The Elaboration of Day-to-Day Operation Procedures for Passenger Rail Transportation Aimed at the Realization of the Strategic Goals of a Passenger Company

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Abstract. This paper is devoted to the development of methodology for the day-to-day operation procedures for passenger rail transportation in the light of decease in passenger traffic. We have accentuated factors that have the most negative influence on the organization of passenger traffic in the Russian Federation. We have determined the goal state for rail transport for commuters and long distance passenger traffic. We also investigated measures for day-to-day operation as well as conditions for employment of these procedures under fluctuations of passenger traffic to substantiate the need for further elaboration and improvement of these procedures. In this work we have developed a sequence of day-to-day operations; as the criterion for switching from one procedure to another we have chosen the seating capacity factor in consideration of the carriage type, demand for a certain car type and the traffic route of the train. The results of experimental research showed the efficiency of the methodology developed.

1. Introduction

In the Russian Federation the railway system is the national carrier that ensures transport accessibility to 77 regions of the country. Regularity, availability and quality of passenger rail transportation are the priority objectives of a passenger company [3]. At the same time, the company must ensure the comfort and safe transportation of passengers and simultaneously be financially stable in the transportation market. This is possible either through retaining and increasing its income or decreasing its expenditures while preserving the quality and comfort of the transportation service [11]. In the Russian Federation long distance passenger traffic is uneven over the course of the year [1], [7]. As research shows, in the summer period (June-August) passenger traffic almost doubles, and this is the period when the passenger company earns its primary income [2]. During the period from November to May the volume of traffic decreases, the majority of trains do not show a profit and the length of this period does not allow the railway to recover expenditures by earnings from the summer period [5]. Day-to-day operation procedures ensure the accomplishment of the strategic purposes and are focused on the correction of current planning, taking into consideration current passenger demand [18]. At the same time, our research has shown that the economic and political situation in the country accompanied by increased competition from other modes of transport contribute to the decrease in the
number of railway passengers, which impedes forecasting passenger traffic and the planning of shipments [4]. Analysis of theoretical works and practical experience has shown that the process of the day-to-day operation of passenger rail transportation includes an elaboration of action sheets for the expansion and contraction of the passenger traffic caused by the seasonal fluctuations in passenger demand. [6]. Nevertheless, the problem of day-to-day operation under unpredictable decrease in passenger traffic is understudied and needs a more detailed elaboration.

2. Urgency
The decrease in passenger traffic prevents a passenger company from achieving its strategic goals. Therefore, improvement of the quality of day-to-day operations becomes one of the company’s key current objectives. These quality improvement measures are focused on correcting the current planning with consideration of the current passenger demand. It is difficult to assess the degree to which various factors impact the decrease in passenger demand initially, therefore it is not possible to always adopt a single right decision which negatively impacts the major economic performances of a passenger company. The major difficulties in the organization of passenger transportation by railways in periods of unpredictable decrease are determined by the underuse of the seating capacity of cars which results in unprofitable transportation.

3. Problem statement
In order to achieve its strategic goals, a company needs to elaborate a sequence of day-to-day operations and to establish criteria for their employment considering the rolling stock type and the passenger demand for seats in different types of carriages.

4. Theoretical substantiation
The key target parameters of the strategy for development of a passenger company are as follows: passenger turnover, revenues, EBITDA, volume of investments, and increase in labor productivity. The formation of the target demand leads to the increase in the passenger turnover and as a consequence to the increase in revenues and EBITDA [19].
The company collects revenues from selling tickets for train journeys from station \( i \) to \( j \). The work of the train will be efficient if the revenues from sales of tickets \( D_{ij} \) exceed expenditures for the organization of the train’s operation \( R_{ij} \):

\[
D_{ij} \geq R_{ij}
\]

Therefore, there exists a specific number of seats that ensures balance between revenues and expenditures, i.e. an acceptable minimum level of the capacity of carriages or passenger car seating capacity ratio. This means that adjustment measures should be taken if the passenger car capacity ratio falls below the acceptable minimum level of the capacity of the carriage and these measures should take into consideration the specificity of the operation territory, train category and passengers’ demand for the quality of transportation [9]. That is why we suggest calculating the acceptable minimum level of the seating capacity of carriages for different directions of journeys, train categories and types of rolling stock.

