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CHOOSING RAILWAY VEHICLES FOR CARRYING PASSENGERS

Stasys Dailydka

Dept of Railway Transport, Vilnius Gediminas Technical University,
J. Basanavičiaus g. 28, LT-03224 Vilnius, Lithuania
E-mail: geltr@vgtu.lt

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Abstract. To carry passengers, diesel and electrical trains, railcars, passenger carriages and hauled locomotives are used in AB 'Lietuvos geležinkeliai' (Lithuanian Railways). In certain sections, the number of passengers is very low (e.g. several or up to twenty passengers per 24 hours), and therefore rolling stock is used inefficiently. For this reason, it is necessary to optimize the choice of vehicles on different routes taking into account the possibilities of their application and fluctuations in the number of passengers. To this end, a mathematical model has to be developed which would allow selecting an efficient means for carrying passengers in each case and, if required, to choose rational routes by applying the above introduced model.

Keywords: diesel trains, electrical trains, passenger carriages, number of passengers, mathematical model.

1. Introduction

Rapid social and economic development, technical progress and globalization trends in the world trade experienced by the member states of the European Union create an enormous need for high-quality transport services. The existing system of transport services is based on road transport and has already become unable to meet the exponentially growing transport needs of consumers. The countries of Western Europe are aiming at promoting the carriage of passengers by rail introducing the means of economic and legal measures in order to save resources related to safety, ecology, energy etc. (Butkevičius 2007, 2008 and 2009; Пастухов 2008; Огинская и Толкачева 2006; Вериго и Коган 1986).

Railway transport is safer and much more environmentally friendly and efficient than road transport (Adamko and Klima 2008; Bureika 2008; Dailydka *et al.* 2008; Lata 2008; Lingaitis and Pukalskas 2008a, 2008b; Вериго и Коган 1986). However, railways require huge investments into their infrastructure (Jarašūnienė 2009; Maskeliūnaitė *et al.* 2009; Lalive and Schmutzler 2008; Morkvėnas *et al.* 2008; Susnienė and Jurkauskas 2008; Šelih *et al.* 2008; Žvirblis and Zinkevičiūtė 2008; Butkevičius 2007, 2008; Vasilis Vasiliauskas and Barysienė 2008; Tolli and Laving 2007; Su *et al.* 2006; Огинская и Толкачева 2006). Therefore, railway transport in Europe is, first and foremost, supported financially by granting soft credits to railways and covering its losses incurred due to loss-inflicting public activities (Jarašūnienė 2009; Alexandersson and Hultén 2008; Asmild *et al.* 2008; Campos 2008; Ivaldi and Mccullough 2008; Johnson and Nash 2008; Lalive and Schmutzler 2008; Akgüngör and Demirel 2007; Butkevičius 2007, 2008, 2009; Reforming Europe's Railways … 2005). Carrying passengers by rail is largely aimed at residents with lower income, and in this case, it is necessary to take into account the satisfaction of the needs of the country residents from the economic, social, environmental and passenger safety perspectives and to ensure the EU principles concerning the free movement of goods and people (Jarašūnienė 2009; Maskeliūnaitė *et al.* 2009; Lalive and Schmutzler 2008; Butkevičius 2007, 2008; Пастухов 2008; Schach and Naumann 2007; Lingaitienė and Lingaitis 2006; Огинская и Толкачева 2006; Reforming Europe's Railways … 2005; Jarašūnienė and Vasilis Vasiliauskas 2005; Butkevičius *et al.* 2004).

Funds required for implementing objectives established in the Long-Term Development Strategy of the Lithuanian Transport System (2005) and the Law on Railway Transport Sector Reform are not allocated. Therefore, the prospect of carrying passengers by rail in Lithuania is not clear. Although the provision concerning the compensation of losses incurred due to undertaking an obligation to provide loss-inflicting public service is enshrined in the Railway Transport Code of the Republic of Lithuania, funds allocated from the state budget by the Ministry of Transport and Communications of the Republic of Lithuania, being the appropriation manager,

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cover only a very small share of losses incurred due to the carriage of passengers. Income derived from carrying goods is used to cover the above discussed losses by AB 'Lietuvos geležinkeliai' (Lithuanian Railways).

