Determining traffic potential as an important part of sustainable railway passenger transport

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Abstract. The main goal of EU transport policy in passenger transportation is to support public passenger transport and railway transport as a key transport mode, to know actual transport needs and to determine traffic potential properly. The paper considers particular current problems of public passenger transport, especially railway passenger transport. It proposes the basics of a methodical process that should increase its efficiency, attractiveness, a better image for the traveling public, but especially the increase of transport performance. A very important part of the methodical process is determining traffic potential. Particular methods of determining it are described and a proposal of a new methodology is included. The main aim of the methodology is to determine the value of the total traffic potential coefficient Kp. This value can be calculated using the proposed formula. It is possible to fit the values of the factors affecting traffic potential into the formula. As a result, there is practical application of the proposed methodology on real railway lines in Slovakia.

1. Introduction

At present, it is very important to ensure the optimal mobility of goods and people and the quality of the transport process. Freight and passenger transport is a significant sector of the national economy. Only a good transport system and transport infrastructure will contribute to the development of industry, agriculture and other manufacturing and non-productive sectors of the national economy. The speed and efficiency of transport, its impact on the environment and energy consumption significantly affect the sustainable development of the area and the development of society.

In recent years, however, public passenger transport performance has been reduced at the expense of individual motoring, which is much more popular among national citizens than mass passenger transport. However, the enormous increase in passenger cars leads to a number of negative facts, in particular congestion and adverse environmental impacts. Therefore, it is now necessary to adopt a number of effective measures to revitalize public passenger transport, which could motivate passengers to use public transport at the expense of individual transport. The European Commission has issued a number of strategy papers to help meet the objectives set.

The paper briefly analyzes and evaluates the current state of public passenger transport with emphasis on rail passenger transport. Furthermore, it proposes a methodological process for a sustainable status of traffic service provided by rail passenger transport linked to the extent of railway infrastructure. It includes sectional important steps which must be observed in the correct order.

Next, traffic potential as a very important part of the process is explained. Particular methods of determining it, including a proposal of a new method and its practical application, are described.
2. Literature review and current status of solving the problems

Transport problems are also addressed by a large number of transport experts and scientists. For example, the book “Transport Modeling” [1] explains the basic principles of traffic planning and modelling. Another publication, “Railway Timetabling and Operations” [2] makes an analysis, modelling, simulation and performance evaluation. There is a lot of useful information about the rationalization and optimization of railway transport operation and railway transport management.

The scientific paper “Improving passenger transportation service as a part of tourism services complex in Russia” [3] explains the theoretical background of travelling motives, transport needs and structure of consumers by type of activity. It is an important part of the proposed methodical process. Another scientific contribution “Relationships between rail passengers’ satisfaction and service quality: a framework for identifying key service factors” [4] focuses on service quality and railway service and proposes a methodology aimed to establishing the importance of the various characteristics of a transit service for the overall service quality, in order to identify the key factors for the users of transit services.

Scientific contributions “Passenger- and operator-oriented scheduling of large railway projects” [5] and “Optimal train routing and scheduling for managing traffic perturbations in complex junctions” [6] include real-time railway traffic management problems, routing, scheduling, passenger perspective and railway infrastructure problems. Publication “The sustainable mobility paradigm” [7] contains measures for improving transport mobility and key elements of sustainable mobility. The diploma thesis “The proposal of the integrated cycle timetable in Slovakia in 2012” [8] proposes an integrated cycle timetable in Slovakia, but there are no general standards of rationalization which can be used all over Europe or the world.

However there are a lot of unexplored theoretical and practical principles in the field of planning, organizing and timetabling a railway passenger transport system and management. Therefore the goal of the study is methodological process proposal of sustainable railway transport and infrastructure and subsequently to define and determine the traffic potential, as an important part of the sustainable railway passenger transport.

2.1. Current issues in public passenger and railway passenger transport

At present, public passenger and non-motorized transport in some European countries is in a difficult situation. There was a sharp decrease in public passenger transport performance in the Slovak Republic from 1995 to 2010. While in 1995 the ratio of public passenger transport to individual car traffic was almost the same, this ratio is currently unfavorable for public passenger transport, because public passenger transport accounts for only 25% of total transport performance. For example, in the Slovak Republic, in 1995 there was 1 motor vehicle for more than 5 inhabitants of Slovakia, while in 2014 it was already 2.8 inhabitants.

