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PLANNING THE CONSTRUCTION OF HIGH-SPEED LINES IN THE CZECH REPUBLIC AND ITS METHODOLOGICAL EVALUATION IN TERMS OF TRANSPORT SERVICE OF REGION

Summary. The aim of the paper is to set priority of The Fast Connection sections building mentioned above by using the STEM method. This method is used to select projects with the maximum benefit if the budget is limited. There has not been set a limit for individual RS sections as a limitation of financial costs. The decisive factor is the order in which individual RS sections should be built on the basis of evaluation criteria.

1. INTRODUCTION

Today a lot of effort is being made in the Czech Republic to prepare the HSL network based on the previously developed RS concept (“Rychlá spojení” in Czech, abbreviation “RS”). Now, the Czech railway network does not have any line in HSL parameters, which is not acceptable in the long term – with regard to sustainable development of the territory and taking into account the situation not only in the neighboring Western European states, but also global development.

The main directions of the fast railway network have been defined:

- RS1 Praha – Brno – Ostrava – [Poland],
- RS2 Brno – [Slovakia/Austria],
- RS3 Praha – Plzeň – [Germany] (western direction – München),
- RS4 Praha – [Germany] (northern direction – Dresden) with branch (Most – Chomutov, Žatec, Louny),
- RS5 Praha – Hradec Králové/Liberec – [Poland].

The implementation of the RS1, RS2 and RS4 sections is a priority. In these cases, Správa železnic (the main infrastructure manager of Czech railway network) has already began the project preparation. The aim of this paper is to evaluate whether the above-mentioned sections in terms of benefits should be actually built first or whether there is a better order of implementation.

The current design state is schematically shown in Fig. 1 on the next page.

2. SOLUTION OF THE ISSUE

The main aim of the paper is to set priorities in the construction of RS in Czech Republic using the STEM method (Step Method).

The use of the STEM method is defined in the following chapter. The method is used for project selection due to limited funding opportunities while maximizing the benefits of their implementation.

In this case, the method was slightly modified.

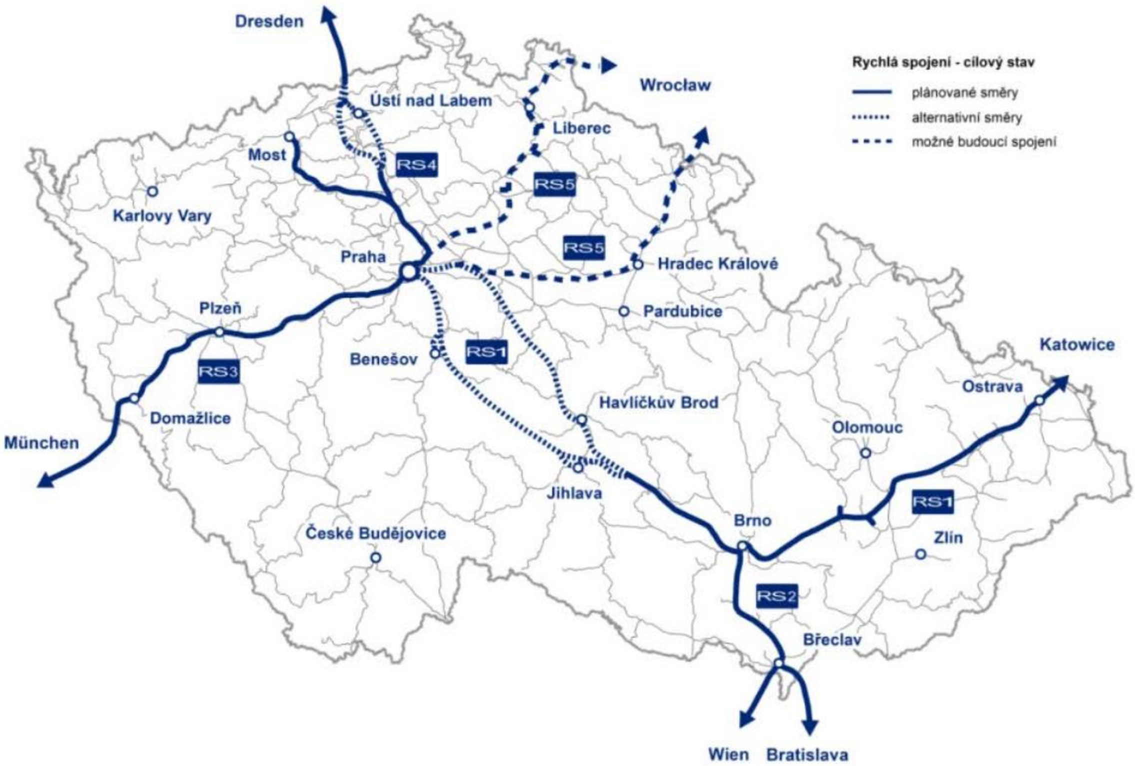

Fig. 1. Suggestion of RS (source: Správa železnic, [2])

