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# Organization of railway freight short-haul transportation on the basis of logistic approaches

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**Abstract**

For railway short-haul transportation to become a viable alternative to road transport and to compete with them, it is proposed to use trains such as CargoSprinter. The use of this type of autonomous rolling stock in the course of short-haul transportation offers the following advantages: it provides high mobility and high speed of delivery of cargoes due to a decrease in dependence on the schedule of trains while reducing the dependence on weather conditions, traffic congestion, as compared with road transport, disappears the need to use shunting locomotives, it is possible to support production logistics chains, which include local production enterprises based on the organization of transportation using logistics schemes such as D2D (door to door delivery) and JIT (just in time delivery). The mathematical model of organization of short-haul railway transportation based on the use of CargoSprinter trains is proposed. The original method of model optimization based on the use of the mathematical apparatus of genetic algorithms is proposed. The developed software allows to obtain a solution in the form of an operational plan, which provides synchronization of the process of transportation for the railway network subsystem, which has a complex topology.


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*Keywords:* CargoSprinter, Organization of short-haul transportation, Mathematical model, Genetic algorithms, Operational plan.

## 1. Introduction

Railway transport of Ukraine in the field of freight traffic at the current stage of operation has weak points. Especially it concerns the cargo owner's demand for the possibility of cargo transportation "from door to door", "just

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in time", cost and flexibility of the schedule in comparison with road transport, information component and so on. The basic information provided by regular customers-cargo owners is a liquefied-monthly order for the carriage of goods in which the total volume of wagons or containers is painted for decades and by days of the month. Usually this volume is distributed evenly over the working days of the month, there is often a tendency to overestimate the volume of the needs of containers or wagons. Therefore, such orders very rarely coincide with the real volumes of the load. The reason for this phenomenon is a number of factors: the irregularity of the work of enterprises, which in turn is due to market volatility, causes frequent changes in wholesale prices for enterprise products, delays in the supply of raw materials, delays in settlements between the consignor and the consignee, caused by the banking system or financial departments of enterprises, changes in demand for products, including those caused by seasonal factors, the lack of modern systems and methods of organization of production in enterprises with insufficient ate peppers nicknames, transport and cargo facilities, depreciation of equipment, causing frequent breakdowns, deliberate overstatement of customer volume requirements for wagons or containers, due to the scarce amount of penalties for failure to use the full load orders. Non-fulfilment of the plan for presenting goods for transportation leads to the fact that the railway provides wagons or containers, are unclaimed, and the other railroad is forced to provide wagons or containers less than indicated in the order and even less than the real need, since for more than one year the iron the road suffers a deficit in all types of rolling stock, especially freight cars and containers.

## 2. Autonomous container trains as a base of new technology of freight short-haul transportation

An analysis of the local work on the transportation of goods by the formation of trains of established long-distance, prefabricated, export, transfer and dispatching locomotives also indicates that the existing means and technology of its organization do not match the growing demands of the transportation market, despite their advantage in covering expenses.

So, for successful competition with road transport in the freight rail market, it is necessary to organize the local work of railway divisions on the basis of logistic principles, for this purpose it is necessary to solve the following tasks:

- Not only to provide an opportunity for customers to place an order online, but also to ensure the most rapid response to them
- To increase the speed of freight transport, to provide the possibility of carrying out express transport operations
- To develop and implement new concepts of freight trains
- To ensure the possibility of carrying out freight rail transportation on the principle of "pick-up and delivery"
- To develop convenient ways for clients to manage operations for the movement of goods and the organization of permanent material flows
- Development of convenient transportation schemes using universal and specialized containers
- Ensuring the development and implementation of a modern operational planning system by local work, which will provide an opportunity for manufacturing enterprises to establish reliable supply chains among themselves and in cooperation with the railway

In logistics systems that operate on a "just-in-time" and "door-to-door" basis, the main factor that ensures efficient work on the supply and sale lines of goods and materials is the new services of transport companies for the collection and distribution of goods. Such services of transport enterprises ensure the acceleration of transportation over long distances from suppliers to producers or markets of final products and often exclude links existing in traditional systems of cargo acquisition. As a result, conducted operations usually are less expensive and higher quality of service is provided than with competitive distribution methods. In addition, companies using new services receive direct benefits, reducing the duration of transportation.