The acceptable minimum level of the seating capacity of carriages for train operation from station \( i \) to station \( j \) depends upon the following factors:
- revenues from ticket sales for carriages of different types [15];
- train service expenses connected with the production activities of JSC “Federal Passenger Company”;
- the works performed by the company’s own (carriage constituent and station constituent);
- expenses connected with the payment for the services of the JSC “RZhD (Russian Railways)” for use of the infrastructure and rent of locomotives (locomotive constituent and infrastructure constituent),
- and upon the number of passengers in a train routed from \( i \) to \( j \):
\[ \alpha_{ij}^{\min} = F(D_{ij}; R_{ij}; A_{ij}; L_{ij}) \]  

where \( D_{ij} \) is the revenues from train operation from \( i \) to \( j \) station; \( R_{ij} \) is the expenses for the organization of the train’s operation; \( A_{ij} \) is the number of passengers travelling from \( i \) to \( j \) station; and \( L_{ij} \) is the distance from \( i \) to \( j \) station.

The expenditures of a passenger company for the formation of a train are divided into the carriage constituent (operation, maintenance and repairs of cars), the station constituent, the locomotive constituent (payment for the rent of locomotives), and the infrastructure constituent (payment for infrastructure services) [14]. The major part of the revenues of the passenger company (more than 90%) comes from ticket sales. The number of travelling passengers has a minimal effect on the share of expenses for making up a train but influences the revenues from the train work almost completely (Fig. 1). The process of juxtaposing revenues and expenditures under the current situation is obviously very complicated as dependent factors for calculating revenues and expenses are different.

Therefore the expenditures on a train can be calculated as follows:

\[ R = R_{\text{car}} + R_{\text{station}} + R_{\text{loco}} + R_{\text{inf,r}} \]  

where \( R_{\text{car}} \) - is the expenses of the carriage constituent, \( R_{\text{station}} \) - is the expenses of the station constituent, \( R_{\text{loco}} \) - is the expenses of the locomotive constituent, \( R_{\text{inf,r}} \) - and \( R_{\text{inf}} \) - is the expenses of the infrastructure constituent [12].

\[ \begin{align*}
R_{\text{car}} & = 14.3 \\
R_{\text{station}} & = 3.7 \\
R_{\text{loco}} & = 2.1 \\
R_{\text{inf}} & = 79.9
\end{align*} \]

Figure 1. Shares of the constituents within the structure of expenditure for train route.

The acceptable minimum passenger car seating capacity ratio for a train assigned to \( ij \) depends upon the number of seats occupied by passengers and upon the number of seats offered by the train:

\[ \alpha_{ij}^{\min} = \frac{b_{ij}^{\min}}{a_{ij}} \]  

where \( b_{ij}^{\min} \) is the minimum number of occupied seats on the train, which allows the designation revenues to cover the expenses for its setting up; \( a_{ij} \) is the number of seats offered on the train assigned to \( ij \); \( ij \) is the designation of the train in accordance with the plan for setting up passenger trains \( i \in [1,2,...,n], j \in [1,2,...,m] \).

The actual income of the company from ticket sales that the company gains at a certain value of the use of the seating capacity for a certain type of carriage, can be recorded as an equation:

\[ D_{ij}^{\text{actual}} = x_{ij} \cdot a_{ij}^x \cdot c_{ij}^x \cdot \alpha_{ij}^x + y_{ij} \cdot a_{ij}^y \cdot c_{ij}^y \cdot \alpha_{ij}^y + z_{ij} \cdot a_{ij}^z \cdot c_{ij}^z \cdot \alpha_{ij}^z + \ldots + k_{ij} \cdot a_{ij}^k \cdot c_{ij}^k \cdot \alpha_{ij}^k \]  

(5)
where \( x_{ij}, y_{ij}, z_{ij}, k_{ij} \) is the number of first-class carriages, compartment carriages, sleepers with numbered berths, and coaches correspondingly; \( a_{ij}^x, a_{ij}^y, a_{ij}^z, a_{ij}^k \) is the number of offered seats in first-class carriages, compartment carriages, sleepers with numbered berths, and coaches correspondingly; \( c_{ij}, c_{ij}^y, c_{ij}^z, c_{ij}^k \) is the fare for first-class carriages, compartment carriages, sleepers with numbered berths, and coaches correspondingly; \( \alpha_{ij}^x, \alpha_{ij}^y, \alpha_{ij}^z, \alpha_{ij}^k \) – carriage capacity ratio for first-class carriages, compartment carriages, sleepers with numbered berths and coaches correspondingly.

