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ANALYSIS OF PASSENGER ROLLING STOCK FAULTS AND ITS STATISTICS IN LITHUANIA

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Abstract. Performed data analysis aims to determine the number of rolling stock breakdowns and how it depends on rolling stock age, the number of passengers and operations. The mathematical model, stated below, analyses correlation between passenger fleet upgrade intensity and the number of faults. When planning to buy some new rolling stock (3÷6 wagons electric or diesel trains) while using this model, the number of faults can be predicted up to five years.

Keywords: railway transport, passengers, rolling stock, vehicles, rail benefits, model.

1. Introduction

Railway rolling stock fleet must be renewed for two main reasons – moral of aging (increasing comfort requirements, design innovation, new technologies) and rising repair and maintenance costs of old rolling stock (Strang *et al*. 2007; Bureika 2008; Stenbeck 2008; Sonmez, Ontepeli 2009; Sivilevičius, Maskeliūnaitė 2010; Dailydka 2010). These two factors are important not only for rail transport, but also to other types of passenger transportation vehicles. In planning passenger rail fleet expansion it is important to determine the optimal fleet renewal schedule. Thus, in particular, performed data analysis, which aims to determine the number of rolling stock breakdowns and how it depends on rolling stock age, the number of passengers and operations (Alexandersson, Hultén 2008; Butkevičius *et al*. 2004; Dailydka *et al*. 2008; Maskeliūnaitė *et al*. 2009; Dailydka 2010). The findings of these studies can determine what should be the optimum age of rolling stock and the fleet renewal schedule.

When analyzing the number of rolling stock breakdowns, we take into account the commuter flow fluctuation, rolling stock technical condition (the age or mileage), their maintenance and repair system. In planning the development of rolling stock fleet, all of these factors are important, but the biggest influence of the first two – changes in passenger flow (regularity and forecasts) and the rolling stock fleet technical condition (usually – rolling stock age) (Lingaitis, Vaičiūnas 2008). Rolling stock maintenance and repair systems generally regarded as a separate issue, because they require deeper analysis and advanced research methods (Povilaitienė *et al*. 2006; Grubliauskas *et al*. 2006). The purpose of the research is to present the mathematical model that describes correlation between passenger fleet upgrade intensity and the number of faults.

2. Factors that determine the number of rolling stock failures

Fig. 1 shows the evolution of passenger traffic in Lithuanian railways.

Both domestic and international passenger traffic flow from 2005 to 2010 decreased. International traffic decreased by approximately 10% during this period, while domestic traffic – 39%. There are two main reasons for decrease of passenger flow: the demographic situation (depopulation) and the growing popularity of road transport. But to evaluate only the number of passengers is not enough. Passenger traffic intensity describes the passenger turnover, which is measured in passenger-kilometers (pkm).

Fig. 2 shows the Lithuanian railways passenger turnover evolution.

Analyzing Fig. 2, we notice that this decrease is not significant – domestic traffic declined from 259 million passengers per kilometer to 213, which is 18% (in comparison to 39% as the number of passengers), while international traffic decreased from 169 million passengers per kilometer to 144, which is 15% (the reduction of 1.5 times higher than the number of passengers).

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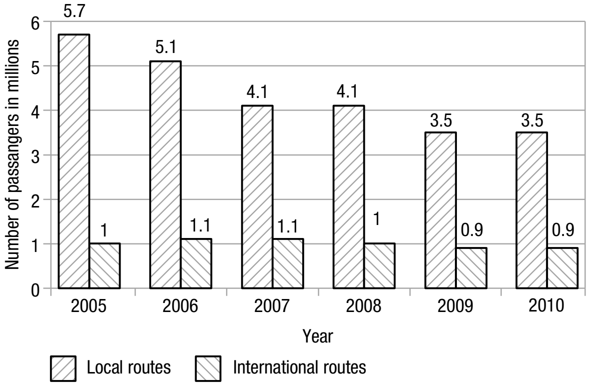