Depending on financial possibilities, the company renews the pool of passenger rolling stock (Butkevičius 2008, 2009; Butkevičius *et al.* 2004; Пастухов 2008). However, the required funds are huge and neither the Government nor AB 'Lietuvos geležinkeliai' (Lithuanian Railways) possesses them at the moment. One of the ways to ensure the carriage of passengers by rail in the future is reducing the costs of the carriage. One of the options to reduce costs is a rational choice of vehicles for different sections (depending on the number of passengers) and operational conditions. Diesel and electrical trains, railcars, passenger carriages and hauled locomotives are used by AB 'Lietuvos geležinkeliai' (Lithuanian Railways) to carry passengers. In certain sections, the number of passengers is very low (e.g. several or up to twenty passengers per 24 hours), and therefore rolling stock is used inefficiently. For this reason, it is necessary to optimise the choice of vehicles on different routes taking into account the possibilities of their application and fluctuations in the number of passengers. To this end, a mathematical model has to be developed which would allow selecting efficient means for carrying passengers in each case and, if required, to choose rational routes by applying the above discussed model.

2. Development of the Mathematical Model

The number of passengers on each route fluctuates and operational costs vary depending on a vehicle. First, a route is divided into sections (usually halts, see Fig. 1) to assess these fluctuations:

Each vehicle incurs certain costs in each section x_i where i = 1, 2, 3, ... n (Fig. 2).

Costs are consistently added up throughout the entire route (Fig. 3).

Fig. 1. The division of the route into halts

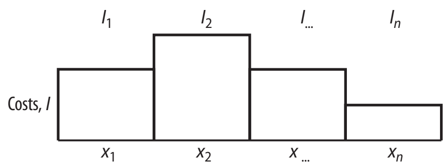

Fig. 2. The costs of the vehicle in the section

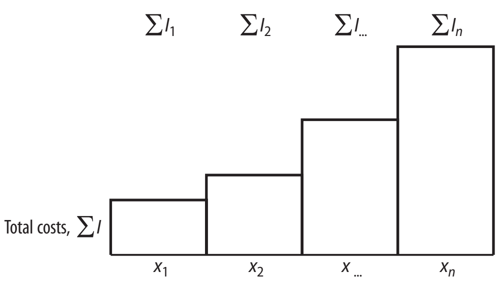

Fig. 3. Costs incurred on the route

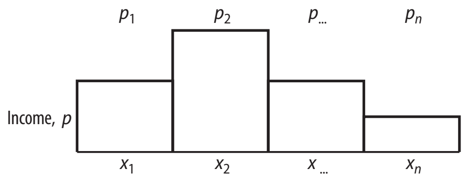

Fig. 4. Income generated on the route

In each section of the route, income is received from ticket sales p_i, where i =1, 2, 3, ... n (Fig. 4).

Economic benefits (or losses) are the difference between income and costs:

$$N = \sum (P - I). \tag{1}$$

Incomes are funds received from ticket sales. In each open line, this income depends on the number of passengers, the length of the open line and the rate of each kilometre run:

$$P_i = \sum l_i \cdot p_i \cdot b_{km}, \tag{2}$$

where: l_i – the length of the open line, km; p_i – the number of passengers; b_{km} – the rate of each passenger kilometre, LTL/km.

Costs may be deemed to be the sum of cost components on the route:

$$I_i = \sum I_j = I_w + I_d + I_f + I_0, \tag{3}$$

where: I_w – pay, LTL; I_d – the depreciation of rolling stock, LTL; I_f –fuel expenses, LTL; I_o – other expenses, LTL.

Another way of revealing the structure of costs is also possible, i. e. costs are considered to be the sum of the costs of open lines by taking into account the length of the open line and operational costs per km:

$$I_i = \sum l_i \cdot e_{km}, \tag{4}$$

where e_{km} – operational costs per km, LTL/km.

Each vehicle on route y_i up to section x_i inclusively generates profit or inflicts losses N_i.