Such new services can be the mass transportation of goods by containers, which is so developed today that it allows to deliver goods, including goods, personal belongings, to any point on the map. The reliability of such delivery, in the vast majority of cases, is guaranteed. Freight containers used for transportation are convenient because they are designed for transportation by various modes of transport, from road to sea. That is, the same container with cargo takes part throughout the logistics chain in its final destination. The railroad should not stand aside from such a transportation chain, but take an active part, it is not possible by the existing technical means.

Therefore, one of the most promising areas for the realization of local cargo transportation is the introduction of autonomous container trains such as the CargoSprinter modular freight diesel train or other modifications. The concept of such small trains corresponds to the possibility of the railway infrastructure in an instant response to the variable and unexpected demands of shippers in terms of time, location, the intensity of the appearance of the cargo, its departure and destination points.

CargoSprinter was developed in 1996 by Windhoff together with cargo operators DB Cargo and Fraport. Technically, the CargoSprinter consists of two motorized front and rear control cabins with container platforms and intermediate plates (intermediate flatbed) for loading containers.

It is possible to load up to seven such trains simultaneously independently from each other at different loading stations before forming one long train. Combining blocks is done in minutes and further movement is carried out by the principle of many units of the cargo terminal (station) of their disengagement. Movement CargoSprinter carried out at a relatively high speed (up to 120 km/h), which allows to ensure freight traffic without much impact on the movement of other trains. Thus, significant advantages of using them are speed, flexibility, maneuverability and cost-effectiveness. The use of such non-self-propelled self-contained two-directional trains can be a factor that will ensure the competitiveness of the railroad with respect to road transport for freight transport. So the system of organization of cargo railroad transportation on the basis of trains such as CargoSprinter creates a synergetic effect from the simultaneous integration of advanced technologies with fairly simple technical solutions, which makes it a successful model for both local and long haul [1].

The implementation of the technology of local work at the railway division, based on the concept of an autonomous combined train, envisions them on arbitrary routes between points of loading and unloading (stations connecting the access roads, freight stations). But such technology will be economically expedient and competitive in comparison with route trains, when for every autonomous train the route will be found with minimum distances if the obligatory condition of exportation or importation of all cargo is "just in time" in the conditions of the current situation in the transport market during the planning period. In other planning periods, which will correspond to other traffic volumes, the route schemes may change, which corresponds to the processes of self-organization of the system.

The complexity of the operation of such trains can be attributed to ramifications of the network, the restriction of the capacity of sections by other categories of trains on the direction (especially single track), the imperfection of automating the technology of servicing local wagons from the point of view of logistics and the constant need for an operative correction of the train schedule.

Thus, the introduction of flexible, automated technology of local work based on a logistical approach using an autonomous train is impossible without the creation of a modern automated operational planning system and requires the formalization of the transportation process in the form of an optimization task.

## 3. Mathematical formulation of the problem

From the point of view of mathematical formulation, the task of transporting local cargo using trains of the CargoSprinter type is a kind of the known problem of vehicle routing problem, which was first formulated in [2]. This problem is very important theoretically that it has connections with some well-known problems of discrete mathematics and also generalizes some other known problems, such as the traveling salesman's problem, therefore, every year the academic interest to it only increases. At present, several dozen formulations of this problem are known, each of which emphasizes certain features of its theoretical formulation or practical implementation. A significant number of scientific publications published in recent years, is devoted to the dynamic formulation of this task, which allows to operate in a stochastic environment, where the parameters of orders such as time, points of loading, unloading, etc. unknown in advance, and the order appears already in the process of operating mobile units [3, 4,5,6].

However, local work on the Ukrainian railway is carried out in the conditions of the functioning of the MESPLAN system, which allows customers to independently register in advance the orders for transportation, a significant part of which is carried out on a regular basis.

