Intelligent Control Systems for the Rolling Equipment Maintenance of Rail Transport

F.F. Paschchenko
Institute of Control Sciences V.A. Trapeznikov Academy of Sciences
Moscow, Russia
feodor@ipu.rssi.ru

E.M. Zakharova
JSC NIIAS
Moscow, Russia

I.K. Minashina
Moscow Institute of Physics and Technology (State University)
Moscow, Russia

N.A. Kuznetsov
The Institute of Radioengineering and Electronics
Moscow, Russia

A.K. Takmazian
Research Institute of Mechanics
Lomonosov Moscow State University
Moscow, Russia
takmaz@imec.msu.ru

***Abstract* — One on the problems to be solved in the rail traffic management is the problem of planning of maintenance requirements of rolling equipment and those assignments by repair facilities. This problem approximates by transportation task and in this paper decides with using auction method.**

***Index Terms* — Rail transport control system, transportation problem, assignment problem, auction method, extreme, optimization problem.**

I. Introduction

Railway transportation is one of the most common ways of transferring large goods over long distances especially in Russia. The railway system covers the whole country, a significant quantity of people and resources are conveying every day by it. To provide such a large-scale volume of transportation company requires containing the appropriate amount of locomotive stock. Each unit must be operable in the relevant situation. Thereby planning of technological maintenance for every locomotive is necessary and very important task. Building a repairs schedule, distributing them at factories is a very difficult because of the large amount of data and a complex, non-linear technological constrains. In this paper we propose a model for necessary repair planning and distribution them by factory for the whole railway system [3].

II. Common problem description

This problem can be formulated as follows: at the entrance serves locomotives with their current mileage and technological mileage norms up to certain types of repairs. The first step is calculating the quantity and time of all type of repairs for every unit. The basis for determining the repair needs of locomotive is the construction of the repair cycle for each locomotive based on the average monthly mileage and locomotives mileage from the latest types of repairs. The solution to main problem is creating a locomotive repairs distribution plan that provides the most efficient use of repair factories taking into account the transport network specific attributes and technological limitations for distributing the maximum number of repairs.

III. Distribution problem

The mileage from the planned types of repairs and maintenance services is calculated for every locomotive. After this they are checked by criteria of validity of individual standards of overhauls for all types of repairs and maintenance. If the value of the actual mileage exceeds the individual unit repair norm this repair should be carried out. Those steps are executed for all locomotives. Finally, all repairs are summarized on types and series. Then those repairs are distributed between corresponding factories. The main criterion for choosing a repair factory is the shortest time from the locomotive's dislocation to the nearest repair factory witch can execute current repair type for current series. After the above calculations plan of locomotives repairs and their carrying out time is provided. The main problem arising in the distribution of repairs to factories is the construction of an optimal decision, which can be reduced to the transport problem solving finding of resource allocation in case of their heterogeneity. In this paper, a modified method of auctions is used to solve this task.

IV. Solving algorithms

In this case the distributing repairs to factories problem is reduced to the problem of multithreaded transport and connected to capacitive networks. There are a kind of capacitive network, consisting of nodes and branches, in which objects are transferred along branches. The main task is to find ways to move these elements without violating the maximum capacity for each arc. The path should not only be quite capacious but also as cheap as possible. Problems with minimal costs for multi-products due to their specific network structure are recorded as a linear programming model. The auction method can be provided for solving this problem. In comparison with others this algorithm first creates a database optimal for each individual product, and then repeats until the final solution will be finding.

A. Assignment problem

The auction method is a method of parallel relaxation for solving the classical assignment problem. The main idea is similarity with competitive bidding, where people provide some price for objects simultaneously, thereby increasing those prices. After determining all the bets, the one who offered the highest price is chosen. In this paper, the algorithm uses a modified auction method to solve the linear transport problem [1].

As with case of real auction, the price of the present participant should be higher than the current price of the object. Thereby a mechanism for increasing the price of the object is provided. The algorithm gradually progresses to the complete assignment of people to the objects, as the prices for some of the assigned objects become sufficiently high, so other objects become more appropriate for receiving rates.

In general, the algorithm can be providing insight into as follows:

There are *N* repair factories and *N* repairs for distributing task. For each factory *i* a nonempty subset *A (i)* of objects is exist, which can be assigned to this. The decision *S* is the set of factory-repair pairs *(i, j)*, so that:

- $j \in A(i)$ *for all* $(i,j) \in S$
- each factory *i* has no more than one pair $(i, j) \in S$
- each object j has no more than one pair $(i, j) \in S$

A *complete assignment* is a set of *N* pairs <*factory, repair*>. In this *S*-context the factory *i* is assigned if an object j exists such that $(i, j) \in S$. Otherwise, *i* is not assigned.