Fig. 1. Evolution of passenger traffic in Lithuanian railways

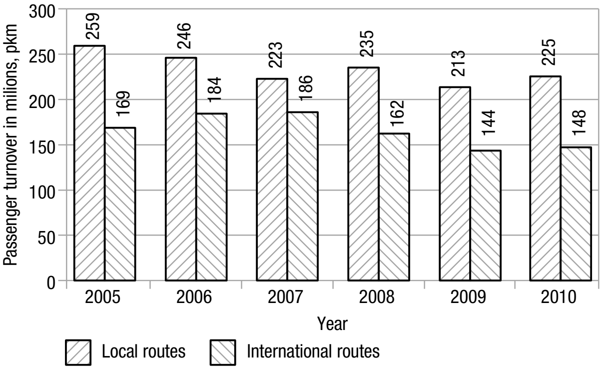

Fig. 2. Lithuanian railways passenger turnover evolution

This indicates that the passengers in local routes started to travel longer distances, where in international routes – shorter distances. Therefore, the number of domestically operated rolling stock faults is increasing (mainly diesel and electric trains). In contrast, the number of rolling stocks faults, which operate on international routes is decreasing (mainly coaches drawn by a locomotive). Rolling stock fleet failure analysis usually starts with analysis of the composition of the fleet.

Fig. 3 shows the number of Lithuanian railways rolling stock evolution. Fig. 4 shows the evolution of the number of faults. Figs 3 and 4 present the numbers to calculate how many faults per one wagon occur per year, and how this ratio varies.

Fig. 5 shows the numbers of faults per rolling stock.

Analyzing Fig. 5, we notice that during the period from 2006 to 2010, rolling stock faults per wagon have fallen from 0.4 to 0.2 (50%). If we analyze the number of electric train faults per wagon, we see that during the year 2006 there were 0.9 failures, and 2008 was a peak – 2.1 wagon failures, and in 2010 – 0.6 fault per wagon. If we analyze diesel train faults per wagon, we see that the peak was in 2009 – it accounted for 1.7 fault per wagon, while in 2006 it was 1.2, and 2010 – 1.5 fault per wagon. Decrease in number of faults of passenger coaches is logical, because of the decrease in passenger flow (Figs 1 and 2). Furthermore, electric and diesel train failures are influenced by other factors. Over the last two years of