However, the time of operation of cargo fronts is very limited, especially if these are small enterprises. The cargo front of each enterprise operates on an individual schedule. So this task must be solved taking into account the time windows of the freight fronts. The task of VRP in this setting is also described in scientific publications [7]. In addition, maximum efficiency with the use of autonomous container trains can be achieved only if the most complete utilization of their carrying capacity on most of the routes. This mode of use can be achieved only if several trains are executed by each train at the same time. That is, the work plan for the trains should be such that at the stations where part of the cargo is being unloaded at the same time there is a pumping of the train, or it should be pumped at stations that are farther from the station for a minimum distance. The tasks of routing vehicles with simultaneous unloading and loading were also considered in the scientific literature [8]. However, the tasks that operate with the simultaneous unloading and loading together with the restrictions that are due to the temporary windows and load-carrying capacity of vehicles have not been practically considered, although they are of the greatest practical interest.

Consequently, the effectiveness of the plan is determined by the minimum operating costs required for its implementation. Thus, operating costs are the only universal criterion that will be presented in the objective function of this optimization task. The real cost structure in the implementation of freight rail transport is very difficult. To simplify the calculation of the cost of operating costs apply the method of expenditure rates, the essence of which in the allocation of two or more meters on which all other items of expenditure depend. In this case, it is expedient to distinguish the following two main components of the operating costs of the train-kilometers, on which the fuel costs for the transportation of goods depend, as well as part of the costs of maintaining the infrastructure; train-hours, on which the costs of employees' wages depend, the costs of depreciation of rolling stock and also part of the infrastructure costs. So the objective function can be written as follows:

$$C(S) = e_{tr\cdot km} \sum_{i=1}^{\#S} \sum_{j=2}^{N_{P_i^S}} L_{j-1,j} + e_{tr\cdot h} \sum_{i=1}^{\#S} \sum_{j=2}^{N_{P_i^S}} \left( \frac{L_{j-1,j}}{v_{i,j-1}} + \sum_{k=1}^{\#R} \left( \gamma_{ijk} \left( t_{ik}^{w} + t_{kj}^{l} \right) \right) \right) \rightarrow \min \tag{1}$$

where:

- $S$ – a variable set of vectors containing information on the assignment of orders for trains and the sequence of service orders for each train, taking into account the sequence of loading and unloading orders
- $\#S$ – the power of a set of vectors $S$, corresponds to the number of trains involved in the implementation of the plan for the transport of local cargo
- $e_{tr\cdot km}$ – cost of train-kilometer
- $N_{P_i^S}$ – the number of stopping points along the i-th train's route
- $L$ – the square matrix of the distances between stations on the railroad network
- $e_{tr\cdot h}$ – the cost of a train-hour
- $v_{i,j-1}$ – route speed, which can develop in the i-th train on segment of its $(j-1)$-th route
- $\#R$ – capacity of many orders for transportation of local cargoes
- $\gamma_{ijk}$ – a variable that takes the value 1 in the case where a freight operation (loading or unloading) is performed at the j-th station of the i-th train route, with the k-th order, or takes the value 0 otherwise
- $t_{ik}^{w}$ – the waiting time for the beginning of the cargo front's operation to be performed by the i-th train of the cargo operation with the k-th order
- $t_{kj}^{l}$ – duration of the cargo operation with the k-th order at the j-th station
- $P^S$ – set of routes of all trains, corresponding to the current plan for the transport of local cargo

When optimizing this objective function, it is necessary to take into account technological limitations. The first limitation concerns the carrying capacity of trains. For any train at any time, the total weight of cargo loaded on it according to the maintenance plan should not exceed the maximum carrying capacity of the train. It isn’t possible to load a cargo on a train if its weight, together with the weight of the load, which is already loaded, exceed the maximum load capacity of the train. The cargo delivery plan must be such that at the time of arrival of the train at each of the stations of its route, the amount equal to the amount of its unused cargo capacity and weight of cargo will first be unloaded at the station, there should not be less weight of loads that will be loaded on this train given station. Therefore, this restriction can be written as follows:

$$\sum_{j=1}^{N_Q}\left(H\left(-\left|\left(\sum_{k=1}^{m_i}H\left(-\left|s_{k,i}-j\right|\right)\right)-1\right|\right)\cdot Q_j\right)\le Q_i^{\max},\quad \forall\ m_i\in S_i,\ \forall\ i=1..\#S,\ \ s_{k,i}\in S_i \qquad (2)$$

where:

- $S_i$ – the set of elements of the vector containing the information on the order sequence of orders by i-th train
- $m_i$ – an arbitrary element number sequence $S_i$
- $s_{k,i}$ – k-th element of the set $S_i$
- $Q_j$ – the weight of the j-th order
- $Q_i^{\max}$ – the maximum carrying capacity of the i-th train
- $H(x)$ – Heaviside function, which is defined as follows:

$$H(x)=\begin{cases}0, & x<0\\ 1, & x\ge 0\end{cases} \qquad (3)$$

The following limitation applies to temporary windows. If the train arrived at the station before the moment of the beginning of the cargo front operation, then an element appears simple waiting for the execution of cargo operations. The qualitative plan has such total value of these elements, which is close to the minimum. So these elements of downtime can’t always be completely eliminated, and their presence does not indicate the impossibility of implementing the plan. The ability to meet orders in full disappears only if the total time of arrival of the train to the station and the duration of the cargo operations exceed the time that corresponds to the moment of completion of the cargo front:

$$t^a_{s^i_j}+t^l_{s^i_j}\le t^c_{s^i_j},\qquad \forall s^i_j\in S_i,\ \ \forall\ i=1..\#S,\ \ j=1..\#S_i \qquad (4)$$

where:

- $t^a_{s^i_j}$ – the time of arrival at the station to perform the cargo operation of the corresponding element $s^i_j$ of the sequence $S_i$
- $t^l_{s^i_j}$ – the deadline for performing cargo operations corresponding to the element $s^i_j$ of the sequence $S_i$
- $t^c_{s^i_j}$ – the moment of the closing time of the cargo front, in which, according to the plan, it is necessary to perform cargo operations corresponding to the element $s^i_j$ of the sequence $S_i$
- $\#S_i$ – the power of the set of elements of the sequence $S_i$ corresponding to the number of operations for loading and unloading orders that the i-th train must perform

## 4. Model optimization and results

In the scientific literature it was proved that the VRP (vehicle routing problem) problem is NP-hard [9]. This means that it is practically impossible to solve with the help of classical methods of optimization the real task of planning the work of several trains, which should serve customers whose cargo fronts are located at several dozen railway stations. For this reason, in the scientific literature, together with the classical methods of mathematical programming, the use of meta-heuristic search methods is proposed, an important element of which is an element of randomness. In particular, a hybrid method is proposed in [7], which is a combination of the taboo-search method and the genetic algorithm.

However, the implementation of such algorithm is rather complicated in practice. In [8], the use of taboo-search in combination with other methods is also suggested. However, in 1993, the rapid convergence of genetic algorithms was proved in comparison with the taboo-search in solving planning problems [10], in addition, since then, genetic algorithms have significantly evolved and their effectiveness has significantly increased. In addition, taboo-search is a method of local search and searches for a solution based on the current state, it does not take into account and does not remember the states already passed. But the genetic algorithm is able to search for large-dimensional solutions in space, its ability to operate simultaneously with the entire population of solutions minimizes the probability of falling into local minima, besides it is much more flexible and universal of other methods.

So it is proposed to choose the genetic algorithm as a mechanism for optimizing the developed model. However, instead of using complex hybrid algorithms, which were described in [6, 7], the use of a conventional genetic algorithm with real coding is suggested. This approach will allow to abandon the multi-stage regimes of solving the problem, will allow to increase the accuracy of the solution and the rate of convergence of the algorithm.

