Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 149 (2019) 50–56

Procedia Computer Science

www.elsevier.com/locate/procedia

ICTE in Transportation and Logistics 2018 (ICTE 2018)

Improving the technology of freight car fleet management of operator company

Oleg Shander[a,]*, Danylo Shumyk[a], Yuliya Shander[a], Oksana Ischuka[b]

[a]*University of Railway Transport, Feuerbach sq. 7, Kharkiv, 61050, Ukraine*
[b]*Transport Insitute of Riga Technical University, Azenes Street 12-316, Riga, LV-1048, Latvia*

Abstract

The study deals with distribution of freight cars of various forms of ownership within the railway network. Some variants of rail network topology were analysed by applying the graph theory and considering complexity of distribution of cars belonging to forwarding companies by routes. The railway subsystem itself should be considered as a compromise between its stability and flexibility. Thus, optimization model which formalizes technological process of freight car fleet management of operator companies has been developed. The objective of the given model is presented in the form of total operating cost and relevant set of constraints that takes into account technological conditions of route formation. On the basis of the systematic approach it has been proved that the increase of railway transport competitiveness is possible provided the railway subsystem acquired invariance properties. The mode optimization model adequately reflects the terms of transportation process, ensures the reduction of transportation costs under the condition of satisfaction of clients' requirements and provides for the formation of computer-aided fleet management technology for cars of different forms of ownership. Taking into account the theory of computational complexity, it is reasonable to choose heuristic method based on mathematical apparatus of genetic algorithms to obtain the optimal car distribution plan according to the routes.

Keywords: Railway transport; Forwarding company; Freight car fleet; Automated management system

* Corresponding author. Tel.: +380-577301088 ; fax.: +380-577301011.
E-mail address: shander@kart.edu.ua

10.1016/j.procs.2019.01.106

1. Introduction

During the reformation of the railway transport of Ukraine and the creation of a competitive environment, a technology for the organization of railway freight transport should be developed, which would take into account the presence of competitive forwarding companies that organize cargo transportation. In such conditions, the needs of customers in the transportation of goods should be met timely, and the rolling stock should be used rationally in the organization of transportation, subject to the peculiarities of the competitive environment in fulfilling the scheduled cargo transportation volumes throughout the Ukrainian railway network [1].

The experience of reformation of railways in the leading European countries has shown that one of the measures to improve the organization of transportation is preserving the state-owned railroad network and creating a competitive environment for railway transport by involving independent forwarding companies. The European model involves the creation of independent forwarding companies (car owners) acting as organizers and operators of cargo transportation on a commercial basis, and a railway company that is a monopolizer of the railway network and gives access to its network by providing a train path for a forwarding company at a charge or part of the capacity of the railway network required to pass a train between two points within a certain time. The process of creating a competitive market environment involves de-monopolization of its certain fields of activities and creation of conditions for the availability of railway infrastructure for users of different forms of ownership.

The analysis of the performance of railway transport showed a tendency for a significant shortage of rolling stock, namely the reduction of the own car fleet of Ukrzaliznytsia over the past few years. Under such conditions, consignors interested in the transportation of goods using their own rolling stock or forwarding companies' cars. Therefore, the access of forwarding companies to the infrastructure with their own car fleets is an important step for ensuring the profitability and competitiveness of the railways [2].

Thus, in view of the requirements of the railway and the forwarding companies, efficient technologies for the organization of freight transport should be formed and introduced, namely the management of the car fleet, and the implementation methods, based on the intellectualization of the system at all levels of the transport process, which in turn will provide flexibility to the system and improve the efficiency of transport services. A scientific problem of the formation of computer-aided management technology of the freight cars fleet of various forms of ownership appears.