In this case, the following matrix is drawn: vehicles y_1, y_2,... y_k are arranged vertically, routes x_1, x_2, ... x_n – horizontally (see Table 1).

Table 1. The distribution matrix of benefits or losses

	x_1	x_2	x...	x_n
y_1	N_{11}	N_{12}	N...	N_{1n}
y_2	N_{21}	N_{22}	N...	N_{2n}
...	N...	N...	N...	N...
y_k	N_{k1}	N_{k2}	N...	N_{kn}

After making calculations, the following points may be considered:

- until what section of route x_i vehicle k is profitable (or loss-making within supposedly permitted limits);
- which vehicles are profitable (or loss-making within supposedly permitted limits) in the sum of sections concerned $\sum x_i$ (on the route or its required part).

3. Solutions to the Mathematical Model

The mathematical model may be realised by selecting the route of passenger railway transport when the size of the passenger flow and its changes as well as the number of trips on the route are known. It is also necessary to have the established nomenclature of passenger rolling stock to be chosen and data about the cost price of carrying passengers using this rolling stock (e. g. the cost price of one km depending on the number of passengers).

4. An Example of the Solution to the Mathematical Model

As the mathematical model consists of two parts (costs and income depending on changes in the number of passengers), the solution should also consist of similar parts. The annual structure of costs incurred in carrying passengers is shown in Fig. 5.

Fig. 5 shows that the pay and depreciation of rolling stock constitute the major share of costs incurred in carrying passengers. Therefore, two conclusions which partially contradict each other may be drawn. First, in order to reduce pay, the pool of rolling stock needs to be renewed. Thus, the scope of maintenance will reduce, thus one engine-driver may be sufficient to manage rolling stock instead of two. On the other hand, new rolling stock is of higher value than the old one (several or a number of times), and as a consequence, it depreciates rapidly. Therefore, in sections where the flow of passengers is not high, it is unreasonable to use very modern rolling stock.

As income changes depending on the number of passengers, change in the number of passengers on the route will be analysed first. For example, Lithuanian railway section Vilnius–Kaunas–Šeštokai is examined fluctuations in the number of passengers in which is shown in Fig. 6.

Fig. 6 shows that the number of passengers travelling from Vilnius Station to Kaunas and Jūrė Stations remains the value within the same order of magnitude (around 60, +/– 15 passengers per 24 hours). The number of passengers starts consistently reducing from Kaunas Station. This is a good example because its analysis reveals several consistent patterns of change in the number of passengers in this railway section. For further analysis, the names of stations have been replaced with numbers (the object of the study is depersonalised). The analysis of changes in the number of passengers is provided in Fig. 7.

