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# EVALUATION OF POTENTIAL OF REGIONAL RAILWAY LINES

**Summary.** There is a significant number of railway networks within many Middle- and East-European countries operated only by regional lines, usually with a great difference between travel demand and transportation offer. This difference is reflected in the whole economic balance of the lines of the service there, resulting as an essential input for the assessment of rail system efficiency. This paper is the conclusion of the Czech Technical University in Prague (CTU), Faculty of Transportation Sciences research and development project (further as the Project), which aims to analyse the current status and potential of the regional railway network in the country. The paper presents the characteristics of that segment of Czech railway network from the perspective of all scopes evaluated within the Project. A general multi-branch categorization of regional lines is proposed, arising from their technical and economical parameters, and potential for travelling.

# BEWERTUNG DES POTENZIALS DER EISENBAHNSTRECKEN VON REGIONALER BEDEUTUNG

**Annotation.** Das Eisenbahnnetz der Länder vor allem im Mittel- und Osteuropa weist einen großen Anteil der Eisenbahnstrecken auf, die nur der Verkehrsbedienung von dem lokalen Charakter mit einem oft abgründigen Unterschied zwischen der Beförderungsnachfrage und dem Verkehrsangebot dienen. Dieser Unterschied beeinflusst das Wirtschaftsresultat dieser Strecken, resp. des auf ihnen betriebenen Verkehrs, und stellt somit eine wesentliche Eingabe für die Bewertung der Effektivität des ganzen Eisenbahnsystems dar. Der Artikel ist eine Zusammenfassung eines Forschungsvorhabens, das an der Verkehrsfakultät der CVUT in Prag ausgeführt wurde und das sich als Ziel setzte, den bestehenden Zustand und das Potenzial des Eisenbahnnetzes von regionaler Bedeutung auf dem Gebiet der Tschechischen Republik allseitig zu analysieren. Der Artikel beschreibt die für die Analyse der wirtschaftlichen Bilanz und für die Analyse des Beförderungspotenzials benutzten Methoden und die Multikriterienbewertung der technischen Parameter der besagten Strecken. Weiter legt der Artikel die Charakteristiken des erwähnten Segments des tschechischen Eisenbahnnetzes in allen geforschten Bereichen vor. In seinem Schlussteil schlägt der Artikel eine gesamte Kategorisierung eines Streckenabschnittes von regionaler Bedeutung in Gruppen laut seinen technisch-ökonomischen Parametern und seinem Potenzial der Beförderungsnachfrage vor.

## 1. INTRODUCTION

The paper describes a possible way to assess the importance and future potential of secondary railway lines, based on the real parameters of the Czech regional railway network. For this reason, the paper first describes the general importance of the railways within the Czech public transportation system, historical context included. A brief description of the railway lines potential evaluation follows, which has been researched during the author's doctoral studies at the CTU Prague, Faculty of Transportation Sciences. The evaluation was prepared for three key areas. As a conclusion, the paper presents a deep proposal for general evaluation of the monitored railway line sections and their classification. This decision-making tool does not attempt to strictly decide which specific lines are to be reduced or abandoned, but identifies perspectives for their possible growth and development.

## 2. RAIL TRANSPORT IMPORTANCE FOR THE TRAFFIC SERVICE IN REGIONS

Generally, the Czech railway network can be divided into two major functional groups: (1) The main skeleton, formed by the lines providing interconnection from the most important population centres, and links the Czech Republic with neighbouring countries. The largest volumes of passenger and freight transport used to be displaced there. (2) Larger group of lines - whose meaning lies at regional or strictly local level, eventually forming feeders for lines from the first group. These lines are commonly characterized only by regional passenger trains service, and also by mostly low-freight service. Both aspects result from the operational parameters of these lines, and from the relationship between their alignment and the structure of the settlement. Public transport services handled by the regional railway lines used to be regulated by the regional offices, whose behaviour differ a lot in each region (railway systems somewhere form the body of integrated traffic systems excellently interconnected with other public transportation systems, elsewhere they were reduced without adequate substitution by bus link).

Without prejudice, we can assume that it is the second group of railway lines that require an independent assessment of their potential, because it is most appropriate to identify where the potential exists and could be effectively developed on the one hand, and where it is impossible to recognize it on the other hand. This evaluation should be realised with regard to the public transportation systems, which sustainably have to ensure the travel needs of population in longer time period. The justified rail network range should be fixed in the region. In addition, its connection to other public transportation systems should be further developed to lend a hand to ensure sustainable development of regions and municipalities.

## 3. DEVELOPMENT OF RAILWAY NETWORK IN THE CZECH REPUBLIC AND IN THE NEIGHBOURING COUNTRIES

The range and topology of Czech railway network has not significantly changed in a long period of time. This fact is particularly noticeable when compared with road networks that have been developing relatively dynamically, especially in recent years. To complete the overall picture of the importance of railway infrastructure in our country, it is appropriate to give an overview of its historical development 1.

The railway network in the territory of today's Czech Republic began, approximately, during the second quarter of the 19th century when the first two horse-drawn railways started. The real development of railways only came with the advent of the steam traction in the 1840s, specifically when the Northern Railway of Emperor Ferdinand started its step-by-step opening in 1839 to connect Vienna and Cracovia. It became one of the biggest private enterprises on the European continent and its realization was completed in 1855. Generally, it is recognized that the private and, later, the national owners involved in the development of railways in that era strictly followed the economic balance, with interest on incomes from operation, resulting in the valorisation of the funds invested.

The initial steam-drawn railways also started to ply the most advantageous routes and directions, guaranteeing optimal conditions for their operation. Till date, we can still identify the highest density of traffic volumes there.

For the years 1855 – 1865, the need for coal shipment became the most important impulse for railway construction; so many new railway companies were established, and the existing enterprises were trying to expand their networks. When many coal mines were exhausted later, the connected railway lines became unprofitable. The Government did not support new lines to be directly built in that era, but it had a significant influence on their alignment due to military and geopolitical reasons, because it was an provider of building licenses and permissions. So many railway lines with an unattractive alignment in relation to the population centres started their operation.

The richest period with the most comprehensive railway lines expansion was from 1866 to 1878, when the overall Czech railway network ballooned with more than 3 500 km. The dynamic construction was motivated by many competing, recently-established private subjects. Significant development of the railway network ended suddenly with the start of an economic crisis in 1878. But, the core of fully functional railway network within the Czech territory had been already completed then.

After the crisis had abated, other requirements for new connections were presented. They referred to localities yet unconnected to the existing railway network, which were more or less unattractive. Nevertheless, the Government decided to willingly support these local activities on the basis of statutory exceptions. State or provincial guarantees provided for new railway lines build up, which we now call "local", "regional", "self-help" etc. These lines are commonly characterised by construction - and operating costs minimization, reduced track speed, and lower traffic density. So, they could often accommodate only a limited group of transportation opportunities, which led to existential problems for many of them later.

