OPTIMIZATION MODELS OF RAIL TRANSPORTATION UNDER THE FINANCIAL CRISIS

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Abstract:*This paper proposes an analysis of the most used models to optimize the rail transportation. Are presented a series of optimization models of labor efficiency in this sector, but also elements that gives the information on the competitiveness of this mode of transport.*

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JEL Classification Codes: **C32, C39, D85, L92, L96**

INTRODUCTION

In rail transport, smooth running of the work requires coordination of productive activity, a significant human and material potential. Need for employment in economic and social process has led to the need to address possible problems of traditional problem-based treatment, organization activities and decision making in this regard. Also need to obtain reduced costs of railway transport as, actually positive influence on cost of goods and increasing the number of passengers approach led to the adoption and use of operational research models, econometric and stochastic in order to obtain results as best of economic, social and technical

1. MODELS FOR OPTIMIZATION OF RAIL IN THE LITERATURE

Fundamental basis to optimize program of movement and loading / unloading of trains is the plan with a single line which determines the number of trains serving the line connecting two terminal stations in a fixed period (Bussieck et al, 1997). Many researchers have tried to solve real problems by adding different constraints and conditions on this basis.

Thus, works of Morlok and Peterson (1970) are known as some of the old in problem of finding solutions to optimize train movements. The purpose of these approaches is to minimize the amount of fixed costs for trains, variable costs for transport, handling and

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storage of goods, and the opportunity costs of using rail equipment, providing goods and timely delivery of time-dependent.

Jovanovic and Harker (1991) have developed the model SCAN-I to build schedules and plans to crossing of the trains, with emphasis on robustness and eliminate random happenings during travel. They considered a discrete and combinatorial optimization algorithm for finding optimal solutions to various problems in the rail to assess whether a calendar is possible based on deterministic assumptions

Kraay et al. (1991) built the MINLP problem for variable speed train (for cases of routes with speed limits), while Jovanovic and Harker (1991) formulated a mixed problem with integer variables for fixed speed. The objective is to minimize delays trains and fuel costs. The result has allowed greater flexibility in programming and reducing fuel costs.

Kraay and Harker (1995) have developed a real-time programming model for freight rail transportation.

Carey and Lockwood (1995) presented the timetable problem on a single rail line assuming a constant speed for each train. They built a timetable and a program to minimize the total delay to maximize speed and line length train loading and unloading.

Higgins et al. (1996) developed a model to optimize the programs of movement the trains on with a single line rail corridors. The objective of this work is to determine a lower limit that will allow finding the optimal solution of the problem in reasonable time.

Marin and Salmerón (1996) have developed a model aggregate steady state planning in freight, the train routes have been determined (including stations), their frequency and number of cars used by each service. Costs include a fixed fee for each train, handling costs and investment costs in delay and additional trains. Constraints refer to the number of cars on each track segment, the number of cars that are used in each yard and the number of trains.

Nozick and Morlok (1997) formulated a discrete time problem to minimize total cost of moving the walls and platform wagons loaded and empty train determined size. They developed a procedure that follows an iterative solving of linear programming problems and some rounding fractional values to determine result feasible integral solutions.

Chang et al. (2000) developed a model for the planning multi-purpose passenger transport services. They determined the optimal allocation of rail passenger services on an inter-city high line speed without secondary lines.

Ghoseiri et al. (2004) have also developed a model for the planning multi-purpose passenger transport services. Design objective is to minimize fuel cost and total travel time.

2. OPTIMIZATION MODEL FOR ORGANIZING A TRAIN

Optimum method of organizing a train (Train Set Organizing Optimization-TSO) aims to form a train for Freight with the new generation facilities and highly trained and professional experts, and is one of the most common methods used in the management of railway transport.

The main objectives of the TSO are: efficient transport, using rail transport fleet reasonably, promoting cooperation between different departments involved in the shipping procedure.

Methodology has several levels of action: the national railway network, or local rail network and operating on a group of operators.

Nationally, the main concerns in the rail network are: Decision types of trains, lining up, number of trains, and detailing their routes. Railway network objectives include improving transport capacity and speed of operation, cost reductions, balancing the pace of work in the divisions and allocation of new employment or redundancies between different stations/stations nationwide.