2. Problem statement of organization of management of the freight car fleet of forwarding companies

Researchers and practitioners of railway transport have been concerned with the problem of managing the freight car fleet recently. However, most of the recently published works have been devoted to the development and improvement of the existing technologies and methods for managing freight cars which are concentrated in centralizing the distribution of cars of the respective forwarding companies, while they did not take into account the separate management of the car fleet by the forwarding companies. The existing planning methods cannot fully address the issue of rational regulation of the car fleet both in the entire network and in transportation directorates. This provision is based on the existence of a number of factors, such as the transition to the transport service market, seasonal transport, human, economic and other. Therefore, a series of complex research and the use of state-of-the-art innovative technologies is an important step necessary for the large-scale implementation of new techniques.

The transition to new methods of organization of the transportation is impossible without the assessment of international experience. International scientific works are particularly focused on determining the performance of transport in the conditions of uneven production flow and the construction of a rational route network. For this purpose, various economic and mathematical methods of modelling, in particular, computer simulation, are widely used.

Considering the European variant of the organization of freight transport, changes in the organization of the transportation will mainly involve issues of access of forwarding companies to the railway network and independent management of its own car fleet [3].

Therefore, the task of distributing and attaching the corresponding cars of forwarding companies along the route of the freight train has to be solved. Formation of routes and allocation of a train path can be implemented in two variants: variant 1 - when the train is formed at the respective departure station by one forwarding company and it takes directly a train path; variant 2 - when the train is formed at different stations by different forwarding companies, and a train path is accordingly provided to them [4,5].

3. Solving the task of distributing the freight car fleet of forwarding companies on the railway network

The choice of the optimal plan for distribution of cars along the routes depends mainly on the number of cars of forwarding companies at the railway stations and their location in space and time. Such conditions require, on the one hand, studying and forecasting the changing arrival of cars for routes, taking into account the inertia of the system, and on the other hand – studying the characteristics of the railway topology or other subsystems of the transport network.

In the article, the railway network is presented in general as a weighted graph *D(V,E)* the nodes of which are the railway stations, and the edges are the tracks connecting them [6,7]. So, set *V(v=1,n)* is a set of nodes, i.e. railway stations, while set *E(e=1,m)* is the set of edges, that is, the tracks connecting them. The weight of the nodes and edges of the graph *D(V,E)* is given. Intensity of the car flow $\mu_v = \mu(v,t)$ is chosen as a function on the nodes, where *t* - time within the planning interval. Herewith, if $\mu(v,t)>0$, then station *v* at moment *t* performs car sending operations and the flow enters the system, if $\mu(v,t)<0$, then station *v* at moment *t* performs operations related to waiting for the corresponding cars, if $\mu(v,t)=0$, then station *v* is either closed for operations or does not performed any at moment *t*. It is advisable to choose the length of the tracks and their capacity as the weight of edges *S(e)*.

Based on the above assumptions, the objective function of the model is given implicitly as follows:

$$C = f(D(V,\ \mathrm{E}), \mu(v,t), R) \Rightarrow min\ , \tag{1}$$

where R – number of trains which can be involved in distribution of cars along the routes on the railway network.

The following factors must be taken into account as constraints:

Length limitations of the freight train:

$$\sum_{\mathrm{v}=1}^{\mathrm{P}} \mu_v(v) \le L_v, \tag{2}$$

where L_v - length of the receiving and departure track at *v* station and $P-$ number of arrival stations on the train route.

Load carrying capacity limitations of the freight train:

$$\sum_{\mathrm{v}=1}^{\mathrm{P}} \int_{t_{0v}}^{t_{kv}} \lambda_v(v)dt \le Q_a \ , \tag{3}$$

where $Q_a -$ maximum load carrying capacity of the freight train, $t_{0v} -$ moment of beginning of operations at *v* station and $t_{kv} -$ moment of completion of operations at *v* station.

Capacity limitations of the railway sections:

$$\sum_e N_{вант.e}^{наявн} - \sum_e N_{вант.e}^{вик.} \ge \sum_e R_e, \tag{4}$$

where $\sum_e N_{вант.e}^{наявн} = r_e$ - available capacity of j - section, trains and $\sum_e N_{вант.e}^{вик.}$ - capacity required to fulfil a transportation plan.