In addition to the decrease of passengers, public passenger transport is currently struggling with various problems of different nature. These are financial problems, organizational problems, problems with transport infrastructure, rolling stock, maintenance, underestimated operating frequency, low vehicle capacity, as well as a negative public image of public transport. Also, the demands of the public traveler are constantly growing, because passengers no longer need to be transported between two selected locations but they are interested in travelling in the required quality. As public passenger transport is not capable of meeting these requirements, it is easier and more efficient for them to address their transport needs through individual transport. However, while the current trend of increasing the number of passenger cars continues, individual passenger motoring will gradually cease to be attractive because of congestion and few parking places. At the same time, there is a further negative effect, namely, the heavy burden on road infrastructure and in particular the negative impact on the environment.

In a number of post-socialist countries, especially in eastern, south-eastern and central Europe, public passenger transport and railway passenger problems appear to be much more intense than in more developed Western countries. The current negative situation of public passenger transport is particularly obvious in the area of rail passenger transport. The main advantages of this transport mode are greatly
underestimated by the advantages of individual motoring. In many of these countries, after 1989 individual motoring has become highly preferred as modern democratic right for free transport mode. Rail transport was ignored as a remnant of the old regime and gradually created various problems related to the organization, operation, problems with rail infrastructure and rolling stock.

The most significant deficiencies in the organization of rail passenger transport are related in particular to the construction of railway time table. Mostly it is constructed with a priority for long-distance transport. This results in insufficient satisfaction of regional train needs. Self-governing regions order bus connections mostly at the same time and almost on the same routes as operated regional trains. It creates the parallel connections of trains and buses.

There are also significant deficiencies in the area of transport planning. These often do not take into account the results of various transport analyses, transport research or ticket sales. Insufficient train connection frequency, weaker time and space availability, i.e. long distance of railway stations (stops) from the centers of villages (towns) have contributed to the weaker attractiveness of rail transport. Small accessibility of long-distance rail transport as well insufficient intervals in regional rail transport (2-hour interval) do not correspond to the basic tasks of rail transport system.

Other problems with rail passenger transport are caused by infrastructure quality. In many EU countries the infrastructure is in adequate with low line speeds and old safety devices. In some countries railway passenger transport rolling stock is often not well maintained and not renewed.

3. Methodology of research

The complex proposal of a methodological process for managing sustainable railway passenger transport consists of several sectional proposals that are closely interrelated. The purpose of the proposal will be a new characterization and classification of transport services provided by rail transport according to various criteria, as well as a definition of the factors affecting traffic service. However, it is essential to take into account current transport needs and current travel motives.

Subsequently, a relationship will be proposed, within the individual aspects of the traffic service, to determine the traffic potential that can be calculated on any selected transport route. It will also be necessary to define the railway infrastructure and its optimum range as an indispensable element needed to carry out the required traffic service. Consequently, it will be important to find the optimal connection between the required range of traffic services and the range of railway infrastructure. If this step is completed, it will be possible to proceed with the proposal of standards within the particular transport systems as well as the standards within the scope of the transport infrastructure range. These standards will then be the basis for the final construction of a diagram of train traffic.

This methodological process will be applicable to any selected railway transport route in particular countries. This process is graphically presented in figure 1 as a flowchart.

The benefits of this methodological process should be significant in theoretical and practical terms, as the proposed steps and measures should offer a conceptual solution to the planning and organization of rail passenger transport, which should lead to its increased attractiveness and, in particular, to increased traffic flows. Every step of the process is important and irreplaceable. Achieving of the detailed individual results of particular steps requires detailed analysis. As an example, the step “determining traffic potential” is described in greater detail in the next chapter.