The character of railway networks started to significantly change, for the last time, when the independent Czechoslovakia was proclaimed in 1918. This changed the orientation of major transportation axis from north - south and east - west direction. The last completely new railway line came into operation in 1953, between Havlíčkův Brod and Tišnov, as an alternative interconnection between the two biggest Czech cities - Prague and Brno. Since that time, only local bypasses were built, often with relation to other investment activities (open-cast mines, new dams), and also short interconnecting sections (like the Ostrava Airport connection to the railway network this year). Since the 1930s (and fully in the 2nd half of 20th century), the economic reasons had led to cancellation of operations on less important lines, which has commonly been followed by their abandonment.

After the Czech Republic was established in 1993, the modernization program of four transit rail corridors came into being, followed by the rationalization of non-corridor lines aimed at reducing operating costs by installation of remotely-controlled interlocking systems. Until quite recently, these lines used to be also equipped with new platforms, together with increasing track speed limits according to operational needs.

The range of regional railway network had been changing also within neighbouring countries to the Czech Republic. While this process in Slovakia, Austria and Poland had been obviously represented by reduction in permanent networks, many railway lines services in Germany, by contrast, were being restored. For example, in Slovakia, railway service on 23 lines had been abandoned between 1993 and 2012 physical demolition will follow concerning approximately 250 km of lines 2. Compared to Czech circumstances, density of railway network is significantly lower, but geomorphological conditions (long deep valleys typically forming narrow urbanized and industrial axes) implicate perpendicular distances between train stops, and settlement centres are obviously shorter. So, the main reason for railway network reduction resides in growing competition of other means of transportation, given growing living standards (car ownership) and experts in the field of bus transportation, supported by authoritative unwillingness for funding the technically outdated rail infrastructure. Another example is the railway service between Bratislava and Komárno, which is being successfully

revived- thanks to the process of liberalization and reconstruction 3. In Poland, many thousands of kilometres of regional railway lines have been gradually abandoned by reason of weak travel demand, occasioned by poor economical savings, bad technical conditions of tracks and strong competition from individual transportation mode 4. The railway service reduction there has its analogy only in Great Britain between 1958 and 1968, where one third of railway network was abandoned 5, 6. Typical for Austria is a different approach from the perspective of each federal county, in relation to public transportation systems. But in general, many railway services were stopped mainly in the 1970s and 1980s, from which many sections were abandoned and replaced with pathways for tourists or bikes 7. The process of rail service reduction in Germany could be logically divided into two time periods: the first after the WWII in western part, and the second in 1990s in eastern part, coming from different eras of early years of opened economies 6. Generally, the differences between Western and Eastern Europe relating to the development of railway network range are illustrated by Fig. 1 below. Today, the situation is stable and many rail services are being regenerated after liberalization, privatization and evaluation, followed by investments and innovative access (e.g. tramtrain), attended by growing travel demand and services profitability 8.
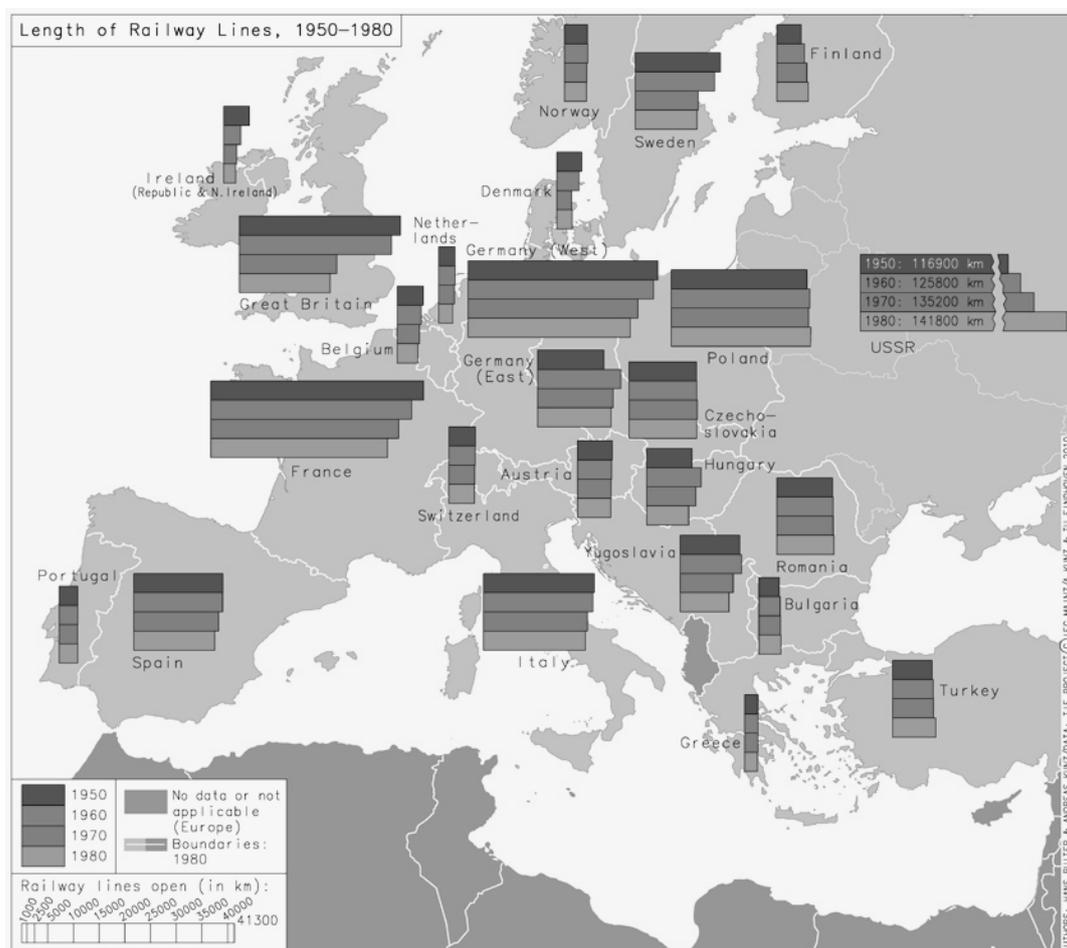


Fig. 1. Development of railway network range within European countries in 1950-1980. The stage of selection (reduction) in Western Europe was noticeable in that era, while to the east of the Iron Curtain, this effect came mostly to societal changes and open economies after 1989 [6]

Fig. 1. Die Entwicklung des Ausmaßes des Eisenbahnnetzes im Rahmen der europäischen Länder in den Jahren 1950–1980. In dieser Periode war die Phase dessen Reduzierung im Westeuropa offenbar, während östlich von dem Eisernen Vorhang dieser Effekt vor allem erst nach den Gesellschaftsänderungen und der Eröffnung der Ökonomiken nach dem Jahre 1989 eintraf. Quelle: [6]

## 4.  RAILWAY LINES ASSESSED BY THE PROJECT

Each railway line belongs to one of following categories, as currently held by the Czech Railway Act 9: the national line, the regional line, the branch line, and the special line. Railway lines designated for public intercity traffic are either national or regional. At the start of the Project, it was necessary to define precisely the object of its interest.

