to calculate the previous case, and we will analyze the advantages and disadvantages of the algorithm according to the results. Now we will take a previous annual space launch plan as an example, and the data of the plan is shown in the following table:

Table 1 The annual space launch plan and the corresponding base and rocket data

No	Launch time	Launch location	Rocket type
1	01-12-30	Ba	A
2	02-02-16	Bc	A
3	02-03-28	Bc	C
4	02-05-12	Bc	A
5	02-05-16	Ba	A
6	02-05-24	Bc	A
7	02-06-21	Bc	B
8	02-09-07	Bc	A
9	02-10-01	Bb	D
10	02-11-29	Bc	B

In this year , there were 10 rocket launch tasks. Ba, Bb and Bc were specific base location for launch, and A, B, C and D stands for different rocket types, which we can use to get how much fuel should be needed.

Use the data above, we can make the annual transportation scheduling plan as the following tables:

Table 2 The annual transportation scheduling plan

No	Vehicle	Departure location	Departure time from base	M	Arrival time from base	Departure time from M	Launch location	Arrival time from M	Capacity loading(T)
1	Nd	Bb	01-12-09	Fb	01-12-19	01-12-21	Ba	01-12-31	90
2	Nd	Ba	02-01-26	Fa	02-02-05	02-02-07	Bc	02-02-17	90
3	Nd	Bc	02-03-04	Fb	02-03-14	02-03-16	Bc	02-03-26	90
4	Na	Bb	02-03-07	Fa	02-03-17	02-03-19	Bc	02-03-29	135
5	Nb	Bc	02-04-21	Fb	02-05-01	02-05-03	Bc	02-05-13	90
6	Nc	Bb	02-04-27	Fa	02-05-07	02-05-09	Ba	02-05-19	90
7	Nd	Bc	02-08-14	Fa	02-08-24	02-08-26	Bc	02-09-05	90
8	Nb	Bc	02-08-17	Fb	02-08-27	02-08-29	Bc	02-09-08	90
9	Nc	Bc	02-08-19	Fb	02-08-29	02-08-31	Bb	02-09-10	90
10	Nd	Bc	02-09-07	Fa	02-09-17	02-09-19	Bb	02-09-29	90
11	Na	Bc	02-09-10	Fa	02-09-20	02-09-22	Bc	02-10-02	135
12	Na	Bc	02-11-08	Fb	02-11-18	02-11-20	Bc	02-11-30	135

M stands for manufacturer

In the annual transportation scheduling plan, there were 12 special fuel transportation tasks. We will find that special fuel transportation task 3 and 4 serve the launch task 3, and special fuel transportation task 9 and 10 serve the launch task 10.

Table 3 The annual maintenance plan for each vehicle

No	Vehicle	Start time	Terminal time	Location	Maintenance type
1	Na	01-12-27	02-02-05	Bb	a
2	Nd	02-03-26	02-06-20	Bc	b
3	Nc	02-07-15	02-08-19	Bc	a
4	Nb	02-05-14	02-06-16	Bc	a
5	Na	02-04-30	02-09-01	Bc	c

According to the rules of the maintenance, each vehicle had been repaired at least once, which provide a reliable guarantee for the safety of special fuel transportation tasks.

Summary

This paper has a comprehensive analysis and research on transportation scheduling algorithm for special fuel of high frequency task. It makes an effective analysis on all aspects in the process of practical special fuel transportation scheduling, pinpoints the constraints and objectives of each procedure of the scheduling task, gives the structure form of scheduling plan and shows a clear and definite expression for the problem. Therefore we get a correct and effective conceptual model for special fuel transportation scheduling problem. Then, the reasonable and effective mathematical model of the problem is established, which presents the optimization objectives, constraint conditions and scheduling rules. According to the determined strategy and algorithm, the actual problems are solved efficiently and correctly, providing a reference for the decision makers to put forward scheduling plan in practice.

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