2.1. Method STEM

The STEM method can solve linear mathematical problems with more purpose functions. The aim of this method is to find compromise solutions, whose realizations should bring most benefits. The main principle of the method is the calculation of purpose function ideal values for individual cases. This calculation is followed by minimizing compromise solution deviation from ideal purpose function values. The basic of the method is an interactive procedure of searching the compromise solution.

Benefit of the STEM method is, that there is only minimal need of communication between a submitter and a solver (comparing to another methods). The scale method for individual criterions is set by calculation. The submitter must decide whether the result of the calculation is acceptable for him or not. So, the method consists of calculation and decision-making process. The calculation is stopped, if submitter finds the result acceptable, otherwise the solver must be informed by submitter in order to change the criterions or their numbers, the whole calculation is made again.

The STEM method consists of following steps:

1. Solver calculates optimal solution for individual criterions (purpose function) separately. The number of calculations fits the number of criterions.

2. Solver calculates the scales of individual criterions according to the formula (1):

$$w_i = \frac{z_{ii} - \min\limits_{i=j\ldots k} z_{ij}}{z_{ii}} \frac{\alpha}{\sqrt{\sum_{i=1}^{n} c_{ij}^2}} \quad (1)$$

where: z_{ij} – element of optimalization criterions values matrix for optimalization in individual optimalization criterion (z_{ij} is the value of optimalization criterion j = 1,…,k in case of optimalization according to the criterion i = 1,…,k), c_{ij} – element of the price matrix – element of individual optimalization criterion coefficients matrix.

Value α comes from the equation (2):

$$\sum_{i=1}^{k} \frac{z_{ii} - \min\limits_{i=j \dots k} z_{ij}}{z_{ii}} \frac{\alpha}{\sqrt{\sum_{i=1}^{n} c_{ij}^2}} = 1 \tag{2}$$

In reality we have to calculate coefficient alfa value first and then count the scales of individual criterions. If the scale fits the constraint $w_i > 0$ for more criterions, the solver adds new variable $d \geq 0$ and solves the model with new optimalization criterion (3).

$$\min f(x, d) = d \tag{3}$$

There is a form (4) for variable d:

$$d = \max_{i=j \dots k} \{ w_i (z_{ii} - \sum_{j \epsilon J} c_{ij} X_J) \} \tag{4}$$

We have to implement constraint (5) for correct calculation:

$$w_{ii} (z_{ii} - \sum_{j \epsilon J} c_{ij} X_J) \leq d \tag{5}$$

If constraint $w_i > 0$ fits for only one value i = 1,…,k, solver can simplify the constraint (5) to (6):

$$\min f(x) = \sum_{i=1}^{k} w_{ii} (z_{ii} - \sum_{j \epsilon J} c_{ij} X_J) \tag{6}$$

3. Solver presents the results to the submitter. The submitter must modify the criterions or add/remove some of them if he does not find the results acceptable. Solver goes back to step 2.

4. Solver has found compromise solution if the submitter of satisfied with the result. The solution is optimal if the value d = 0 is reached.

2.2. Calculation according to the STEM method and result

For the purposes of the calculation, a total of six logical RS sections were identified:

1. Praha – Brno,
2. Brno – Ostrava – [Poland],
3. Brno – [Slovakia/Austria],
4. Praha – Plzeň – [Germany],
5. Praha – Ústí – [Germany],
6. Praha – Hradec Králové/Liberec – [Poland].

The following evaluation criteria were used to determine priorities in the construction of RS sections:

- **average coefficient of reduced travel times in chosen connections**: the research team (authors of the paper + colleagues from the department) determined RS sections, including international ones, for which the RS construction is crucial. For these sections there was calculated the number of shorter travel times compared to the current situation and in the case RS section is realized. Then these numbers were distributed on individual RS sections and the average for these sections were calculated,
- **number of redirected long-distance lines expressed as an importance**: three categories were set for each evaluated section based on the evaluation below:
    - 1: up to 10 redirected long-distance routes in both directions per day,
    - 2: up to 30 redirected long-distance routes in both directions per day,
    - 3: over 30 redirected long-distance routes in both directions per day.