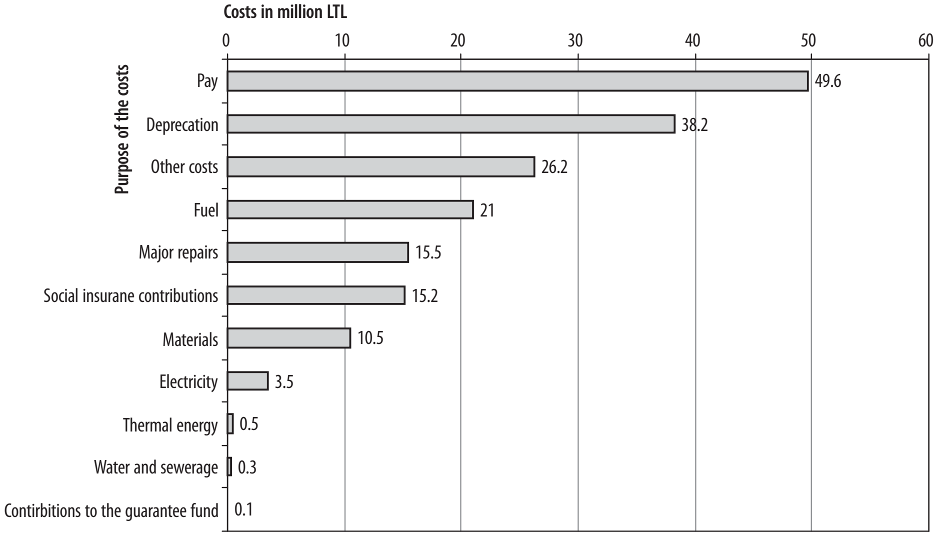

Fig. 5. The structure of costs incurred in carrying passengers

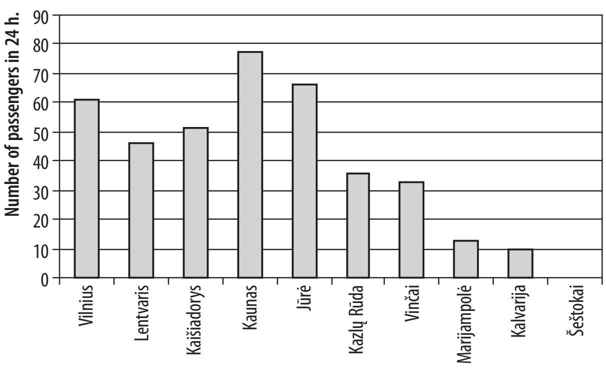

Fig. 6. Fluctuations in the number of passengers in section Vilnius–Kaunas–Šeštokai

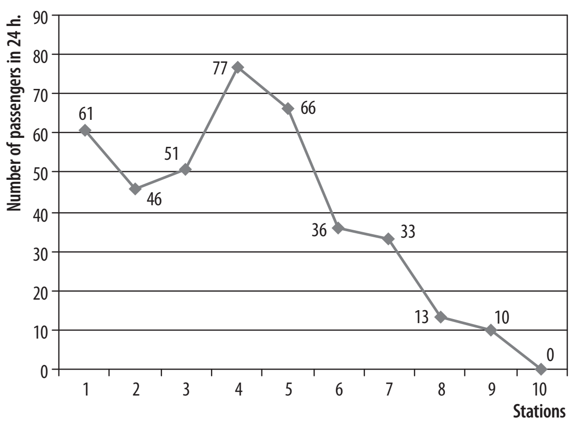

Fig. 7. The analysis of changes in the number of passengers in the section

Fig. 7 shows it is impossible to correctly describe changes in the number of passengers in the section on the basis of one consistent pattern as the patterns differ depending on the position of stations in a row.

Changes in the number of passengers from station 1 to station 5 are presented in Fig. 8.

Changes in the number of passengers from station 4 to station 10 are shown in Fig. 9.

If income received from one passenger kilometre and the costs of one kilometre run by rolling stock (4) are entered into formula (2), benefits (or losses) for each piece of rolling stock and each open line can be calculated by applying (1).

Income received from tickets by open lines is shown in Fig. 10.

The costs of open lines are shown in Fig. 11.

The economic effect (benefits or losses) of open lines is presented in Fig. 12.

Fig. 12 shows it may not be assumed that the economic effect changes in proportion to the number of passengers (Fig. 7) or to any other value. The economic effect is determined by a large number of factors (e. g. the price of tickets, changes in the number of passengers per 24 hours, changes in demand depending on the economic situation of the country, changes in the costs of rolling stock maintenance, prices of resources). Therefore, solutions to this mathematical model may be calculated by making a search, applying multi-criteria optimisation methods when income criteria such as the number of passengers, ticket prices, the costs – amounts of fuel consumed, the pay of service staff etc. are expressed in mathematical dependencies on the basis of statistical data.