There is some given integer value $a_{i,j}$, which the factory *i* is associated with repair $j \in A(i)$. It is necessary find a complete assignment maximizing the following function:

$\Sigma_{(i,j) \in S} a_{i,j}$

This task is called the primary assignment task. In this paper we use the auction algorithm which solves the problem of dual purpose:

- minimize $\Sigma N_i=1\ _{ri} + \Sigma N_j=1\ p_j$
- subject to $r_i + p_i \geq a_{ij}$, $\forall i$ and $j \in A(i)$.

The dual variable p_i is called the price *j*. A vector *p* with coordinates p_j. $j = 1 \ldots N$, is called the price vector. In this case, the price is minimized when r_i is the maximum value of $a_{ij} - p_i$ over $j \in A(i)$. Therefore, p_j are the only variables for the dual problem. For a given vector, the value of the object $j \in A(i)$ for factory *i* is defined as

$v_{ij} = a_{ij} - p_i$

The maximum value of the objects $j \in A(i)$ is in turn a profit:

$\pi_i = max\ v_{ij}$.

From the theory of linear programming, we have that the complete assignment for primal and dual optimal is simultaneously only such in the case of:

$\pi_i = max_{k \in A(i)}\{a_{ik} - p_k\},\ \forall (i, j) \in S$

That is, the maximization of profit is realized if and only if a factory chooses an object with a maximum value. This is known as the complementary slackness condition. This condition allows a factory to choose an object with a price in the ε-neighborhood of the maximum solution. In this case, vector *S* and a price vector *p* satisfy *e-complementary slackness* if:

$\pi_i - \varepsilon = max_{k \in A(i)}\{a_{ik} - p_k\} - \varepsilon \leq a_{ij} - p_j,\ \forall (i, j) \in S$

That is, complete assignment S satisfies *e-complementary slackness* together with some price vector is optimal if $\varepsilon < 1/N$.

B. Common description of auction algorithm

- Initialization: Firstly, algorithm calculates the price for each repair to search for the individual optimal i.e. maximum one. This is provided with a one-commodity minimal cost flow problem solving. After this, in the light of the conflicts appearance of assigning of two identical repairs on the same path, an auction begins.
- Step 1. Each of the repairs involved in the auction should formulate a price to use this path, so each of them calculates the cost of changing the current one to another. This is done by solving the single-threaded task of minimum flow with taking into account the current optimal value.
- Step 2. The highest price should be chosen. This repair is assigned to this path, while others change the maximum cost on this path to zero.
- Step 3. There is repeating of the second step for those repairs that became unassigned earlier and now have to change their route. Therefore, they need to recalculate the prices which were made at previous auctions. As their prices change, they can resume the previous auction, changing the price to the original.

The algorithm is described in more detail in [2].

V. Results

In experiments the transport park with about 5000 and 65 repair factories with different types of repairs and a set of series was used. For this data volume the 16,000 repairs of different types were planned. Of these, 14,000 have been distributed and about 1500 have not been distributed. The calculation time is about 10-15 minutes approximately. Since this task was previously solved only manually, there is no possibility to compare the result with other systems, but technological experts note an efficiency increasing of the repair factories capacity using and reduction situations in which locomotives have overtaken mileage (untimely repairs).

VI. Conclusion

This work is devoted to the set of subsystems which was developed for solving the task of planning and distributing repairs needs to ensure the fulfillment of a repairs plan for a given period. To make an optimal distribution of repairs for factories schedule, taking into account various technological limitations, the modified auction method proposed by Bertsekas in [1] was used. This set of subsystems was implemented by JAVA language. This complex was developed, tested and allow not only could automate the calculation of the repairs plan for the specify period, but also distribute them for repair factories, maximizing both the number of distributed repairs and the overall utility Distribution, depending on various technological factors. Also, in connection with the automation of these calculations, the cases of over mileage of locomotives were reduced, which in turn shows an increase in the efficiency of the use of the locomotive resource park and the repair factories capacities.

References

[1] D.P. Bertsekas, D.A. Castaton, “The auction algoritm for the transportation problem,” Annals of Operations Research, 1989, vol.20 issue1, pp 67-96

[2] S.Smit, An Auction Based Approach to Multicommodity Minimal Cost Flow Problems, Vrije Universiteit, Amsterdam Faculteit der Exacte Wetenschappen, BMI Paper ,2007

[3] Pashchenko F.F., Kuznetsov N.A., Minashina I.K., Zakharova E.M., N.G. Ryabykh, Intelligent control system for the rail transportation, proceeding of AICT2016, 2016

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