  In this criterion there is an evaluation if it is possible to route current existing long-distance line on the new RS network, especially on the sections that are close to agglomerations (Praha, Brno, Ostrava), which are already congested,

- **routing difficulty**: the average was calculated based on the questioning an expert team of four experts. The issue of routing was considered broadly (not only regarding natural barriers, but also possibility through cities, etc.) and values are divided into these categories:
  - 1: very difficult routing,
  - 1,5: difficult routing,
  - 2: medium difficult,
  - 2,5: routing without major problems,
  - 3: simple routing,
- **road traffic redirection potential**: for all RS sections, a section on the road network was determined, from which the decisive load value in wagon / 24 hours was taken. The source of data is National traffic census 2016. In all cases, the section on a parallel highway network with logical minimum value of traffic volumes was taken into account, so this criterion represents the minimal potential for traffic redirection from roads.
- **agglomeration potential**: the research team had set agglomerations, including foreign ones, on which the RS sections are going to have a direct influence. For all agglomerations the number of inhabitants was found and then their relation to individual RS sections was evaluated. For example, for Pilsen agglomeration the RS3 section is crucial, but the RS2 section has a minimal importance – this logic was used to evaluate all agglomerations regarding a number of inhabitants. The importance of an agglomeration for a given section was multiplied with its number of inhabitants and the final values were cumulated into individual sections.

All criteria have been compiled in such a way that as their value increases, their benefits are maximized.

The specific values of evaluation criteria are summarized in Tab. 1.

Tab. 1

Specific values of evaluation criteria

section of railway line RS	average coefficient of reduced travel times in chosen connections [-]	number of redirected long-distance lines expressed as an importance [-]	routing difficulty [-]	road traffic redirection potential [vehicles per day in thousands in chosen point of a road network]	agglomeration potential [-]
Praha - Brno	2,13	3	1,6	39	22
Brno - Ostrava - PL	1,85	2	2,5	22	15
Brno - SK/A	1,85	2	3,0	23	21
Praha - Plzeň - D	1,73	3	1,6	31	13
Praha - Ústí n. L. - D	2,23	2	1,5	24	20
Praha - HK/Lbc - PL	2,39	1	1,9	23	12

The STEM method is a very interactive method because it calculates the weight criteria for every mathematical model. There were two mathematical models considered in the calculation (the first one to select two projects out of six and the second one to select four projects out of six), therefore weights were determined twice. These weights are shown in Tab. 2.

In both models, the highest criteria weights were assigned to the **number of redirected long-distance lines expressed as an importance and routing difficulty**, both above 30 %. The **average coefficient of reduced travel times** in chosen connections has a value oscillating around a weight of 20 %. On the other hand, in both calculations there were assigned very low values for **road travel redirection potential** and **agglomeration potential**, these weights are lower than 5 %.

The calculation was performed for both versions of the model, and in neither case d = 0 was achieved. It shows that compromise solutions, not optimal ones, have been achieved.

The two top prioritized high-speed railway line sections have been set by the STEM method:

- Praha – Brno,
- Brno – [Slovakia/Austria]

These two sections have middle priority:

- Brno – Ostrava – [Poland],
- Praha – Plzeň – [Germany].

The rest of sections has a low building priority:

- Praha – Ústí nad Labem – Germany with branch,
- Praha – Hradec Králové/Liberec – [Poland].

Tab. 2

Weight criteria set by STEM method for cases of selecting 2 and 4 projects

	weight criteria for selecting 2 projects	weight criteria for selecting 4 projects
average coefficient of reduced travel times in chosen connections [-]	0,181	0,251
number of redirected long-distance lines expressed as an importance [-]	0,407	0,372
routing difficulty [-]	0,361	0,337
road traffic redirection potential [vehicles per day in thousands in chosen point of a road network]	0,024	0,013
agglomeration potential [-]	0,027	0,028

3. POSSIBLE LINE ROUTING IN LONG-DISTANCE INTERNATIONAL TRANSPORT

Goals of RS network construction of railway transportation development are essential:

- increasing the importance of the Czech railway network for international transport,
- reducing the travel times between Praha and all other regional capitals to 120 minutes or less, to achieve this goal RS lines should be used both by high-speed and conventional trains.
- lowering traffic density on the congested section of railway network, so suburban and freight trains could use it.