However, taking into account the fact that it is simultaneously necessary to compare the order numbers with the numbers of trains and also determine the sequence of actions when servicing orders, the chromosome must have 2 separate logical parts. The first part of the chromosome represents the numbers of trains, finding a certain numerical value at a certain position means that the train with the number corresponding to this number has an order corresponding to the position number intended for servicing. The other part of the chromosome contains information about the order of service orders, so it must be processed on a combinatorial basis. It contains a constant set of values, only their sequence changes.

For the correct processing of chromosomes, which have such heterogeneous structure, the standard genetic algorithm requires only modifying genetic operators. It is proposed to create a crossing operator by combining a simple arithmetical crossover and a simple unary two-point combinatorial crossover operator. Also, small changes are suggested for the mutation operator, which must operate with genes depending on the location of the gene in the chromosome, if the mutation occurs in the first part of the chromosome, a random change in the gene value occurs, if the mutation occurs in the second part, the two adjacent genes are rearranged.

Based on the created model, software was developed in the MATLAB environment. The simulation was carried out for a virtual railway test site, which numbered 59 stations and was represented by a graph that had a branched network structure. The task was in building an optimal plan for the delivery of goods in order to fulfill 24 orders with the help of six autonomous trains. In solving this problem, the genetic algorithm demonstrated a confident and rapid convergence (see Fig. 1).

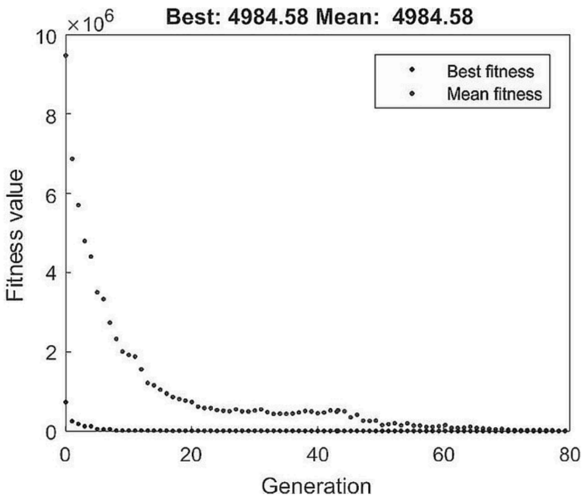


Fig. 1. Average and best values of the target (fitness) function, depending on the number of the solution population.

Fig. 2 shows the railway range as well as the routes of autonomous trains with the specified stations for the operations of loading and unloading orders, the number of containers and the times of operations.

The mode of operation of all cargo fronts was adopted the same and corresponded to the time windows from 7:30 to 17:30. It is possible to design the optimal plan for the interaction of autonomous trains with cargo fronts (the numbers of which are indicated on the abscissa axis), which was built by the program and presented in the form of a contact schedule.

According to this plan, none of the six autonomous trains was idle for a moment in anticipation of operations, each of the six autonomous trains used almost the same time to accomplish their task. Thus, on one train, on average, there were 4 orders, each of which had both a loading station and an unloading station.

According to the received plan, all orders were fulfilled in spite of the fact that a significant number of stations were located from each other at a distance of several hours of the autonomous train.