Only lines representing the so- called Trans-European Network (some of the national lines) were eliminated from the assessment process. Their significance is primarily to provide high-quality rail infrastructure for both passenger/freight, and national/international transport with highest priority. Their share within overall length of Czech railway network covers 27.45% (2 575 km). Another reason for the elimination of TEN-T network is its link to strategic documents, which does not allow its destruction at the European level; so it does not make sense to look for potential and meaningfulness of TEN-T's operation, because this will definitely remain an integral part of the Czech railway network.

The bouquet of lines monitored consists of those outside TEN-T, the rest of the national lines (belonging to the so- called European Railway System), and the regional lines (lines outside the European Railway System). Their rate has been changing since 2010, when the conception Categorization Concept of Czech Railway Network 10 started to regulate their proportion within the whole network, based on the decision-tree, consisting of operational criteria for both passenger and freight traffic, and their topology. The Project then assesses the share of the remaining 72.55% (6 803 km) of Czech railway network (Fig. 2). All data are valid as at June 10, 2012 (within 2011/2012 traffic timetable).
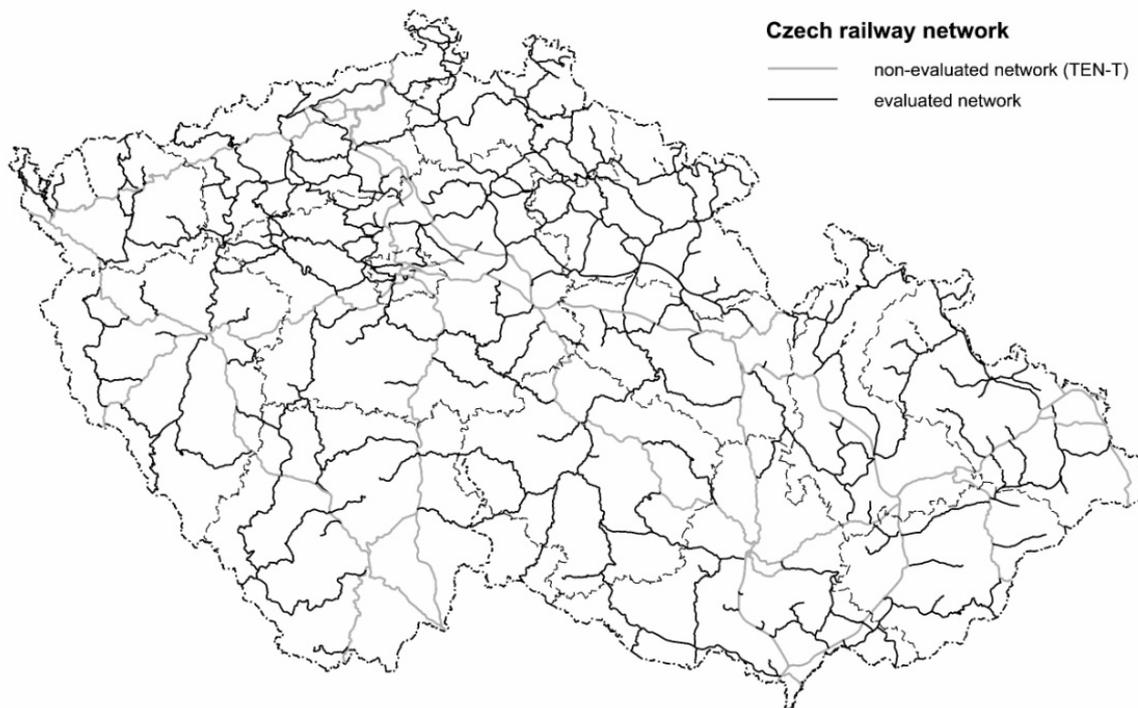


Fig. 2. Map of evaluated and non-evaluated railway lines by the Project
Fig. 2. Die Karte der im Rahmen des Projekts bewerteten und nicht bewerteten Streckenabschnitte

## 5. EVALUATION OF THE RAILWAY NETWORK AND ITS CURRENT CONDITION

As a part of the Project, 202 railway lines were nominated to be analysed and divided into 327 homogenous sections, from the territorial, technical and operational points of view (so the sections are bordered somewhere by starting and terminal points, at other places by the intermediate stopping points dividing the whole line into sections, with different number of tracks, interlocking, catenary, line category, number of trains operated etc.). Somewhere, it was necessary to admit some simplification to keep the acceptable number of evaluated sections for the subsequent analysis. The sections were inserted into the database, where more than 100 data parameters for each section were associated.

To be objective, our research focused on three key areas directly influencing the overall potential of the railway line sections:

- initial technical parameters and their current condition (enabling the trains' operation),
- potential for travelling (quantity of people possibly served),
- economic balance (rate between overall benefits and costs).

### 5.1. Technical parameters and current condition of railway line sections

Technical parameters and conditions are key factors affecting transportation offer on the one hand (for example, capacity influences the possible number of trains operated, headways, departure times, journey times, etc.), and travel demand on the other (for example, line alignment, and stopping points location influences the distances). It might be useful to clarify both terms:

- **technical parameter** represents theoretical value of magnitude characterizing the infrastructure at the time of its launching,
- **current technical condition** represents the condition of the relevant element at a time, which could negatively affect the technical parameter.