3.1. Determining traffic potential as an important part of the proposed methodical process

Determining traffic potential is a necessary part of the methodical process. However it is very complicated to establish it exactly. For example, empirical models can be used for its optimal determination. The most appropriate one is Lill’s gravity model. It is described below and subsequently there are opportunities for extension of Lill’s gravity model and also foe developing a new method for determining traffic potential.
3.1.1. Lill’s gravity model. Lill’s gravity model serves to determine the optimum number of return journeys of all types of public passenger transport between two selected traffic points. The model considers the number of inhabitants of these transport points and the distance between them. Calculated optimal number is directly proportional to the number of inhabitants of both transport points, the K coefficient and the inversely proportional distance of these traffic points. The model has the following formula, the result is always rounded up:

\[ j_{1,2} = \frac{A_{1}A_{2}}{d^2} K, \]  

where \( j_{1,2} \) is the optimal number of journeys (connections) between selected traffic points over a certain period of time; \( A_{1,2} \) – population number (current, in thousands) of selected toll stations representing traffic points; \( d \) – distance between transport points, km; \( K \) – coefficient (depends on the character and boundaries of selected areas).

3.1.2. Another method for determining traffic potential. To ensure an attractive railway passenger transport system, it is necessary to analyze, among other things, the traffic potential of particular railway lines or transport routes. On the basis of the results of these analyses, it will then be easier to find bottlenecks on the railway lines or routes and then set the optimum service concept for them.
To determine traffic potential, a methodology is proposed that takes into account all relevant factors affecting this potential. This method is not an empirical model. Its basis is the formula, where it is possible to fit the values of the factors affecting the traffic potential. The main objective is to determine the value of the total potential coefficient $K_p$. The value of the coefficient is a non-dimensional number that is directly proportional to transport potential, which means the higher the value, the higher the potential of the chosen railway transport route and the need to set up a service concept with maximum use of rail transport. The directly proportional factors of the resulting value are placed in the numerator of the formula, inversely proportional in the denominator. The overall formula is as follows:

$$
K_p = \frac{A C_A}{L D C_0},
$$

where $K_p$ is total transport potential coefficient – the final value is directly proportional to traffic potential; $A$ – average value of population of the each railway station or stop; current, in thousands; $L$ – average value of transport distance between particular railway stations and stops in a chosen area, km; $D$ – railway station or stop availability – average distance of all stations or stops from the center of adjacent towns or villages, km; $C_0$ – overlapping of the railway line with road coefficient – comparison the total journey time by road and by rail on the chosen transport route, ratio of the running time by rail and by road; the final value is also average value of particular values. $C_A$ is the average value of attractiveness coefficient of a chosen transport route. It expresses the extent to which the railway is attractive for tourism, employment and other. Coefficient $C_A$ consists of three proposed sub-factors, which are expressed by additional coefficients, because the attractiveness of the monitored area is influenced mainly by the number of jobs, the number of different institutions for meeting the basic needs of citizens and the number of tourist centers. For the exact expression of these subfactors are proposed particular subcoefficients – subcoefficient of city size $C_E$, tourism subcoefficient $C_{CR}$ and subcoefficient of unemployment rate $C_N$. The final calculation of $C_A$ then will be:

$$
C_A = \frac{C_E C_{CR}}{C_N},
$$

The values of the particular subcoefficients were determined using the method of creative thinking and based on consultation with transport experts, it takes values from 1 to 5 where the higher the final value, the more attractive the selected territory and the higher the transport potential.

### 4. Results and discussion

Subsequently, the proposed methodology is tested on 2 real railway lines in Slovakia. The first example is Žilina-Vrútky railway line (shown in Picture 3 in red) and Hronská Dúbrava - Banská Štiavnica railway line (shown Picture 3 in blue). Subsequently, the final values are inserted into the formula. Particular values including the final $K_p$ value are shown in table 1.

In the second case, the particular values were changed except for transport distance. The changes were done intentionally, because it is important to prove that increasing the directly proportional values in the numerator of the formula causes an increase in the final $K_p$ value and on the contrary indirectly proportional values in the denominator of the formula causes a decrease of the final $K_p$ value. It follows that a decrease of the factor values that favourably influence the increase of $K_p$ causes the decrease of the final $K_p$ value and vice versa. An example is given in table 2.