In addition to the tasks that the staff railway station, establishing a seal, forming a train according to the norms required by the railway network, on all types of freight cars, are involved to in this process a series of operations relevant, such as collection or delivery, handling, loading/unloading and checking cars. The main concerns of the railway station personnel are conducting operations efficient, economical and safe, rational use of transport devices such as railway lines, shunting locomotives, marshalling hump; setting with specialized programs, operations steps and cooperation between those working in the steps of the framework program of railway network.

Due to the complexity of processes occurring in the formation and movement of trains for transporting goods, can be made simplifying assumptions of the model, namely:

1) the rail transport offer is less than demand, the scope of TSO is to fully utilize the transmission capacity;
2) topographic structure of the railway network is a circle of railway lines, this assumption is made to specify the continuous nature of transport;
3) the main line is double, to run to run simultaneously two trains between two stations, running in opposite directions;
4) under the railway network between the technical stations A and B, there are not others of the same type;
5) unit of workload related to handling and transshipment cargo operation is the same for all technical positions, for the same train at each station is assigned technical time to complete the same load.

Based on these assumptions, decision makers of rail network wish density trains (as measured by time intervals between any two adjacent trains in circulation) and train length is as large as possible to achieve maximum transport capacity. However, for safety reasons, the density is determined by the length of railway network and the seal is determined by the driving force of the locomotive / locomotives used.

Sometimes these constraints are ignored, because a greater length train seal leads to lower operating costs. Operating efficiency is done by the number of trains sorted and transshipment cargo per unit time, while operating cost unit is the cost for one train. On the other hand, the operating time for maneuvers and transshipment of goods, which affect costs will increase if the seal length increases.

2.1. Theoretical formulation of the model TSO

Be $x = (x_1, x_2, \ldots x_n) \in X \subset \mathbf{R}^{\mathbf{n}}$ (1)

$y = (y_1, y_2, \ldots y_n) \in Y \subset \mathbf{R}^{\mathbf{n}}$

$F, f : X \times Y \to F(\mathbf{R})$

where: x_i is the length of the train seal in station *i*,

y_i is the density of the train seal in the station *i*, It's desired, to obtain a maximum transfer capacity of freight at a certain time:

$$\max_{x \in X} F(x, y) = \frac{a_1 \cdot \sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i \cdot y_i} \quad (2)$$

with $\sum_{i=1}^{n} w_i \cdot x_i / \sum_{i=1}^{n} w_i \cdot y_i$ average number of wagons loaded/unloaded per time unit.

It is considered that the length of the seal is determined by the limits of locomotive power and the useful length of the line of departure-arrival. Restrictions can be generated by total weight, wagons-locomotive-load which can not exceed its upper limit, namely:

$$\sum_{i=1}^{n} w_i \cdot x_i < m \quad (3)$$

Seal length can not be very close to the threshold of safety, c_1 is the minimum time between any two trains, according to the list of "rules of safety".

$$\sum_{i=1}^{n} w_i \cdot y_i > c_1 \quad (4)$$

where n is the number of technical railway stations in the network rail;

w_i relative weight of the station *i* and the railway network;

a_1 time period (if $a_1 = 24$, then $a_1 / \sum_{i=1}^{n} w_i \cdot y_i$ is the average number of trains running on the network within 24 hours; $a_1 \cdot \sum_{i=1}^{n} w_i \cdot x_i / \sum_{i=1}^{n} w_i \cdot y_i$ is the number of seals in the network per day, with $a_1 > 0$);

m maximum number of cars in a seal covered by the "road safety".

Of economically seeks to minimize costs:

$$\min_{y_i} f_i(x_i, y_i) = -b_1 \cdot x_i - b_2 \cdot y_i \quad (5)$$

where: $\min_{y_i} f_i(x_i, y_i)$ indicates efficient seal, maneuvers necessary to lower costs as and time and the term „$-b_1 \cdot x_i - b_2 \cdot y_i$" indicates the length of time remaining seals in the station with higher costs.

Stations with the technical mean have their own time limits for sorting and transshipment of goods:

$$c_2 \le \frac{x_i}{y_i} \le c_3 \quad (6)$$

There is also a period of time for technical stations to complete the operation: $y_i > c_4$

2.2. Example of application of the model TSO

It is assumed that trains sorted and loaded / unloaded coming from the direction of station B, which has different location of station A. Distribution of weights of wagons is in Table 2 and the engine used is type SS1 (137 tons, 1.9 units of length). Useful length of a car is calculated from front face shutter to rear front shutter (11 m). Real length of the wagon is obtained by multiplying the usable length with a characteristic coefficient (for example, for a wagon type B23, actual length is): $11 \times 2{,}1 = 23{,}1\,m$).