Closer overview of one technical parameter and operational parameter resulting from technical parameters in general is demonstrated by the following figures (Fig. 3, Fig. 4).
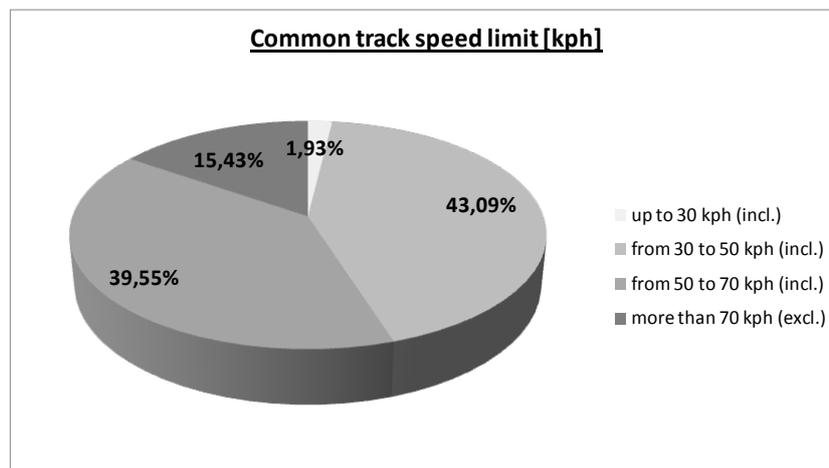


Fig. 3. Percentage of line sections split by common track speed limits
Fig. 3. Der Anteil der Streckenabschnitte, nach der durchschnittlichen Geschwindigkeit geteilt

**Quantity of trains for passenger transport ordered [links per a day, in both directions]**

18,35%

24,46%

7,95%

21,71%

27,52%

- up to 6 (incl.)
- from 6 to 16 (incl.)
- from 16 to 26 (incl.)
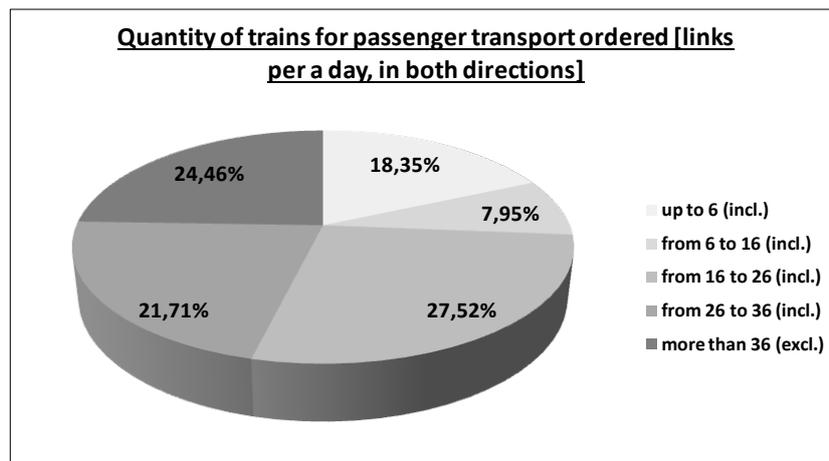- from 26 to 36 (incl.)
- more than 36 (excl.)

Fig. 4. Percentage of line sections split by train quantities for passenger transport ordered
Fig. 4. Der Anteil der Streckenabschnitte, nach dem Umfang des bestellten Personenverkehrs geteilt

## 5.2. Relationship between population centres and regional railway lines. Demographic potential for travelling

The Czech Republic is characterized by significant numbers of smaller villages, some very dominant regional centres and only one metropolitan city, with worldwide importance (Prague, the capital). The Population and Housing Census released in 2011 pointed out that 78% of all population centres, by contrast, were formed by villages with less than 1,000 inhabitants, where only 17% of the whole population lived. Approximately, 62% of the population lived in the medium-size cities, with 1 to 100 thousand inhabitants and 21% in the metropolitan cities, with more than 100 thousand inhabitants. The total number of population centres in the Czech Republic was 6 250, and the urbanization rate was 70% 13.

The intended purpose of passenger railway transportation can be fulfilled when sufficient numbers of regular passengers are served, especially between places of residence and work or school. In Czech conditions, 55% of all transported passengers only moved during five peak hours, while others moved during rest of the day 11. For this reason, it is essential that the railway lines run through the population centres (respecting the hygienic and environmental limits), representing attraction zones. There are some differences in stopping points accessibility, according to their location within the municipality. Before the authors started calculating the demographic potential of travelling, they had decided to simplify these positions into three categories:

- centre – stopping point is located in the (historical) centre of built-up area with multifunctional utilization;
- suburb – stopping point is located outside the centre in the area with lower population density or within industrial part of the cities;
- outside – stopping point is located outside the built-up area, or adjoining the municipality via very sparsely populated area.

Also, the categories of own municipalities were defined, respecting the principles of urbanistic theory described in the document 12, among others. Size of municipality forms some spatial, functional and social differences, and it is possible to identify some common features within the following ranges[1]:

- 0–5 000 inhabitants,
- 5 000–30 000 inhabitants,

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[1]Prague, the only city with more than 1 million inhabitants, was not incorporated into the statistics due to influential reasons.

- 30 000–100 000 inhabitants,
- 100 000–500 000 inhabitants.

Stopping point's localization and approximated demographic data from the Population and Housing Census 2011, and the Czech Statistical Office 13 were utilized for the so-called Passenger Line Potential (PLP) calculation. Its principle is based on the commuting model, working with limited number of journeys to work/school/services specified for each category of municipality. This number results from population density, access time isochrones, active travel behaviour and modal-split. The category of stopping point located outside the built-up area has been judged unattractive, with zero potential for travelling 14, 15.

The following table (Tab.1) summarizes expertly-determined values for above - mentioned magnitude; the last row represents the maximum considered for appropriate stopping point.

Table 1

The overall summary of several population centres characteristics

| Characteristic | inhabitants | 0-5,000 | | | 5,001-30,000 | | | 30,001-100,000 | | | 100,000-500,000 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | unit | centre | suburb | outside | centre | suburb | outside | centre | suburb | outside | centre | suburb | outside |
| Average quantity of inhabitants | people | 675 | 675 | 0 | 10862 | 10862 | 0 | 55037 | 55037 | 0 | 236974 | 236974 | 0 |
| Inhabitants density | people/ km | 100 | 60 | 0 | 750 | 300 | 0 | 1500 | 500 | 0 | 2500 | 1000 | 0 |
| Isochron diameter | km | 1.0 | 1.0 | 0.0 | 1.5 | 1.5 | 0.0 | 2.0 | 2.0 | 0.0 | 2.5 | 2.5 | 0.0 |
| Isochron area | km sq. | 3.0 | 3.0 | 0.0 | 7.0 | 7.0 | 0.0 | 12.5 | 12.5 | 0.0 | 20.0 | 20.0 | 0.0 |
| Inhabitants in the isochron area | people | 300 | 180 | 0.0 | 5250 | 2100 | 0 | 18750 | 6250 | 0 | 5000 | 20000 | 0 |
| Share of active travellers | - | 0.6 | 0.6 | 0.0 | 0.6 | 0.6 | 0.0 | 0.6 | 0.6 | 0.0 | 0.6 | 0.6 | 0.0 |
| Active travellers in the isochrone area (TAP - see chapter 6) | people | 187.8 | 112.7 | 0.0 | 3286.5 | 1314.6 | 0.0 | 11738.0 | 3912.5 | 0.0 | 31300.0 | 12520.0 | 0.0 |
| Modal split | - | 0.3 | 0.3 | 0.0 | 0.3 | 0.4 | 0.0 | 0.2 | 0.3 | 0.0 | 0.1 | 0.2 | 0.0 |
| PLPi | people | 56 | 34 | 0 | 986 | 526 | 0,0 | 2348 | 1174 | 0 | 3130 | 2504 | 0 |

Outputs from the demographic potential analysis are presented graphically by figures below (Fig. 5, Fig. 6).