The final $K_p$ values are not limited. Based on the values fit into the formula, the final value may be within the first extreme, for example 0.10, or within the second extreme, for example 50 and more. It expresses the traffic potential on the chosen transport route and its comparison with other transport routes, for example how many times it is higher or lower than the other line and so on. Consequently, it will then be possible to calculate optimal number of trains that should by operated in the railway line. The exact procedure of this calculation will be the subject of further scientific and research work of the authors.
Table 1. Example on Žilina-Vrútky railway line.

|          | Žilina | Varín | Nezb. Lúčka - Strečno | Vrútky | Final average values |
|----------|--------|-------|------------------------|--------|----------------------|
| A        | 82.92  | 3.82  | 2.56                   | 7.76   | 24.27                |
| C₄       | 8      | 2     | 2                      | 6      | 4.50                 |
| Cₑ       | 4      | 1     | 1                      | 2      | 2                    |
| C₉       | 4      | 4     | 4                      | 3      | 3.75                 |
| CN       | 2      | 2     | 2                      | 1      | 1.75                 |
| L        | 8      | 8     | 4                      | 9      | 7.00                 |
| D        | 0.5    | 1.8   | 1.3                    | 0.5    | 1.03                 |
| t railway, min | 7  | 7     | 3.5                    | 7.5    | 6.00                 |
| t road, min  | 13 | 13    | 6.5                    | 15     | 11.50                |
| CO       | 0.54   | 0.54  | 0.54                   | 0.50   | 0.53                 |

\( K_p \)  

28.95

Table 2. Example on Hronská Dúbrava - Banská Štiavnica railway line.

|          | Hronská Dúbrava | Kozelník | Banská Belá | Banský Studenec | Banská Štiavnica | Final average values |
|----------|----------------|----------|-------------|-----------------|-----------------|----------------------|
| A        | 0.42           | 0.16     | 1.17        | 0.46            | 10.03           | 2.45                 |
| C₄       | 1              | 1        | 1           | 1               | 3               | 1.40                 |
| Cₑ       | 1              | 1        | 1           | 1               | 3               | 1.4                 |
| C₉       | 3              | 3        | 3           | 3               | 3               | 3                    |
| CN       | 3              | 3        | 3           | 3               | 3               | 3                    |
| L        | 8              | 8        | 7           | 3               | 2               | 5.00                 |
| D        | 0.3            | 0.7      | 1.3         | 5               | 1.1             | 1.68                 |
| t railway [min] | 11.5 | 11.5   | 10          | 4               | 4               | 7.38                 |
| t road [min] | 9      | 9       | 8.5         | 13              | 9               | 9.88                 |
| CO       | 1.28           | 1.28     | 1.18        | 0.31            | 0.44            | 0.80                 |

\( K_p \)  

0.51

In the case of the two monitored railway lines it means that on Žilina-Vrútky railway line traffic potential will be around 56 times higher than on Hronská Dúbrava - Banská Štiavnica railway line. It means that on Žilina-Vrútky railway line there should be 56 times more seats available on a train than on Hronská Dúbrava - Banská Štiavnica railway line. It could correspond to reality, because the Žilina-Vrútky railway line is part of the main corridor railway line Bratislava - Košice and Hronská Dúbrava - Banská Štiavnica is a short regional railway line in middle Slovakia. Nowadays there are approximately 10 regional trains operated daily in both directions on Hronská Dúbrava - Banská Štiavnica railway line with approximately 600 seats on the trains. There are operated approximately 90-100 trains (regional and long distance) in both directions on railway line Žilina-Vrútky approximately with 34000-40000 places to sit on the trains. It follows that the capacity of seats on the trains is about 60 times higher on Žilina-Vrútky railway line than in the case of the Hronská Dúbrava - Banská Štiavnica railway line. This value can approximately correspond to calculated traffic potential.

4.1. Variant calculations of chosen railway lines

However, if particular parameters are changed in the formula, the final \( K_p \) value will be changed too. Several variations of chosen railway lines are shown in tables 3 and 4.

The parameters in brown were changed in the tables. It can be seen how the final \( K_p \) value changed.