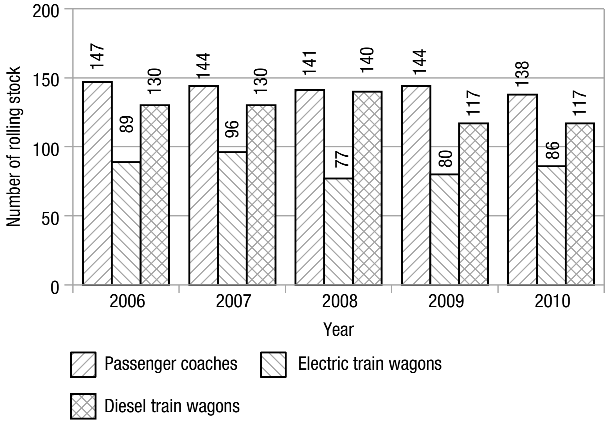

Fig. 3. Lithuanian railways passenger rolling stock evolution

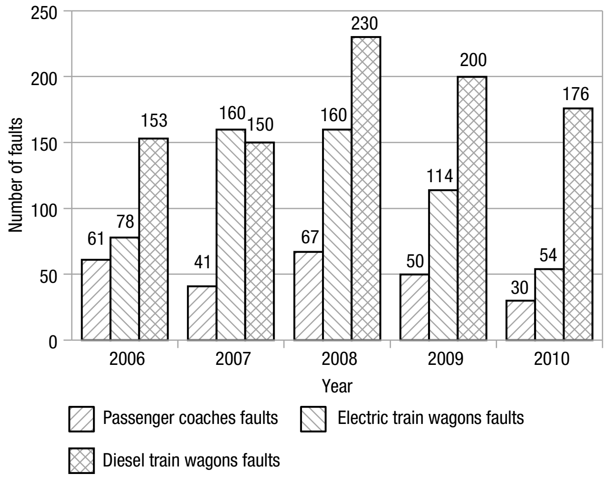

Fig. 4. Evolution of the number of faults

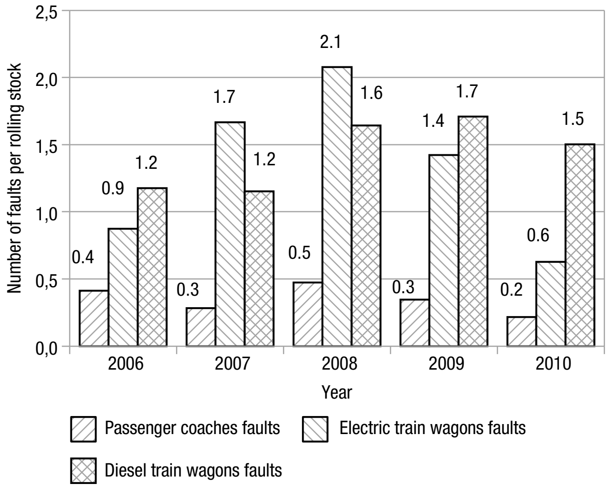

Fig. 5. Number of faults per rolling stock

study period (2009 and 2010), the number of faults has been decreasing because of rolling stock fleet upgrade. Yet, until the electric and diesel train fleet renewal (until 2008), the number of faults per wagon had grown, although the number of passengers decreased (Figs 1 and 5). Such growth of faults per wagon could be attributed to the aging of electric and diesel trains (gears, engines and etc). The fault number of passenger coaches (which has no engine) is directly proportional to operational intensity. Rolling stock with engines (diesel and electric trains) deteriorates over time more and more intensely, especially for the aging. Therefore, when planning to upgrade the rolling stock fleet, particular attention must be paid to such rolling stock (with engines) fleet. The main goal of the current study is to establish consistent pattern between the rolling stock fleet upgrade intensity and the number of faults in the fleet. In other words, the degree to which will reduce the number of faults, if update a certain part (e.g. a quarter or a fifth) of the park. This regularity can be described in the original mathematical model (Lingaitis, Vaičiūnas 2008). Extension of the model can be used to evaluate the economic effectiveness of rolling stock fleet development. This model will help to determine the optimal fleet development intensity, to the required economic period (e.g. according to the bank loan interest rate changes). Favorable economic period in the development of the park – to reduce the number of failures as much as possible, and unfavorable – to stabilize the number of failures (maintaining a minimum intensity necessary to upgrade the park).

3. Mathematical modeling of rolling stock breakdowns number

The average age of passenger rolling stock (one type of rolling stock), using the weighted average cost formula. When the fleet composition is static (this type of rolling stock), railway fleet average age increases by one year per year:

$$A_{(aver)\ j+1} = 1 + \sum A_i \cdot \frac{N_i}{N}, \quad (1)$$

where: A_i – rolling stock age in years; N_i – the number of rolling stocks whose age is A_i; N – total number of vehicles of that type.

This type of chart is a linear dependence and increases by one unit per year. Rolling stock fleet, in any case, is updated from time to time. Therefore, the actual average age of rolling stock fleet consistent pattern is more complex than it shows formula (1). For the calculation only of the past and present facts of the rolling stock fleet depreciation or aging outcome (not considering prospective) formula (1) is sufficient to calculate the average age. Data used in this formula is only of the wagons that have been (or still are) in operation, and its depreciation is not analyzed mathematically. This is an example of an electric train fleet average age calculation (each year). If each year we calculate the average age of the train fleet, we will be able to monitor its deterioration over the time period. Electrical train fleet age variation in 2005–2010 year is shown in Fig. 6. This approach can create charts of other rolling stock fleet age variation too.

Such a model (as shown in Fig. 6) is sufficient for this type of passenger fleet status (static) assessment. The average age is comparable to the manufacturer's specified age, but is not advisable to draw conclusions from the average age, because it is the rolling stock fleet average age, not average age of single rolling stock. We can determine the average age changes of the rolling stock fleet, depending on rolling stock fleet renewal. After 2008, since the electric train fleet has been updated, their average age is decreasing. However, more substantial conclusions from this model are not visible. This model is suitable for predicting the average age of the vehicle only if the park is not updated in the future. To obtain a more accurate chart of the average age and to continue the calculation, it is necessary to use the formula (1). It is obvious that such an age prediction model is not flexible enough and not enough to assess the future (or potential) of the train fleet development correctly. Therefore, it cannot predict the number of rolling stock faults and repair costs. Model should be expanded, taking into account the update of the park. Then the formula (1) acquires the form:

$$A_{(aver)\ j+1} = 1 + \sum A_e \cdot \frac{N_e}{N_e + N_n} + \frac{N_n}{N_e + N_n}, \quad (2)$$

where: N_e – number of existing rolling stock; N_n – number of rolling stock that expected to acquire per year; A_e – average age in years of existing rolling stock.