## 5.3. Economical balance of the railway line sections

Simplified economic balance (benefit-to-cost or revenue-to-expense ratio) represents a key decision-support instrument regarding necessity of money saving activity implementation. The so-called rail market liberalisation started in 2003 to completely split the structure of originally united railway system (represented by former Czech Railways, public enterprise) into three main bodies: the passenger transport operator, the freight transport operator and the manager of infrastructure, whose competencies have been adjusting to the current status when they are completely independent. So, when we would like to evaluate the economic balance, we may choose one of the bodies involved in the system, or we may evaluate the system as a whole.

**Type of residence where the train stops**

5,29%
1,46%
16,58%
76,67%

- village and small town
- small city
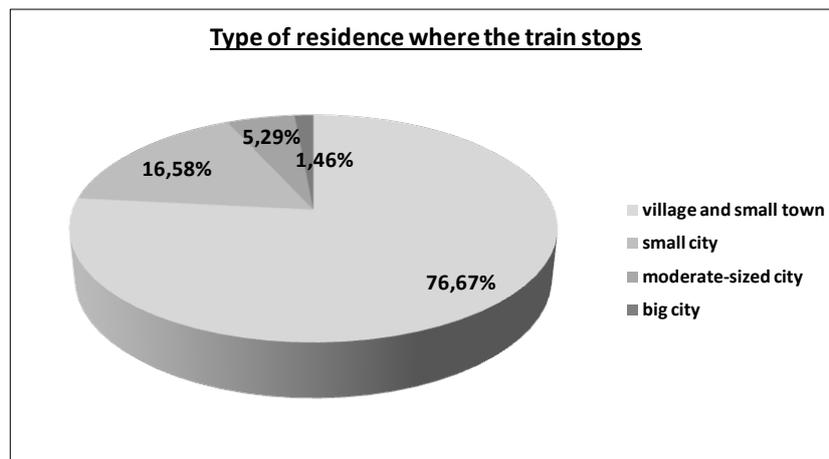- moderate-sized city
- big city

Fig. 5. Percentage of line sections split by type of residence where the train stops
Fig. 5. Der Anteil der Streckenabschnitte, nach der Sorte des bedienten Ortes geteilt

**Location of stopping poit relaed to the centre of built-up area**

12,83%
38,85%
48,32%

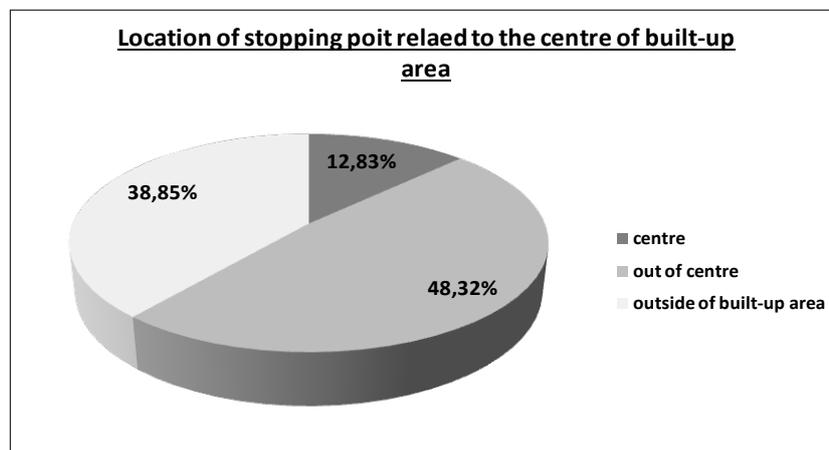- centre
- out of centre
- outside of built-up area

Fig. 6. Percentage of line sections split by location of stopping point related to the built-up area
Fig. 6. Der Anteil der Streckenabschnitte, nach der Lage der Haltestelle in Beziehung zur bebauten Fläche des Ortes geteilt

Plus, the private companies should be involved. The Project compared costs and benefits generated by passenger transport operators, freight transport operators, and transport operators in general, infrastructure managers and the railway system as a whole. From that, the basic results are presented by the figures below (Fig. 7, Fig. 8), representing the statistics of Czech regional railway lines according to their revenue-to-expense ratio, expressed by percentage allocation (Fig. 7), and quantitative allocation (Fig. 8). The statistics results from the calculation, with detailed explanation is provided by formulas (17) and (18) in Chapter 6.

## 6. METHODICAL PROPOSAL FOR EVALUATION OF THE REGIONAL RAILWAY LINES POTENTIAL

The overall evaluation of each railway line section should be based on fair-minded approach, so the proposal made within this Project consists of particular criteria reflecting the above- mentioned key areas characterizing the monitored railway network:

- $C_1$ - mobilization of travel demand (traffic volume to demographic potential ratio),
- $C_2$ - technical/technological parameters and condition of line (real to ideal values ratio),
- $C_3$ - quality of service (offered passenger trains capacity to demographic potential ratio),
- $C_4$ - overall economical balance[2] (overall benefit-to-cost ratio).