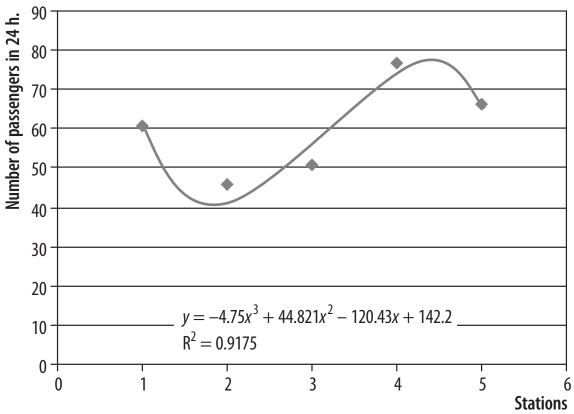

Fig. 8. Changes in the number of passengers from station 1 to station 5

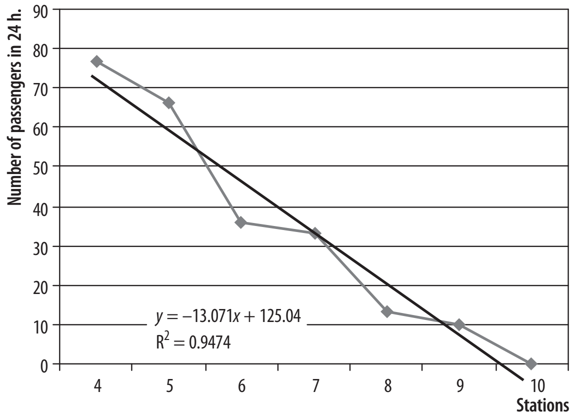

Fig. 9. Changes in the number of passengers from station 4 to station 10

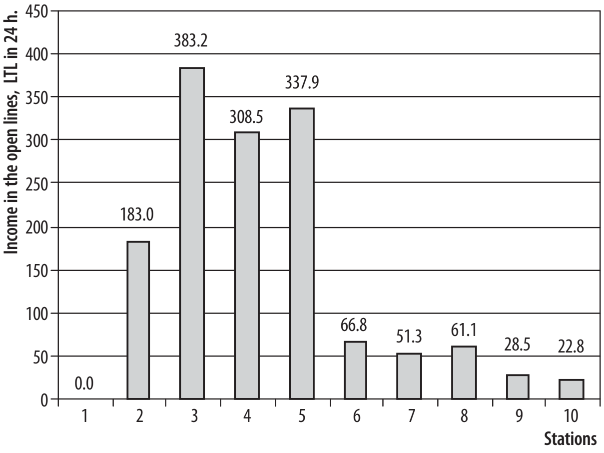

Fig. 10. Income received from tickets by open lines

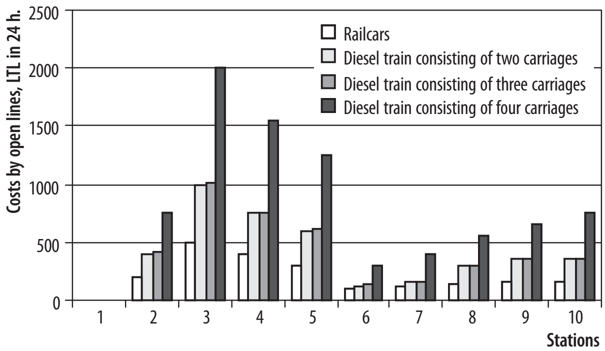

Fig. 11. The costs of open lines

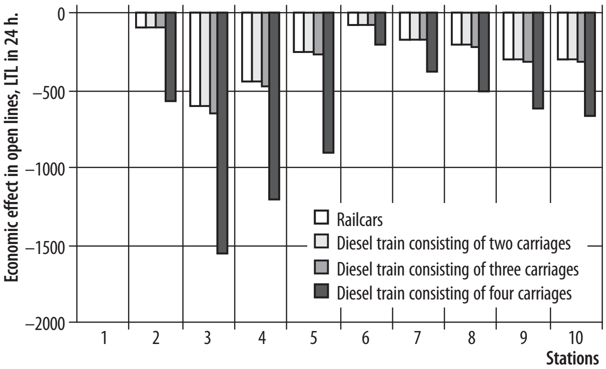

Fig. 12. The economic effect (benefits or losses) of open lines

5. Conclusions

1. In order to maximise income and minimise expenses, from the technical and economical perspectives, the developed mathematical model allows choosing beneficially the type of passenger transport for a specific route depending on the size of passenger flow and considering its changes on the route.
2. On the basis of the developed mathematical model, it is possible to make a rational choice about the length of the route for the selected passenger vehicle.
3. Upon drawing the functions of changes in the number of passengers in the sections, solutions to this mathematical model may be calculated by making a search and applying multi-criteria optimisation methods.

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