Fig. 7 shows the electric train fleet average age after renewing. Therefore, the average age is calculated starting from the 28.5 years (see Fig. 6, year 2010) and as Fig. 7 showed the first year is the year of 2011.

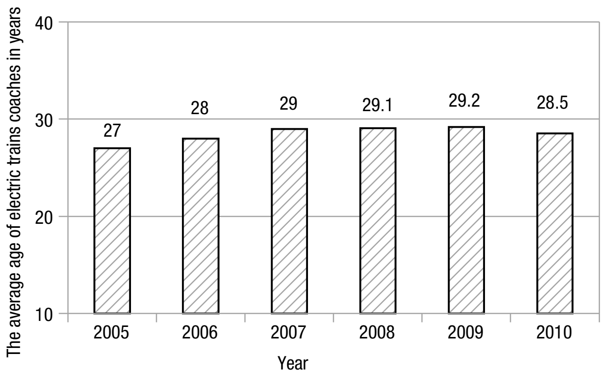

Fig. 6. Electrical train fleet age variation

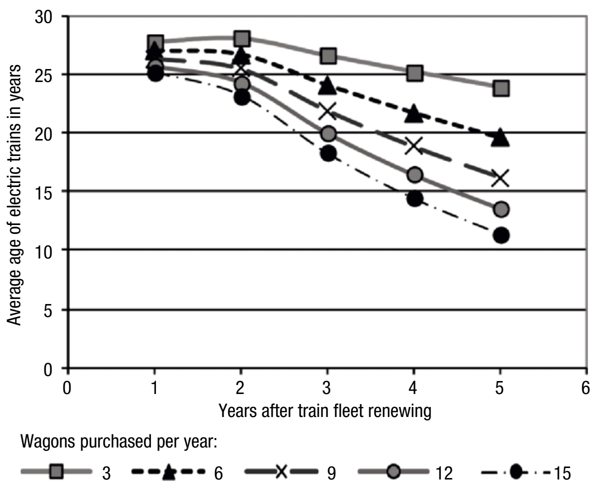

Fig. 7. Electric train fleet average age after renewing

Yearly acquired number of wagons is increased by three units, because for the most electric trains this is the minimum excepted number of wagons on the train itself (motor wagon, trailer wagon and control wagon).

Fig. 8 shows electric train average age decreasing per year, during fleet renewing.

Electric train's average age during the year is calculated by the formula of function:

$$A_{aver} = 0.003 \cdot N_p^3 - 0.016 \cdot N_p^2 + 0.3639 \cdot N_p - 0.1924, \quad (3)$$

where N_p – number of purchased wagons per year.

Analyzing Figs 5 and 6, we see that the number of wagon breakdowns are directly related to their age. When we have the data of electric train average age decrease per year, then we can predict the annual decline of faults. This requires to link mathematically wagon age and number of faults.

Fig. 9 shows the number of faults per wagon per year in comparison to the average age.

If the electric train age is 0 years, the number of faults per wagon per year will also be 0, if train age is 29 years, the number of faults per wagon per year will be 1.6. If average age increases by one year, then the number of faults per wagon will increase by 0.053 per year (see Fig. 9). Pattern of dispersion is 0.14 and the average standard deviation of 0.375. Knowing which rate of decrease of number of faults corresponds to each year of decrease of the average age of the fleet (renewing the fleet) formula (3) can be applied to forecast the decrease of the number of faults (decrease of the number of faults per wagon per year).

$$\Delta G = \Delta g \cdot A_{aver} = \Delta g \left(0.003 \cdot N_p^3 - 0.016 \cdot N_p^2 + 0.3639 \cdot N_p - 0.1924\right), \quad (4)$$

where: Δg – Number of faults (per wagon per year) decreasing, when the average age of rolling stock fleet decreases by one year (in this case, $\Delta g = 0.053$).