**Annual economical balance of sections as an unitary system (percentage of sections related to revenue-to-expense ratio)**

5,20%
4,59%
10,70%
25,99%
53,52%

- less than 0,25
- from 0,25 to 0,49
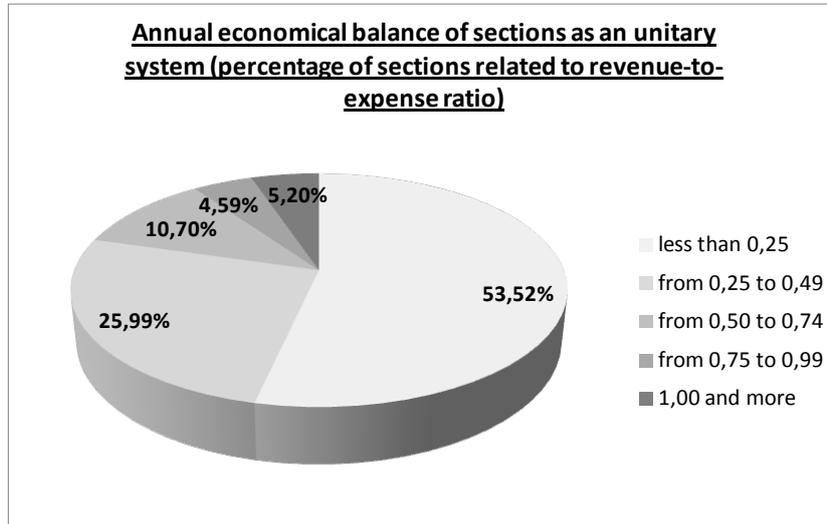- from 0,50 to 0,74
- from 0,75 to 0,99
- 1,00 and more

Fig. 7. Percentage of line sections split by annual economical balance from "unitary" point of view
Fig. 7. Der Anteil der Streckenabschnitte, nach der jährlichen Wirtschaftsbilanz aus der „unitären" Sicht geteilt

**Annual economical balance of sections as an unitary system (quantity of sections related to revenue-to-expense ratio)**

175
85
35
15
17

less than 0,25 | from 0,25 to 0,49 | from 0,50 to 0,74 | from 0,75 to 0,99 | 1,00 and more
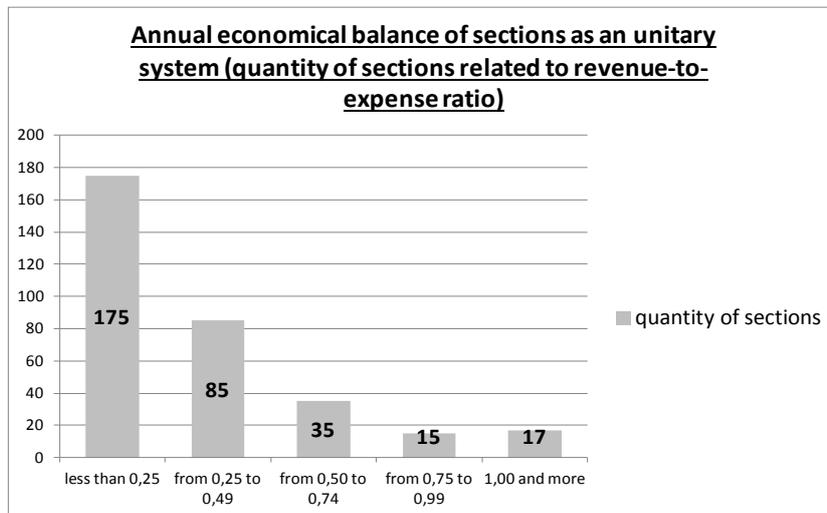
- quantity of sections

Fig. 8. Quantities of line sections split by annual economical balance from "unitary" point of view
Fig. 8. Anzahlen der Streckenabschnitte, nach der jährlichen Wirtschaftsbilanz aus der „unitären" Sicht geteilt

With respect to our theory, the overall potential of each $i$-railway-line-section (further marked as $C_{overall}$) results from the weighted sum of above- mentioned criteria, none of them preferred[3]:

$$C_{overall,i} = \sum_{j=1}^{n} s_j \cdot C_{i,j} \tag{1}$$

where: $\forall C_j: C_j \in \langle 0; 1 \rangle, \forall s_j: s_j \in \langle 0; 1 \rangle$ and $\sum s_j = 1$

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[2]Economical balance really depends on all parametres of transportation offer and travel demand, so it used to be commonly considered as a decision-support criterion resulting in the range of train operation upon the railway line section. This Project judged it as a one off/ particular criterion only.

[3]The weights may differ in praxis according to their real importance, but the formula $\sum s_j = 1$ has to be always respected.

for n = 4 and $\forall s_j$: $s_j = \frac{1}{n} = \frac{1}{4}$

$$C_{overall,i} = \frac{1}{4} \cdot \left( C_{i,1} + C_{i,2} + C_{i,3} + C_{i,4} \right) \tag{2}$$

Any section, lines or wider parts of the network may be compared with each other, and it is also possible to classify all sections into categories according to their results on the field of particular criteria or the overall potential.

**Mobilization of travel demand ($C_1$)**

This criterion represents share of actually transferred passengers in the overall demographic potential for travelling per day, so is the rate for satisfied demand. The values lie within the range <0; 1>. The formula for this criterion is defined below:

$$C_{i,1} = \frac{P_i}{2 \cdot \sum_m PLP_m} \tag{3}$$

where: P – total daily passenger traffic flow in both directions [passengers/day]; $PLP_m$ – passenger line potential of the *m*-population-centre [people]

$$OPT_m = \pi \cdot r_m^2 \cdot \rho_m \cdot DAO_m \cdot MS_m \tag{4}$$
$$PLP_m = \pi \cdot r_m^2 \cdot \rho_m \cdot TAP_m \cdot MS_m \tag{5}$$

where: $r_m$ - *m*-access-time-isochrone diameter [km]; $\rho_m$ - population density within the *m* - access-time-isochrone [people/km²]; $TAP_m$ - share of active travellers (workers and students) within the *m*-access-time-isochrone [-]; $MS_m$ - modal split within the *m*-access-time-isochrone [-].

**Technical/technological parameters and condition of line ($C_2$)**

This criterion influences the transportation offer, so it is also partly integrated as an input to the economic balance. Nevertheless, the technical and technological parameters can serve as an independent potential for further development of the railway line section. So, the authors decided to evaluate them independently as a full-value criterion, which is presented as a rate between real values achieved and some theoretical ideal that could be possibly achieved. The ideal value is one, but lower result can still represent sufficient and fully functional system. The criterion consists of the following parameters: tortuosity ($T_1$), average track speed limits ($T_2$), access-distance of stopping points from the centres of municipalities ($T_3$), level crossings reducing track speed limits, ($T_4$), track speed reduction caused by other reasons ($T_5$), line load category ($T_6$) and type of line interlocking ($T_7$). The values lie within the range <0; 1>. The formula for this criterion is defined:

$$C_{i,2} = \overline{T_i} = \frac{1}{m} \sum_{k=1}^{m} T_{i,k}, \tag{6}$$

then $\forall T_k$: $T_k \in \langle 0; 1 \rangle$ and $\sum T_k = 1$

for *m*=7: $C_{i,2} = \frac{1}{7} \sum_{k=1}^{7} T_{i,k}$.

Then

- **Parameter $T_{i,1}$** – reciprocal value of tortuosity, it is represented by the rate between aerial distance between starting and terminal stopping point of the section and its real length by the formula:

$$T_{i,1} = \frac{L_{aerial,i}}{L_{axial,i}}, \tag{7}$$

where: $L_{aerial,i}$ ... aerial distance between starting and terminal stopping point within the *i*-section [km], $L_{axial,i}$ ... real length between starting and terminal stopping point within the *i*-section [km].