Within a month, the station has managed both technical passenger transport and the passenger.

Tabel nr. 1 *Distribution of wagons in a train*

The type of wagon used **(WT)**	Empty wagon Weight **(WS)** **(tone)**	Weight of goods to be loaded **(tone)**	Share a type of car, all cars in the train **(%)**	Coefficients to determine the actual length
B23	38	40	3	2,1
P64A	26	58	3	1,5
G70	23	58	9	1,1
G60	23	50	50	1,1
G70	23	55	35	1,1

In the application considered = 24, and weight train seal should not exceed 3,500 tonnes, length of line used to the destination station is 890 m. If the braking distance, for trains to stop safely, is 30 meters, the maximum train length is 860 meters.

The length of a train, which forms in the station A, using data from Table 1, will be:

$$l_1 = 2{,}1 \times 0{,}03 + 1{,}5 \times 0{,}03 + 1{,}1 \times 0{,}09 + 1{,}1 \times 0{,}5 + 1{,}1 \times 0{,}35 = 1{,}142$$

and final weight:

$$w_1 = (38+40) \times 0{,}03 + (26+58) \times 0{,}03 + (23+58) \times 0{,}09 + (23+50) \times 0{,}5 + (23+55) \times 0{,}35 = 66{,}95$$

The maximum number of empty wagons in a train is given by:

$$m_e = (860 - 1{,}9 \times 11)/(1{,}142 \times 11) = 66$$

and the maximum number of loaded wagons into a train is:

$$m_l = (3500 - 137)/66{,}95 = 50$$

It is considered $m = \min\{m_e, m_l\} = \min\{66; 50\} = 50$, $c_1 = 0{,}2$ because, if carried out safely transport was considered as the range (distance) between two adjacent trains from the network graph to be 10 km, which means 0.2 hours of travel between two stations.

$\begin{cases} b_1 = 0{,}4 \\ b_2 = 0{,}6 \end{cases}$ is the weight of the length and density of trains at the station

$\begin{cases} c_2 = 30 \\ c_3 = 150 \end{cases}$ is the minimum respectively maximum number of maneuvers that up with trains that can be made per hour, and $c_4 = 0{,}68$ is the shortest time needed to complete the maneuver and transshipment operations in station A.

With these assumptions and values, the objective function becomes:

$$\max_{x \in X} F(x, y) = \frac{24x}{y} \text{ with } x < 50 \text{ şi } y > 0{,}2$$

and relation (5) can be written as:

$$\min_{y_i} f_i(x_i, y_i) = -0{,}4 \cdot x - 0{,}6 \cdot y$$

with $\begin{cases} 30 \le \dfrac{x}{y} \le 150 \\ y > 0{,}68 \end{cases}$

Optimal solution for this example is the point $(x^*, y^*) = (50;1{,}67)$, the objective functions have values: $F^* = 718{,}6$ and $f^* = -21{,}002$, which determines the maximum transfer of the rail network of 718.6 trains a day, if the rail network decision-makers determine the average number of trains to 50, following that, the station A to determine the range time between two adjacent trains at 1.67 hours.

The model applied to optimize handling and loading activities in Station A, leads to reasonable results and can be helpful in organizing trains.

However, because of model restrictions, many practical details have not been taken into account in it.

3. OPTIMIZING PROCESSES IN ROMANIAN RAILWAYS

In rail transport, the activity is complex in preparation and execution of transport, working more specialized branch railway, broken, in turn, in more technical specialties: building and maintaining lines (lines, telecommunications and signaling equipment, buildings , bridges, tunnels, locomotives, coaches) and organize the operation activity.

Due to the considerable development of the work technologies, the number of operations and the complexity of the logical interdependencies between them, in recent years, there has been an important change in the way of representing the processes by switching from the Gantt chart representation, to the representation of other systems, of which, some of the most important used by Romanian railway network are: block diagram, signal graph and activity's graph.

Among the models with which an analysis can be done to optimize the processes, can be listed: critical path method and specific models of theory expectation.

3.1. Optimization of train traffic organization

Organizing the movement of trains is an important issue in the rail transport, because it depends to large extent results of operations. These problems, witch can be solved with some difficulty with linear programming models, find a general solution by algorithms Ford-Fulkerson (which optimizes the transport in a network in a single transport capacity) and Fulkerson algorithms (which optimize the transport in a network with more transportation capacity assumptions).