Movement speed limitations:

$$V_{ae} \le V_{xe}, \tag{5}$$

where $V_{ae} -$ the speed of the freight train on j - edge and V_{xe} - nominal running speed.

The main criterion for constructing an operational management plan for the forwarding companies' fleet should be the minimum operating costs related to its implementation, but at the same time, the volume of fulfilment of orders should be maximized provided they are fulfilled in time. Therefore, the task of distributing and attaching the corresponding cars of forwarding companies following the route of the freight train is solved in the work.

The model of distribution of the forwarding companies' cars taking into account the attachment of orders to the routes of freight trains can be presented in the form of a graph which is shown in Fig. 1.

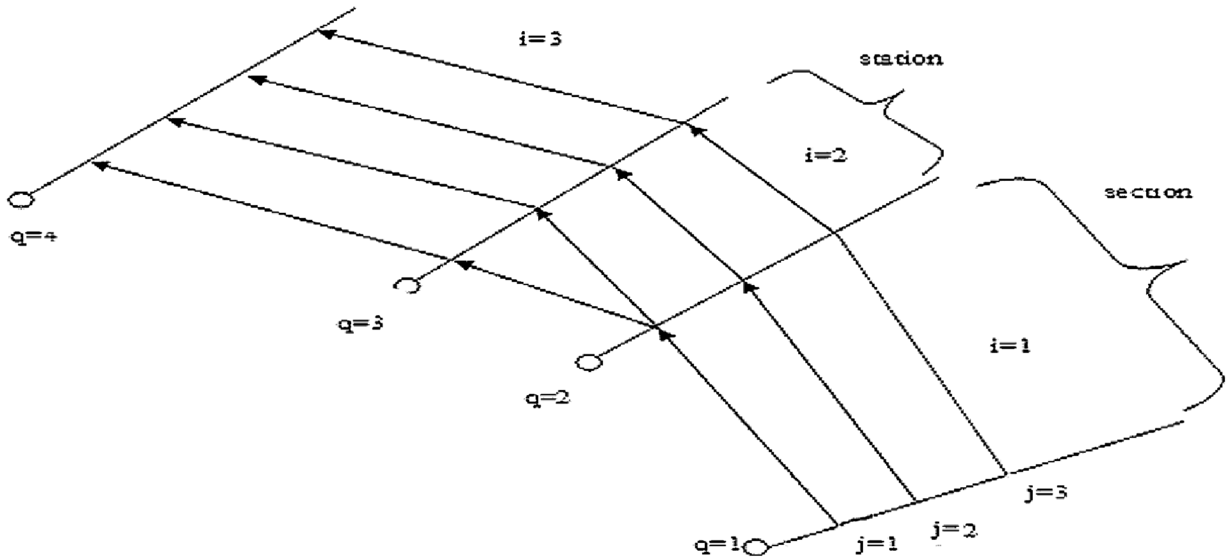

Fig. 1. The option graph of cars travelling along the route by the specified orders.

The graph shows the routes to which orders can be attached. The route can be understood as a combined, section, pick-up or another train, to which cars will be hitched. In accordance to the graph, an mathematical optimization model of the forwarding companies' car fleet management is proposed:

$$F = \sum_k \left[\sum_i \sum_j X_{ij}^k \cdot t_{ij} \cdot c_{ij} \cdot m_k + \sum_i \sum_j \gamma_j^k \cdot c_j^{переф.} \cdot X_{ij}^k \right] \rightarrow \min, \tag{6}$$

With limitations:

Load capacity of the freight train:

$$X_{ij}^k \cdot Q_m^k + Q_{скл}^{ij} \leq Q_{ij}^{\max} , \tag{7}$$

Freight train length:

$$X_{ij}^k \cdot m_k \cdot l + L_{скл}^{ij} \leq L_{ij}^{\max} , \tag{8}$$

Provided:

$$\sum_{j \in V \setminus \{i\}} X_{ij} = 1 \forall i \in V; \qquad \sum_{i \in V \setminus \{j\}} X_{ij} = 1 \forall j \in V; \qquad \sum_j X_{ij} = 1. \tag{9}$$

where $X_{ij}^k -$ variable which models the attachment of order k to train path j in section i; $X_{ij}^k \in \{0,1\}$ if 1 – cars from order k follow the path j in section i; 0 – otherwise; t_{ij} $-$ time which it takes the train to passing section i

by path j; c_{ij} – single cost rate of car-hour in section i ; $c_j^{переф.}$ – costs for re-composition on the route in sections i ; m_k – number of cars in order k.

This model takes into account all basic cost items depending on the chosen route travelling option for cars and can be used with any proposed technologies in the car fleet management. To adapt the model to the specific chosen technology, only the limitation system of the model should be changed by excluding, adding or correcting limitations. Thus, the developed model will solve the tasks of operational car fleet management and efficient interaction of the railways and the forwarding company.

Given the complexity of the problem, since the size of the matrices of adjacency varies within (200x282), an original heuristic method using the mathematical apparatus of genetic algorithms is proposed for its solution. There are multiple selection, transcription and mutation operators, the combination of which causes the existence of different types of genetic algorithms that have fundamental differences. These differences are as significant that certain types of optimization tasks can only be solved with the help of a certain type of genetic algorithm. To solve a unique task, creating special selection, cross-linking and mutation operators may be required, which will be adjusted to the task characteristics and data types that reflect the solution. It should be noted that different types of genetic algorithms can differ not only by types of genetic operators, but also by the principles of organization and the sequence of computing [7,9].

Thus, a type of genetic algorithm should be chosen, genetic operators should be chosen or created, and a fitness function should be created for the successful application of the mathematical apparatus of genetic algorithms for solving the optimization problem. However, the most important is the way to present a solution in the form of a chromosome. This method is related to a type of genetic algorithm with which it will be used, therefore, a way to represent a solution in the form of a chromosome should be created simultaneously with selecting a type of genetic algorithm. The proposed chromosome structure is shown in Fig. 2.

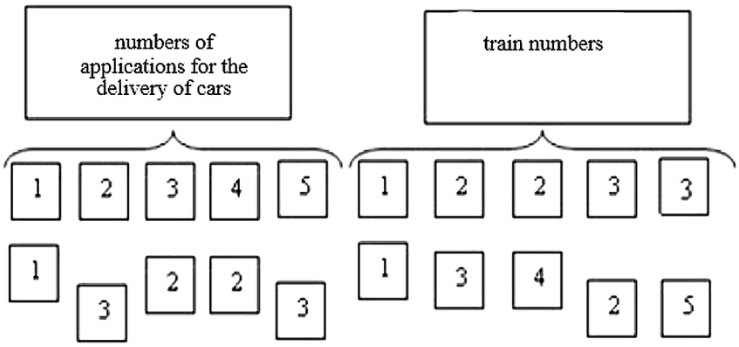

Fig. 2. Chromosome structure for searching for the optimal car distribution plan by train routes.

The chromosome consists of two parts, the first part genes match the order numbers with the numbers of the trains that fulfil them, the second part of the genes contains information about the route travelled by the respective trains. For efficient use of the developed model of the forwarding companies' car fleet management and computer-aided work planning in the railway network, a prediction model should be developed for bringing the accuracy of the input information to the appropriate level, namely the number of cars and the time of delivery of cars to the corresponding station.