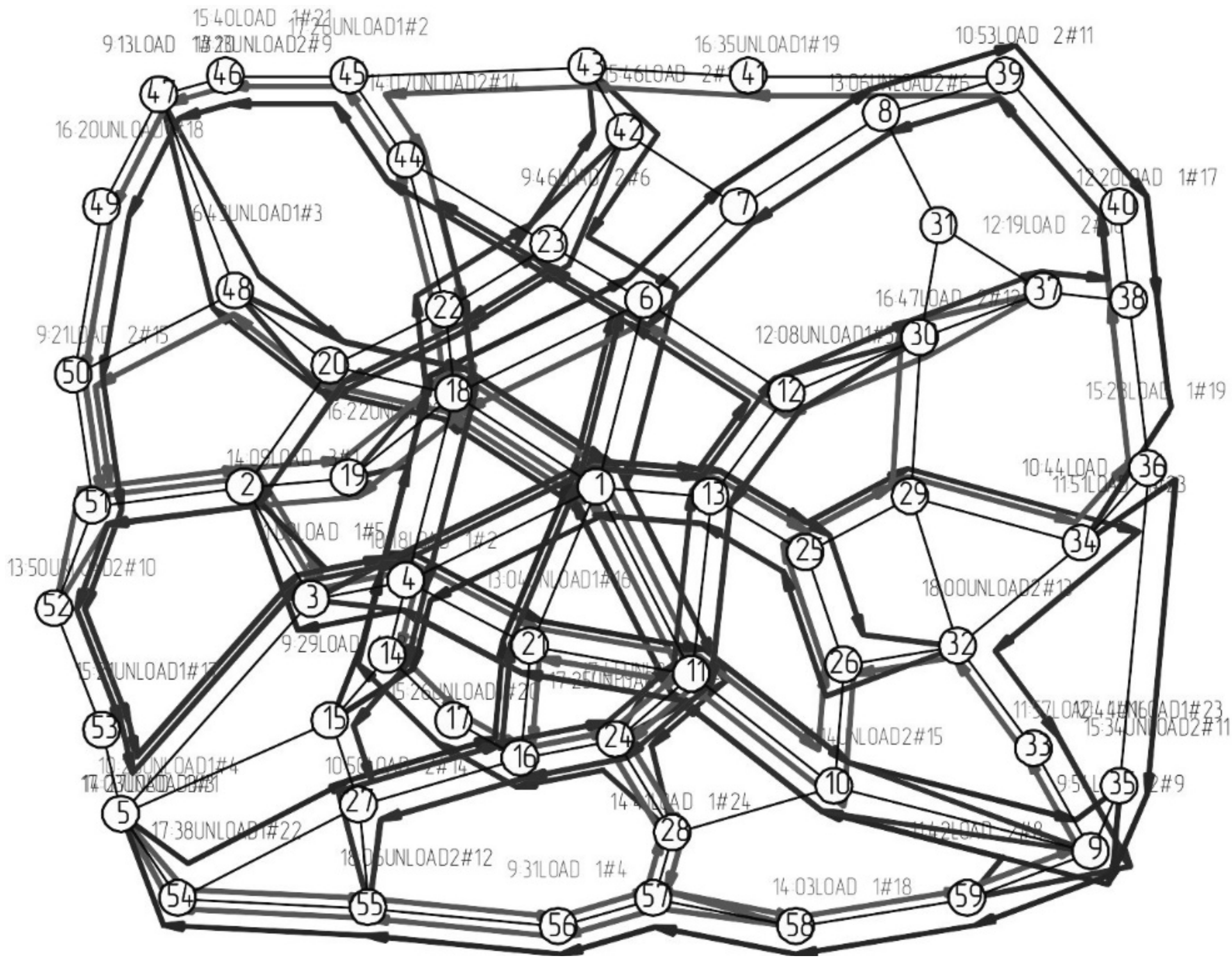


Fig. 2. The graph of the network of the railway training ground with the autonomous trains marked on it, the times of the beginning of the operations of loading and unloading, the order numbers and the number of loaded or unloaded containers.

## 5. Conclusion

Thus, the problem of routing vehicles taking into account the time windows of the operation of freight fronts and restrictions on cargo carrying capacity, as well as the possibility of pumping cargo and their associated unloading is in demand and is of considerable interest at the present stage of development of rail freight traffic in Ukraine.

The creation of an effective and convenient method for solving this problem, including for a large-scale case, will allow to formulate a procedure for constructing rational operational plans for local work, as well as plans for the transportation of goods over medium distances with the help of autonomous trains such as CargoSprinter.

The conditions for freight rail and road transport in Ukraine differ significantly from similar conditions in the European Union countries, which allows to hope that this technology will prove to be not only viable, but also a successful example of the introduction of logistics principles in the field of freight rail transport. This technology can prove to be a powerful argument in the tough competition with truckers in the freight market for short and medium distances.

So the task of routing vehicles is of considerable practical value for the development of this technology. As the results of the research have revealed, this problem can be effectively solved even in its most complete formulation with the help of only a genetic algorithm of the usual type without using complicated methods of hybridization of algorithms.

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