The endowment of railway with locomotives equipped with ERTMS systems and asynchronous motors is a large-scale investment and operation of locomotive fleet is a very important problem.

By optimizing the schedule of locomotives are seeking a better use of the locomotives according to timetable of train and depending on type of the trains, how to exploit them (holding teams or not), characteristics of traffic sections, of the available locomotives park, etc. In general, the locomotives schedule change is made with timetables, and regular time intervals. Usually, the schedule of locomotive is made with the change of train's timetables, and periodically from time to time.

Following the introduction of new electronic traction control (Siemens and ICOL traction type computers) and asynchronous traction motors, the question of optimizing schedule of locomotives, and thus optimize traction staff schedule, which will lead to savings rolling stock and staff in operating activities.

From mathematical point of view, the schedule of locomotives problem or traction staff schedule, are problems solved by some classical models of operational research: simplex algorithm, the algorithm Ford-Fulkerson, Hungarian algorithm, castling method. Route optimization and training plan of freight trains have a special importance, for rail transportation, forming a fundamental set of problems for freight transport efficiency.

Circulation of a freight wagon between loading and unloading stations raises two principle issues:

- cargo wagon, considered as a unit, must be guided between loading and unloading stations so that to travel on a route, which in economic terms is better than other possible routes, i.e. the choice of optimal route;
- cargo wagon passing by the departure station to the receiving station, is subject of a category of optimization problems whose aim is to minimize the number of sorting of wagons or training plan optimization of freight trains.

The organization of development preparation trains plan consists, at the principle, of 68 activities. The introduction of new IT systems within and between CFR regional railways, the development of specialized programs to optimize processes with qualified personnel allow enable the plan of trains' preparation.

The implementation of IRIS system allows an integrated approach to activities, whether it takes place in different companies, but ensuring privacy of each company. Among the methods used to determine the optimal travel route for wagons are:

- virtualization distances method;
- virtualization method, with respect to time of real distances.

3.2. Optimization of operating decisions for fleet cars using Markov chains

Markov processes are based on assumptions:

- a phenomenon characterized by a particular state evolves by passing instant at the end of a period of time *t* to another state;
- the times are equal and can be considered as a unit of time;

In these circumstances, it is considered that the phenomenon evolves step by step, or that jump out at the end of a state to a state whose probability of existence is given by:

$$p_j(1) = \sum_{i=1}^{N} p_i(0) \cdot p_{ij} \qquad (7)$$

where p_{ij} - probability of passage or transit from state *i* to state *j*;

$p_i(t)$ - probability of state *i* at time *t*;

$p_i(0)$ - probability of state *i* at baseline 0;

N – number of different states of the system.

State probability phenomenon, at time $t+1$ is therefore:

$$p_j(t+1) = \sum_{i=1}^{N} p_i(t) \cdot p_{ij} \qquad (8)$$

For example, if you want to determine the optimal size of fleet cars, after the exit from the active fleet of wagons send to repair, is considered the problem:

- be a railway network, on which is considered to be *n* main points (knots) noted C_i ; $i = \overline{1;n}$) concentration of a particular fleet type cars V_k .

Between these nodes there is an exchange of loaded and empty wagons, that is a cross currents of cars that can hardly be avoided.

- always within 24 hours, there is a medium balance, i.e. an average number of cars that are parked for loading, unloading or other operations.
- a monthly average daily park, estimated to be, for example, 1,200 cars, many of them get (calendar) date for submitting to periodic repairs and overhaul, which includes:
  - knowledge development park cars in a predetermined period (for example, three months);
  - active park needs to allow permanent use of wagons required level;
  - between the centers are formed currents of cars whose percentage distribution is known, including the number of cars that is always in the center of origin considered, is also associated crossing matrix a column representing the weight of wagons repaired and a line representing state probability of this phenomenon.
  - knowledge development park cars in a predetermined period (for example, three months);
  - active park needs to allow permanent use of wagons required level;
  - between the centers are formed currents of cars whose percentage distribution is known, including the number of cars that is always in the center of origin considered, is also associated with crossing matrix a column representing the weight of wagons repaired and a line representing the probability of state this phenomenon.