- **Parameter $T_{i,2}$** – rate between average track speed within the section and the maximum reached value of it within the whole batch of monitored sections represented by formula:

$$T_{i,2} = \frac{V_i}{V_{max}}, \tag{8}$$

where: $V_i$ ... average track speed within the *i*-section [kph], $V_{max}$ ... maximum reach value of track speed within the whole batch of monitored sections [kph].

- **Parameter $T_{i,3}$** – rate between quantity of stopping points located in centres of municipalities and overall quantity of stopping points within the section by the formula:

$$T_{i,3} = \frac{H_{centr,i}}{H_{overall,i}},$$
(9)

where: $H_{centr,i}$ ... number of stopping points located in centres of municipalities within the $i$-section [pcs], $H_{overall}$ ... overall number of stopping points within the $i$-section [pcs].

- **Parameter $T_{i,4}$** – ratio of sectional length with reduced track speed limit (due to bad parameters or condition of level crossings) to overall length of the section:

-

$$T_{i,4} = \frac{L_{total,i} - \sum L_{red,i}}{L_{total,i}} = 1 - \frac{2 \cdot X \cdot s}{L_{total,i}} = 1 - \frac{2 \cdot X}{L_{total,i}} \cdot \frac{V_i^2 - V_{0,i}^2}{2 \cdot a} = 1 - \frac{0,001 \cdot X \cdot (V_i^2 - 225)}{L_{total,i} \cdot a \cdot 3,6^2} = 1 - \frac{X \cdot (V_i^2 - 225)}{10368 \cdot L_{total,i}},$$
(10)

where: $a$ … average value of train's deceleration before - and acceleration behind railway crossings: $a = 0,8$ m/s$^2$ (determined by authors, identical for all the sections), $V_{0,i}$ … speed limit within the area of level crossing: $V_{0,i} = 15$ kph (determined by authors, identical for all the sections) [kph], $V_i$… obvious track speed limit within the $i$-section [kph], $X_i$… number of level crossings reducing the speed limit within the $i$-section [pcs], $L_{total,i}$… overall length of $i$-section [km], $L_{red,i}$… $i$-sectional length with reduced speed limit due to bad parameters or condition of level crossing(s) [km].

- **Parameter $T_{i,5}$** – rate between points received within the criterion "speed reduction" and theoretical maximum (no speed reduction), where the worst result is represented by 16 penalty points, which is rooted in an internal multicriteria analysis:

$$T_{i,5} = \frac{B_{SR,max} - B_{SR,i}}{B_{SR,max}} = 1 - \frac{B_{SR,i}}{16},$$
(11)

where: $B_{SR,i}$ ... points received within the criterion "speed reduction" for the $i$-section <0;16> [-].

- **Parameter $T_{i,6}$** – rate between points received within the criterion "line load category" and theoretical maximum (20 tons and more per axle and 7.2 tons and more per longitudinal meter), where the worst result is represented by 16 penalty points, which is rooted in an internal multicriteria analysis:

$$T_{i,6} = \frac{B_{LC,max} - B_{LC,i}}{B_{LC,max}} = 1 - \frac{B_{LC,i}}{16},$$
(12)

where $B_{LC,i}$ ... points received within the criterion "line load category" for the $i$-section <0;16> [-].

- **Parameter $T_{i,7}$** – rate between points received within the criterion "type of line interlocking" and theoretical maximum (line with "automatic signal boxes "or" automatic block"), where the worst result is represented by 16 penalty points, which is rooted in an internal multicriteria analysis:

$$T_7 = \frac{B_{INT,max} - B_{INT,i}}{B_{INT,max}} = 1 - \frac{B_{INT,i}}{16},$$
(13)

where $B_{INT,i}$ ... points received within the criterion "line interlocking" for the $i$-section <0;16> [-].

Then for the whole criteria

$$C_{i,2} = \frac{1}{7} \cdot \left[ \frac{L_{aerial,i}}{L_{axial,i}} + \frac{V_i}{V_{max}} + \frac{H_{centr,i}}{H_{overall}} + \left(1 - \frac{X \cdot (V_i^2 - 225)}{10368 \cdot L_{total,i}}\right) + \left(1 - \frac{B_{SR,i}}{16}\right) + \left(1 - \frac{B_{LC,i}}{16}\right) + \left(1 - \frac{B_{INT,i}}{16}\right) \right].$$
(14)

**Quality of service ($C_3$)**

This criterion represents the dimension of daily train links range compared to the theoretical range needed, which would fully satisfy the transportation demand. The more means better, till rate of 1, higher rate than 1 would be negatively reflected in the economical balance ($C_4$ criterion). It is necessary to normalize the original range into the interval <0; 1> with regard to the weighted sum formulating the overall criterion. The formula for this criterion is defined below:

$$C_{i,3}{}' = \frac{(T_{Os,i} \cdot K_{Os,i}) + (T_{R,i} \cdot K_{R,i})}{2 \cdot \sum_i OPT_i},$$
(15)

$$C_{i,3} = \frac{C_{i,3}{}'}{C_{3,max}},$$
(16)

where: $T_{Os,i}$ ... total daily number of the so-called passenger train links within the $i$-section [trains/day], $K_{Os,i}$ ... average capacity of one passenger train operated within the $i$-section [passengers],

$T_{R,i}$ ... total daily number of the so-called fast train links within the $i$-section [trains/day], $K_{R,i}$ ... average capacity of one fast train operated within the $i$-section [passengers], $C_{3,max}$... maximum value of the "Quality of service" criterion [-].

It is possible to express the quality of service in more depth, for example see 16.

**Overall relative economic balance of unitary railway system($C_4$)**

An economic evaluation means to analyse the benefits (takings from fares), compared to the operational costs of operators and infrastructure managers. The criterion can achieve all the values above zero (profitable system is characterized with the value 1 and more), so it is necessary to normalize the range into the interval <0; 1> with regard to the weighted sum formulating the overall criterion. The formula for it is defined below:

$$C_{i,4}' = \frac{benefits}{costs} = \frac{benefits_{(FARES,P)} + benefits_{(FARES,F)}}{costs_{(P+F)} - tolls_{(P+F)} + costs_{(INFRA)}}, \tag{17}$$

$$C_{i,4} = \frac{C_{i,4}'}{C_{4,max}'}, \tag{18}$$

where: *benefits $_{(FARES,P)}$* - benefits from passenger transport fares [currency unit], *benefits $_{(FARES,F)}$* - benefits from freight transport fares[currency unit], *costs $_{(P+F)}$* - operational costs of all the operators [currency unit], *tolls $_{(P+F)}$* - tolls paid for use of the infrastructure by all the operators [currency unit], *costs $_{(INFRA)}$* - operational costs of the infrastructure manager [currency unit], $C_{4,max}$. - maximum value of the "Overall relative economic balance of a unitary railway system" criterion [-].