One of the modern directions in the development of computer-aided prediction models is the use of the mathematical apparatus of artificial neural networks which enable to detect uncommon, invisible even for the expert's eye laws in the data analysis and provide for making high-quality predictions. However, in order to solve the problem of prediction of parameters of car delivery orders at the station in the network, the prediction model should provide prediction of two parameters: time of delivery of cars to the client to the corresponding station and the number of cars. In addition, the information about the number of ordered car provided by the customer to the railway should be taken into account. Thus, the proposed prediction model based on the Elman neural network should contain two inputs and two outputs. The first output of the network is designed to output information about the predicted car delivery time to the station. In order to take into account the information on the ordered number of cars, it is advisable to predict not the number of cars that the client will be able to load, but the difference between the ordered number of cars and the one that is supposedly will be actually used. Then, the second output of the model represents the predictive difference between the order and the actual need of the customer in the cars at the relevant station. During the study and use of the model, historical data are fed to the first and second inputs of the model in the form of time series of the time when the beginning of car delivery to the load station by the railway, and the difference between the ordered and actually used cars, respectively [8]. The basic form of the architecture of the artificial Elman recurrent neural network, which is the basis of the established prediction model, where x_1, x_2 — neurons of the input layer y_1, y_2 — neurons of the hidden layer, u_1, u_2 — neuron of the context layer, z_1, z_2 — neurons of the initial layer, W_x, W_y — weight of connections between neurons is shown in Fig. 3.

Only minimal number of neurons in each layer is shown, the optimal number of neurons, which provides a given accuracy of the prediction, is determined by modelling. Neurons that are part of the recurrent block (hidden and context layers) have an sigmoid activation function, the neurons of the input and output layers have a linear activation function.

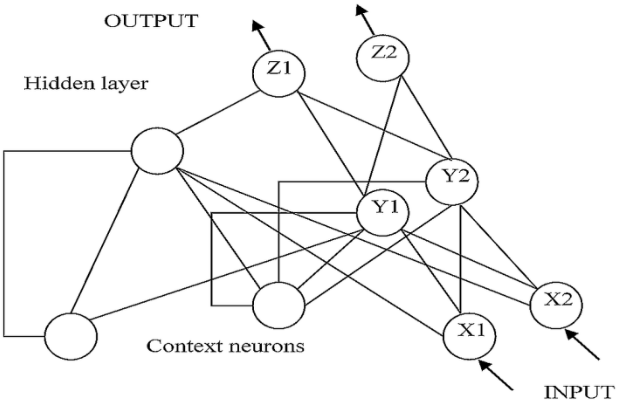

Fig. 3. Architecture of the artificial neural network model for predicting the car delivery time and the number of required cars.

The proposed model is implemented in the software. The adequacy and accuracy of the model was checked using the actual data of railway stations about the number of cars, the car delivery time and the predicted values of these parameters obtained using the model for the same planning period.

4. Results of simulation of car distribution by the routes

To implement the computer-aided car fleet management system, software was developed that contains tools for solving optimization problems, in particular, using genetic algorithms, and also has wide opportunities for creating graphical interfaces. The objective function and the of constraints system of the proposed mathematical models were implemented as a fitness function used by the genetic algorithm to assess the quality of solution options when selection of operations among the solution population is performed. Upon receipt of the input data, the program generates a genetic algorithm that executes a controlled stochastic search using the developed functions of population solution generation, mutations, crossing, and choosing the best solutions for creating subsequent populations. The algorithm ends when one of the stopping criteria is reached, such as reaching the limit of the number of population solution generations, the number of calculations of the fitness function, the running time of the algorithm, or the given calculation accuracy of the fitness function [9]. Fig. 4 shows the improvement of the fitness function during the execution of the genetic algorithm. The time spent by the software to make the corresponding work plan was about 2 minutes.

The simulation was conducted on a created virtual operating domain, which is represented by a graph numbering 50 nodes (stations). The task of modelling was to make a car distribution plan for the respective trains specified in the given base, which must fulfil the specified number of transportation orders. The planning period was 12 hours. After the genetic algorithm ends, the program interprets the chromosome which contains the optimal solution and executes the procedure for making a car distribution plan [10].