In the case of Žilina-Vrútky railway line the marked in brown parameters were changed for the worse, but they were change for the better in the case of Hronská Dúbrava - Banská Štiavnica railway line. The final \( K_p \) value will then be only approximately 2.64 times higher in the first case than in the second case after these changes.
Table 3. Example on Žilina-Vrútky railway line after some parameter changes.

| Parameter | Žilina | Varín | Nezb. Lúčka - Strečno | Vrútky | Final average values |
|-----------|-------|-------|------------------------|-------|----------------------|
| A         | 62.92 | 3.82  | 2.56                   | 7.76  | 19.27                |
| C_A       | 4     | 1     | 1                      | 1.33  | 1.83                 |
| C_E       | 4     | 1     | 1                      | 2     | 2                    |
| C.CR      | 3     | 3     | 3                      | 2     | 2.75                 |
| C.N       | 3     | 3     | 3                      | 3     | 3                    |
| L         | 8     | 8     | 4                      | 9     | 7.00                 |
| D         | 0.5   | 1.8   | 1.3                    | 0.5   | 1.03                 |
| t_railway, min | 7 | 7 | 3.5                  | 7.5 | 6.00                 |
| t_road, min     | 13   | 13   | 6.5                    | 15    | 11.50                |
| C_O       | 0.54  | 0.54  | 0.54                   | 0.50  | 0.53                 |
| K_p       |       |       |                        |       | 9.36                 |

Table 4. Example on Hronská Dúbrava - Banská Štiavnica railway line after some parameter changes.

| Parameter | Hronská Dúbrava | Kozelník | Banská Belá | Banský Studenec | Banská Štiavnica | Final average values |
|-----------|-----------------|----------|-------------|-----------------|-----------------|----------------------|
| A         | 0.42            | 0.16     | 1.17        | 0.46            | 10.03           | 2.45                 |
| C_A       | 4               | 2        | 2           | 2               | 6               | 3.20                 |
| C_E       | 2               | 1        | 1           | 1               | 3               | 1.6                  |
| C.CR      | 4               | 4        | 4           | 4               | 4               | 4                    |
| C.N       | 2               | 2        | 2           | 2               | 2               | 2                    |
| L         | 8               | 8        | 7           | 3               | 2               | 5.00                 |
| D         | 0.3             | 0.2      | 0.4         | 2.5             | 0.5             | 0.78                 |
| t_railway, min | 8 | 8 | 7         | 3               | 3               | 5.25                 |
| t_road, min     | 9               | 9        | 8.5         | 13              | 9               | 9.88                 |
| C_O       | 0.89            | 0.89     | 0.82        | 0.23            | 0.33            | 0.57                 |

4.2. Comparison of the K_p calculation with Lill’s formula

For comparison it would be useful to calculate the optimal number of connections on the chosen railway lines using Lill’s gravity model too. Only the population of the starting and destination station and distance between them are fit into the formula. However, it is very difficult to determine the $K_p$ coefficient. Its value for Slovakia should be 100.

In the case of Žilina-Vrútky railway line the final value is as follows:

$$j_{1,2} = \frac{82.92 \cdot 7.76}{21^2} \cdot 100 = 145.91.$$  

In the case of Hronská Dúbrava - Banská Štiavnica railway line the final value is as follows:

$$j_{1,2} = \frac{0.42 \cdot 10.03}{20^2} \cdot 100 = 1.05.$$  

It follows from the calculated values that the final value for the first monitored railway line is more than 138 times higher than the final value of the second monitored railway line. It is too high and inaccurate. The calculation of transport potential using the proposed formula for $K_p$ calculation is more accurate and objective. Therefore, it is more suitable to use the proposed methodology for other railway lines too.

5. Conclusion

This contribution addresses the current state of public passenger transport, highlighting its current problems and weaknesses, especially in the field of its operation and organization. The main proposal...
consists of the methodical process, which will be the basis for ensuring optimal transport service by rail passenger transport in the monitored area as well as the optimal range of railway infrastructure. The proposed methodological process contains a number of sub-steps and objectives, which when fulfilled will help to achieve the main objective. The most important part of the process is determining traffic potential. The paper explained current methods and also the new proposed methodology. The main aim of the proposed methodology is to determine the value of the total traffic potential coefficient $K_p$. This value can be calculated by using the proposed formula. Finally, there was practical application of the proposed methodology on real railway lines in Slovakia.

Generally, the calculated values of the traffic potential do not have to be exact values, it is only recommended mathematical value which should be taken into account when constructing train traffic diagram. Other detailed solutions of the proposed method and the specific solutions of other mentioned partial steps as well as the overall methodology proposal will be the subject of further scientific and research work of the authors.

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