The company will gain maximum revenue \( D_{ij}^{\text{max}} \) from trains running the route \( ij \) if the cars of each type this train consists of are completely full:

\[
D_{ij}^{\text{normal}} = D_{ij}^{\text{max}} \text{ at } \alpha_{ij}^x = 1, \alpha_{ij}^y = 1, \alpha_{ij}^z = 1, \alpha_{ij}^k = 1
\]  
(6)

The number of tickets sold for train \( ij \) должны быть такими, чтобы обеспечить компания’s minimum revenue from a train run on the designated route \( ij \):

\[
D_{ij}^{\text{min}(s)} \geq b_{ij}^x \cdot c_{ij}^x; D_{ij}^{\text{max}(s)} \geq b_{ij}^x \cdot c_{ij}^x; D_{ij}^{\text{min}(c)} \geq b_{ij}^y \cdot c_{ij}^y; D_{ij}^{\text{max}(c)} \geq b_{ij}^x \cdot c_{ij}^x
\]  
(7)

where \( D_{ij}^{\text{min}} \) is the minimum revenue from a train running the route \( ij \) that covers all the expenses of the train’s formation; \( b_{ij}^x, b_{ij}^y, b_{ij}^z, b_{ij}^k \) is the number of the occupied seats in a car of the corresponding type in the train running the route \( ij \):

\[
b_{ij}^x = a_{ij}^x \cdot \alpha_{ij}^x; b_{ij}^y = a_{ij}^y \cdot \alpha_{ij}^y; b_{ij}^z = a_{ij}^z \cdot \alpha_{ij}^z; b_{ij}^k = a_{ij}^k \cdot \alpha_{ij}^k;
\]  
(8)

Adjusting measures should take into consideration the fact that reduction of the number of cars in a train, cancelling trains, lessening the frequency of running, and uniting/joining up trains can have a negative influence and cause a drop in the seating capacity factor due to the incompatibility of the clients’ preferences and the company’s offer [16]. In the situation when seats in compartment carriages are absent passengers more willingly buy free seats in sleepers with numbered berths then in the opposite situation. With the first-class carriages and coaches, such a situation is not observed. Gaining revenues under such conditions can be presented as a system of inequalities:

\[
D_{ij}^x \geq b_{ij}^y \cdot c_{ij}^y + b_{ij}^z \cdot (1 - \epsilon_{ij}^{\text{y\rightarrow x}}) \cdot c_{ij}^y + b_{ij}^y \cdot c_{ij}^y + \ldots + b_{ij}^k \cdot c_{ij}^k
\]

\[
D_{ij}^z \geq b_{ij}^x \cdot c_{ij}^x + b_{ij}^y \cdot c_{ij}^y + b_{ij}^x \cdot (1 - \epsilon_{ij}^{\text{y\rightarrow x}}) \cdot c_{ij}^x + \ldots + b_{ij}^k \cdot c_{ij}^k
\]  
(9)

where \( \epsilon_{ij}^{\text{y\rightarrow x}} \) is the probability of trip withdrawal if the demand for a seat in a compartment carriage is not met and a seat in a sleeper with numbered berths is offered; \( \epsilon_{ij}^{\text{y\rightarrow x}} \) is the probability of trip withdrawal if the demand for a seat in a sleeper with numbered berths is not met and a seat in a compartment carriage is offered.

The economic effect of the work of a train on the route \( ij \) is determined by the revenues from ticket sales for this train that can cover the expenses on the operation of cars of each type [17]. This condition is achieved at the acceptable minimum passenger car seating capacity ratio for a certain car type in a train on the route \( ij \):

\[
a_{ij}^x \cdot c_{ij}^x \cdot \alpha_{ij}^x \geq a_{ij}^y \cdot c_{ij}^y \cdot \alpha_{ij}^{(\text{min})}
\]

\[
a_{ij}^y \cdot c_{ij}^y \cdot \alpha_{ij}^y \geq a_{ij}^y \cdot c_{ij}^y \cdot \alpha_{ij}^{(\text{min})}
\]

\[
a_{ij}^z \cdot c_{ij}^z \cdot \alpha_{ij}^z \geq a_{ij}^z \cdot c_{ij}^z \cdot \alpha_{ij}^{(\text{min})}
\]