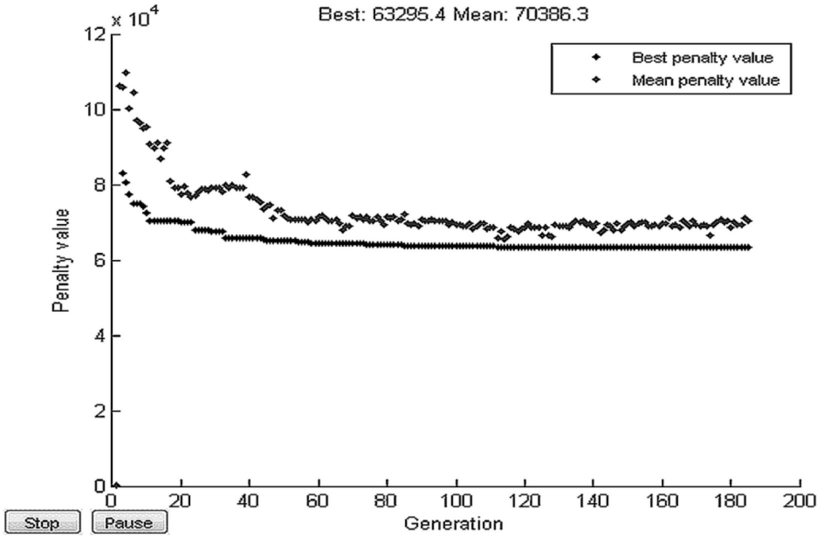

Fig. 4. Changes in the values of the fitness function during the execution of the genetic algorithm.

5. Conclusion

Modern approaches to improving the technology of freight car fleet management should focus on increasing the competitiveness of railway transport by providing the railway subsystem with the invariance properties, which should be considered as a compromise between its stability and flexibility. In order to provide these properties to the railway system, an optimization model was developed that formalizes the technological process of the forwarding companies' freight car fleet management, with the objective function in the form of total operational costs and the corresponding set of constraints which takes into account the technical and technological conditions of the process of formation of the corresponding routes. The developed optimization model adequately reproduces the conditions of the transportation process, which provides for reduction of transport costs and satisfaction of the requirements of clients (forwarding companies).

References

[1] Butko, T., A. Prokhorchenko. (2013) "Investigation into Train Flow System on Ukraine's Railways with Methods of Complex Network Analysis." *Science and Education Publishing From Scientific Research to Knowledge, American Journal of Industrial Engineering* **1(3)**: 41-45.

[2] Ahuja, R.K., C. B. Cunha, and G. Sahin. (2005) "Network Models in Railroad Planning and Scheduling." *Tutorials in Operations Research INFORMS* **1(1)**: 54 – 101.

[3] Narisetty, A. K., J. P. Richard, D. Ramchar, D. Murphy, G. Minks, and J. Fuller. (2008) "An Optimization Model for Empty Freight Car Assignment at Union Pacific Railroad." *Interfaces, INFORMS* **38(2)**: 89–102.

[4] Verma, M., A. V. Verter, and M. Gendreau. (2011) "Tactical Planning Model for Railroad Transportation of Dangerous Goods." *Transportation Science* **45(2)**: 163-174.

[5] Lulli, G., U. Pietropaoli, and N. Ricciardi. (2011) "Service Network Design for Freight Railway Transportation: The Italian Case." *Journal of the Operational Research Society*.: 1 – 3.

[6] Zhuang, Q., and X. Zhang. (2014) "Slot Allocation Algorithm of Railway Freight Transportation Based on Sales Agreements." *ICLEM*.:129-135.

[7] Butko, T., and O. Shander. (2014) "Formalization of the process of freight car fleet management of operator company." *Eastern-european journal of enterprise technologies* **2/3(68)**: 55-58.

[8] Medsker, L.R., and L. C. Jain. (2000) "Recurrent neural networks: design and applications." *Boca Raton, FL: CRC Press.*: 25-27.

[9] Gladkov, L. A., V. V. Kureychik, and V. M. Kureychik. (2006) "Geneticheskie algoritmyi." *Fizmatlit*.: 402.

[10] Sherali, H., and A. Suharko. (1998) "A tactical decision support system for empty rail car management." *Transportation Science* **32**: 306–329.