The weights $C_i - C_j$; $i, j = \overline{1;n}$ are the probabilities of state, the existence of the park in the center, and $C_1 - C_j$; $j = \overline{2;n}$ represent probabilities of transition after a period t to another state (if deemed weights as daily average monthly, t representing a month).

Distribution of cars park on the period considered, resulting from the application of Markov chain, for example, for 10 knots, allowing the extraction of conclusions, namely:

a) considering that the initial state is valid at time t = 0, and weights expresses monthly average daily values (so step t is equal to one month), can be inferred that: at t = 1, the park will decrease by 60 cars, at t = 2, the park will fall by another 70 cars or 130 cars combined, at t = 3, the park will fall by another 64 cars, or combined 194 cars;

b) for repair, periodic or capital a car, is needed about a month. To meet the traffic stood at 1,200 cars /day is necessary to increase the park, up to 1,270 cars.

3.3. Markovian model for the analysis of labor mobility in a railway network

Labour mobility, defined as responsiveness and adaptation of individuals or groups of people to the challenges of socio-economic environment is therefore a social phenomenon dependent on time and space. If deemed appropriate time scale, can identify that part of the workforce experiencing changes from time to another. It is assumed that at some point, an employee would be employed in any of the departments considered in the analysis I proposed. The number of employees in the system is assumed to remain the same for the entire period of analysis.

It is assumed that the number of employees who changed jobs during any interval is known. Also, it is assumed that their distribution is also recorded.

Assuming that the present experience and qualifications of employees in a department influences the choice of other departments, Markov chain model gives a real approximation of behavior of employees in the workforce rail network subsystems.

Be $\{S_n, n = 0,1,2,...\}$ the state employees at a time and n is the number of observations. Transition probability matrix can be estimated using statistical data and information on the characteristics of labor mobility in the respective units.

Propensity of certain categories of employment not to change the workplace for a long time, determine the division of human resources in the railway system into two categories: one that includes those people who do not change their place of work, and another, including people who change work.

If we consider m units of activity, with s_i $(i = 1,2,...,m)$ the fraction i containing the population that do not change their workplace, and, then crossing probability matrix for the entire population of railway facilities is:

$$\mathbf{P} = \begin{pmatrix} s_1 + (1-s_1)R_{11} & (1-s_1)R_{12} & ... & (1-s_1)R_{1m} \\ (1-s_2)R_{21} & s_2 + (1-s_2)R_{22} & ... & (1-s_2)R_{2m} \\ . & . & ... & . \\ . & . & ... & . \\ (1-s_m)R_{m1} & (1-s_m)R_{2m} & ... & s_m + (1-s_m)R_{mm} \end{pmatrix} \qquad (9)$$

For the first n steps of the transition probabilities, it is assumed that no changes occur in the first category of labor.

Then: $$\left\| P_{ij}^{(n)} \right\| = \mathbf{S} + (\mathbf{I} - \mathbf{S})\mathbf{R}^n \qquad (10)$$

with $\lim_{n\to\infty} R^n = \mathbf{\Pi}'$, where the matrix $\mathbf{\Pi}'$ is identical lines, each line representing the limit vector: $(\pi_1^{'}, \pi_2^{'}, ...\pi_m^{'})$ for category of employees who changed jobs.

Be $\{p_j^{(n)}\}_{j=1}^{m}$ the employee distribution after n transitions.

For vector: $p^{(n)} = (p_1^{(n)}, p_2^{(n)}, ..., p_m^{(n)})$ obtain: $p^{(n)} = p^{(0)}S + p^{(0)}(I - S)R^n$, and for $p^* = \lim_{n\to\infty} p^{(n)}$ obtain: $p^* = p^{(0)}S + p^{(0)}(I - S)\Pi'$.

In practical problems, the application of the Markov model requires estimation of transition matrix elements and the number of employees in each category in each unit/ regional departments review.

4. CONCLUSIONS

The issue addressed by these models to optimize the rail is wide and each of them aims to optimize certain sectors in this field.

The rapid development of computers and IT technology have enabled the development of more complicated models using various operational research techniques and probability theory, models which can be obtained through quantitative and qualitative information on specific rail optimization problems.

Models presented can be applied to optimize various sectors of the Romanian railway transport, and allow a technical, economic and social X-rays of the current situation, it. Adaptation of models used in optimizing rail from other EU Member States to the actual situation in Romania will allow a comparative analysis of the competitiveness of the sector

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