\[
a_{ij}^k \cdot c_{ij}^k \cdot \alpha_{ij}^k \geq a_{ij}^k \cdot c_{ij}^k \cdot \alpha_{ij}^{(\text{min})}
\]  
(10)

where \( \alpha_{ij}^{(\text{min})} ; \alpha_{ij}^{(\text{min})} ; \alpha_{ij}^{(\text{min})} ; \alpha_{ij}^{(\text{min})} \) is the acceptable minimal car capacity ratio for first-class carriages, compartment carriages, sleepers with numbered berths, and coaches correspondingly, at which the revenues from ticket sales cover the expenses of the organization of train operation on the route \( ij \) in full.
Taking into consideration the specific features of the regions of the Russian Federation \[8\], a passenger train trip from departure station \(i\) to the destination station \(j\) does not always take place. Quite frequently, a passenger makes a trip for a shorter distance within the frameworks of the railway section, therefore the same seat can be bought several times and this can increase the revenues from ticket sales for different types of carriages of certain trains \[10\], \[13\]. This process can be described by a system of inequalities that is made for each plan of train formation with a shorter route, denoted by \(p\). In this case the revenues from selling tickets for a shorter distance on the seats according to a car type will increase by value \(\Delta\), that is determined in the following way:

\[
\Delta^i = a_{ip}^x \cdot c_{ip}^x
\]

\[
\Delta^y = (1 - e_{ip}^{x \rightarrow z}) \cdot a_{ip}^z \cdot c_{ip}^z
\]

\[
\Delta^z = (1 - e_{ip}^{y \rightarrow z}) \cdot a_{ip}^z \cdot c_{ip}^z
\]

\[
\Delta = a_{ip}^y \cdot c_{ip}^y
\]

\[(11)\]

where \(e_{ip}^{x \rightarrow z}\) is the probability of trip withdrawal when the demand for seats in a compartment carriage is not met and a seat in a sleeper with numbered berths on the route \(ip\) in a train within the route \(ij\) is offered; \(e_{ip}^{y \rightarrow z}\) the probability of trip withdrawal when the demand for a seat in a sleeper with numbered berths is not satisfied and a seat in a compartment carriage on the route \(ip\) in a train within the route \(ij\) is offered.

At the same time, the number of carriages of each type must not be less than the acceptable minimum for a train on the route \(ij\):

\[
x_y + y_y + z_y + \ldots + k_y \geq m_{ij}^{\text{min}}
\]

\[(12)\]

where \(m_{ij}^{\text{min}}\) is the minimum number of cars in a train for the route \(ij\).

The methodology developed was tested on trains in the Far Eastern region of the Russian Federation. This paper presents an example for the train 113/114 on the route Khabarovsk – Tikhookeanskaya. The calculations performed showed that expenses on the train operation decrease with the reduction of the number of carriages. At the same time, the degree of seating capacity increases and even at the original number of passengers there exists a potential between the revenues and the expenses that will not lead to a negative result if passengers do not purchase tickets for the train. The potential for 14 carriages is 3.2\%, i.e. the revenues cover the expenses at a train occupancy rate of 55.8\%. The potential for 13 carriages is 7.2\%: the revenues cover the expenses at the train occupancy rate of 57.8\%. The potential for 12 carriages is 11.2\%: the revenues cover the expenses at the train occupancy rate of 59.8\%. The potential for 11 carriages is 15.2\%: the revenues cover the expenses at the train occupancy rate of 60.8\% according to Fig 2.

If we take proper account of the availability of several variants of train composition, proceeding from a demand for a certain type of carriage we can determine the degree of train occupancy that will ensure that revenues cover expenses. We can also determine the number of passengers who can leave at this train composition. When changing types of carriages in a train the passengers’ demand for a certain carriage category should be taken into consideration.
5. Conclusion
The methodology developed was tested for trains of different routes of the Russian Federation railways. In addition, different variants of train compositions within the frameworks of the established scheme of a train composition were considered. We determined the upper and lower limit for the acceptable minimum carriage capacity ratio. This elaborated methodology for day-to-day regulation allowed an average two months increase in the profitability period of train operation due to increase in the carriage capacity use: for first class carriages by 4.3 % on the average; for compartment carriages by 12.2 % on the average; for sleepers with numbered berths by 10.9 %; and for coaches by 5.6% on the average at the same level of passenger turnover.

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