Inserting into the formula $\Delta g = 0.053$ we get:

$$\Delta G = 0.000159 \cdot N_p^3 - 0.000848 \cdot N_p^2 + 0.01929 \cdot N_p - 0.0102. \quad (5)$$

Fig. 10 shows predicted number of faults decrease dependence from newly acquired electric train wagons.

Fig. 10 shows the steady pattern with the new train purchase plan that can be used to predict the number of faults of the train fleet. For example, updating the Lithuanian railways electric trains' current fleet (108 wagons now) with a one new train (3 new wagons), the number of faults will be reduced from about 0.044 per wagon per year, i.e. if we update 3% of electric train fleet, then the number of faults will be reduced 7.3 %.

When planning to buy some new rolling stock (3÷6 wagons electric or diesel trains) while using this model, the number of faults can be predicted up to five years. In order to predict the longer term or larger number of trains purchased, the mathematical model needs to be improved, taking into account more factors and patterns.

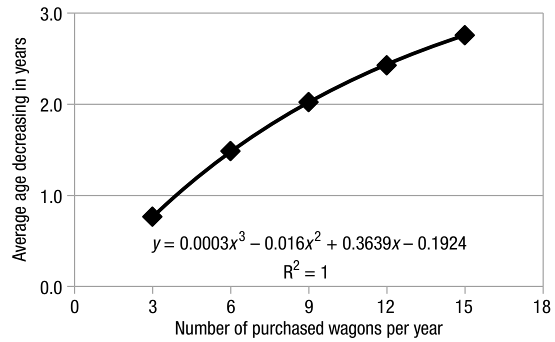

Fig. 8. Electric train average age decreasing per year, during fleet renewing

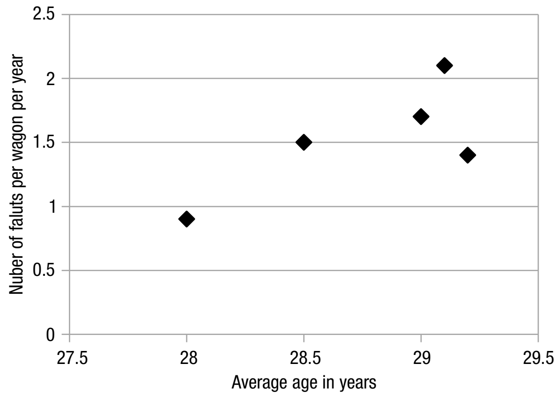

Fig. 9. Number of faults per wagon per year dependence from average age

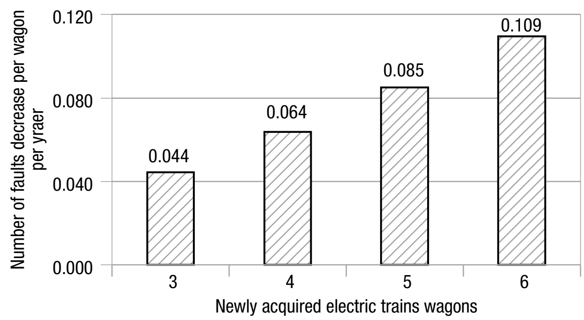

Fig. 10. Predicted number of faults decrease dependence from newly acquired electric train wagons

4. Conclusions

1. Passenger coaches, which have no engine, faults number is directly proportional to operational intensity. Rolling stock with engines (diesel and electric trains) deteriorates over time, more and more intensely, especially for the aging.
2. A mathematical model that describes correlation between passenger fleet upgrade intensity and the number of faults has been analyzed.
3. The mathematical model is realized in the Lithuanian railways electric trains' fleet. It was found that, updating the Lithuanian railways electric trains' current fleet (108 wagons now) with a one new train (3 new wagons), faults number will be reduced about 0.044

per wagon per year, i.e. if we update 3% of electric train fleet, then the number of faults will be reduced 7.3 %.

4. When planning to buy some new rolling stock (3–6 wagons electric or diesel trains) while using this model, the number of faults can be predicted up to five years. In order to predict the longer term or larger number of trains purchased, the mathematical model needs to be improved, taking into account more factors and patterns.

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