## 7. CATEGORIZATION OF THE EVALUATED CRITERIA AND DIVIDING THE RAILWAY LINE SECTIONS INTO CLASSES

It is possible to sort out all the package of railway lines into classes, according to the achieved value of each particular criterion ($C_1$, $C_2$, $C_3$, $C_4$). Our proposal of rating system, and related statistics are presented in the tables below (Tab. 2, Tab. 3).

Table 2

Classes of railway line sections according to value of $C_j$ and relevant rating system

| Class | For interval of $C_i$ | For j=1: mobilization of travel demand is... <br> For j=2: technical/technological parameters and condition of line are... <br> For j=3: quality of service is... <br> For j=4: overall economic balance is... |
|---|---|---|
| $A_{Cj}$ | <0.0; 0.2> | Very unsatisfactory |
| $B_{Cj}$ | (0.2; 0.4> | unsatisfactory |
| $C_{Cj}$ | (0.4; 0.6> | average |
| $D_{Cj}$ | (0.6; 0.8> | satisfactory |
| $E_{Cj}$ | (0.8; 1.0> | excellent |

Similarly, it is also possible to define the classes for particular spans of the consequential criterion $C_{overall}$. This criterion is generated by the weighted sum of the sub-criteria $C_1$, $C_2$, $C_3$ and $C_4$ that are heterogeneous, with different variances of their values. Additionally, weights of the sub-criteria need not be strictly identical (some of them could be preferred). So, the authors would like not to define the overall classes for particular spans of $C_{overall}$ criterion. Finally, estimation of each railway line section should be executed by identification of problematic sub-criteria, and the possible resolution that should consist of the steps mentioned below leading to growth of their attractivity:

- modification of their alignment,
- modification of their technical parameters,

- improvement of their technical condition (and ideally their maintenance ),
- change of stopping points quantity and/or location, as well as loading yards or branch lines approaches,
- change of operational concepts (like quantities of links, operated stopping points, links connections, time-slots for freight trains etc., always providing basic service in public transport, reliable attractive freight transport, and positive economical balance).

Table 3

Number of railway line sections according to the span of above-defined particular criteria

| *Span of values within $C_j$ criterion* | *quantities of lines according to spans of $C_1$ criterion* | | *quantities of lines according to spans of $C_2$ criterion* | | *quantities of lines according to spans of $C_3$ criterion* | | *quantities of lines according to spans of $C_4$ criterion* | |
|---|---|---|---|---|---|---|---|---|
| <0,0; 0,2> | 175 | 54% | 0 | 0% | 56 | 17% | 268 | 82% |
| (0,2; 0,4> | 59 | 18% | 18 | 6% | 10 | 3% | 45 | 14% |
| (0,4; 0,6> | 31 | 9% | 151 | 46% | 15 | 5% | 7 | 2% |
| (0,6; 0,8> | 26 | 8% | 145 | 44% | 16 | 5% | 4 | 1% |
| (0,8; 1,0> | 36 | 11% | 13 | 4% | 230 | 70% | 3 | 1% |
| Total | 327 | 100% | 327 | 100% | 327 | 100% | 327 | 100% |

Each railway line can be generally characterized by some deficiencies and some positive aspects on the other hand, so it would be useful to recognize each of them and to assess them separately. The real examples of railway line sections with their results within particular and overall criteria are described below (Tab. 4).

Table 4

Typical examples of railway line sections and their results within particular criteria

| Line N° | Section | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_{overall}$ | Note |
|---|---|---|---|---|---|---|---|
| 096 | Račiněves – Mšené Lázně | 0.00 | 0.45 | 0.00 | 0.00 | 0.11 | 1) |
| 014 | Kolín – Ledečko | 0.04 | 0.59 | 0.45 | 0.04 | 0.28 | 2) |
| 092 | Neratovice – Kralupy nad Vltavou | 0.11 | 0.62 | 1.00 | 0.60 | 0.50 | 3) |
| 031 | Pardubice – Jaroměř | 0.29 | 0.73 | 1.00 | 0.39 | 0.60 | 4) |
| 323 | Ostrava-Kunčice – Frýdek-Místek | 0.69 | 0.80 | 1.00 | 0.69 | 0.79 | 5) |

1) Single-track and non-electrified regional railway line located within agricultural areas and out of significant population centres; it was extensively repaired in 2006, but the passenger transport operation has been stopped and substituted by bus service; there is no freight traffic except diverted or exceptional trains;

2) single-track and non-electrified regional railway line located within agricultural areas and out of significant population centres, but with very good connection to surrounding rail network; municipalities located along the line still have acceptable travel-time-distances to the capital city, but the line alignment is attractive, only in relation to local district centres;

3) single-track and non-electrified regional railway line located within agricultural areas, but also connecting industrial centres with very good connection to the capital city; in addition, there are many branch lines with active freight transport operation, that positively influences the overall economical balance significantly;

4) single-track and electrified national railway line connecting the urbanized axis of two regional centres with approximately thousands of inhabitants to the first national railway corridor; it serves as a joint line for two other national lines running to the important tourist areas, so it is an essential rail network outside TEN-T, which is being modernised;

5) single-track and non-electrified national railway line with very frequent suburban traffic and tourism potential, especially during weekends, connecting the third and the seventeenth biggest

Czech cities; it lies in an urbanized area, where the freight traffic is supported by significant industrial parks.

## 8. CONCLUSION

The aim of the paper is to describe the regional railway network outside TEN-T in the Czech Republic, and to present an instrument for its significant evaluation considering overall future operational potential. It represents a very sensitive topic within all Middle-European countries. Nowadays, the discussion sometimes metamorphoses into the dilemma of holding or cancelling the operation there. But no systematic or comprehensive evaluation of their overall potential has been applied yet. It is not a good idea to make any evaluation inspired by few preferred criteria (for example, unprofitability), or current range of operation (for example, when it is currently cancelled). It is necessary to consider two main factors: (1) Maintaining rail operation requires huge amount of money, and it is necessary to take advantage of these costs. (2) There are many examples where it is very simple to attract travel demand with only relatively low-level investment, or operational costs (towards the infrastructure and vehicles), or with relevant changes of operational concept for the serviced areas.

The authors believe it would be possible to utilize their way of evaluation within praxis to bring help to local territory services offered by public mass transportation.

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