Another important issue is the organization of railway operation on new RS lines. Currently railway operation is organized according to the graphical timetable. This approach should be also applied on the new RS lines.

Principles of graphical timetable can be mathematically described by using two simple equations. The edge equation has the following form:

$$t_H = n \cdot \frac{1}{2} t_T \tag{7}$$

The second formula is the circumferential equation:

$$\sum t_H = n \cdot t_T \tag{8}$$

Above-stated variables mean:

t_T – tact time (service interval),

t_H – time weight of the edge between two tact nodes,

n – natural number (depends on individual situation). [1]

Both these equations can be easily explained in order to understand their real meaning.

The edge equation shows that vehicles from one line are passing each other after one-half of the tact time. In case of public transport line with tact time 60 minutes the vehicles of opposite directions pass each other every 30 minutes. Vehicles pass on the route at the place where the symmetry axis is. On single-track railway line, we have to build a passing point. On the lines with two or more tracks, vehicles can pass each other on the route. We can assume that the perfect travel time between two important transport nodes equals one-half of the tact time.

Circumferential equation is related to the term circle (close sequence of edges and nodes) from the graph theory. It says that total count of system travel time on the all edges should ideally equal a multiple of natural number of the tact time. In such case, strong relations between the lines in the nodes are ensured.

Construction of the RS1 and RS2 sections is crucial for national transport relationships, because it can significantly help to overloaded sections of first and third transit railway corridor. We can also assume, that lines on HSL will be integrated to the international connections – **HSL are used both by national and international lines**.

There are already international lines on the Czech railway network. Those lines have high quality vehicles, but their travel speed does not exceed 100 km/h, which is not sustainable in the context of today's "distance reduction". Selected lines are even bypassing Czech Republic, because longer route outside of the Czech Republic offers better travel time. Construction of the RS network should improve this situation and increase the importance of the Czech railway network for international transportation.

Possible conception of international lines is shown on the network graphics in the Fig. 2. on the next page.

Following lines of international trains can create the core of transport services in the RS network scenario:

- Wien – Brno – Praha – Dresden – Berlin. This line should ideally reach systemic travel time four hours along the entire route, which means one hour between each city. This should provide optimal travel time between individual nodes. Current travel time is eight hours – construction of RS1 and RS2 can cut down the travel times by one half. **It is alarming, that current fastest connection Wien – Berlin is not routed through the area of the Czech Republic, but only through Germany and Austria**. Travel time of connection routed through the area of the Czech Republic is slightly longer – this clearly proves unsatisfactory condition of our railway network for international transportation,
- Warszawa – Ostrava – Brno – Praha – Plzeň – München. This line also contains section of the RS3. Current travel time of long-distance train lines is eleven hours, **but these lines are also not routed through the area of the Czech Republic**. At the same time, there is not an intention to build the RS3 in the parameters of HSL. Reaching the travel time under eight hours can be considered as a success. We should reach following travel times for the optimal locations of graphical timetable nodes: Warszawa – Ostrava three hours, Ostrava – Praha two hours and Praha – München 3 hours.

The above-stated network is basic and it consists of two lines with international meaning. For its addition and full use of the RS network, we can also assume following lines:

- Košice – Ostrava – Brno – Praha – Plzeň – Nürnberg, similar to line Warszawa – München in east-west direction. It connects east part of Slovakia, Czech Republic and Germany. Travel time through Czech Republic should not exceed 4 hours. Travel time on the area of other states should not be higher in order to keep the international line attractive for passengers,

- Budapest – Bratislava – Brno – Praha – Most/Chomutov – Karlovy Vary is a line, which connects the capitals of the Czech and Slovak Republic. It does not have to end in the Praha, but it can go to the area of Most (on the designed RS line) and further to the Karlovy Vary (on the conventional line),
- It is appropriate to mention the line Linz – České Budějovice – Praha – Warszawa in case of construction of the RS5.

International lines can create following peak intervals on the area of the Czech Republic (assuming that they will be operated with the 60 minutes interval):

- interval 15 minutes Praha – Brno,
- interval 30 minutes Praha – Ostrava,
- interval 30 minutes Praha – Plzeň.

With these operational parameters and sufficient length of the trains, the international lines can serve the national relations without any additional national lines. For example, there is 15 minutes interval on the relation Praha – Brno, which is close to the parallel graphical timetable of subway.

It is apparent that Praha will become an important railway node at an international level. Its significance could be very close to nodes such as Wien and Berlin.

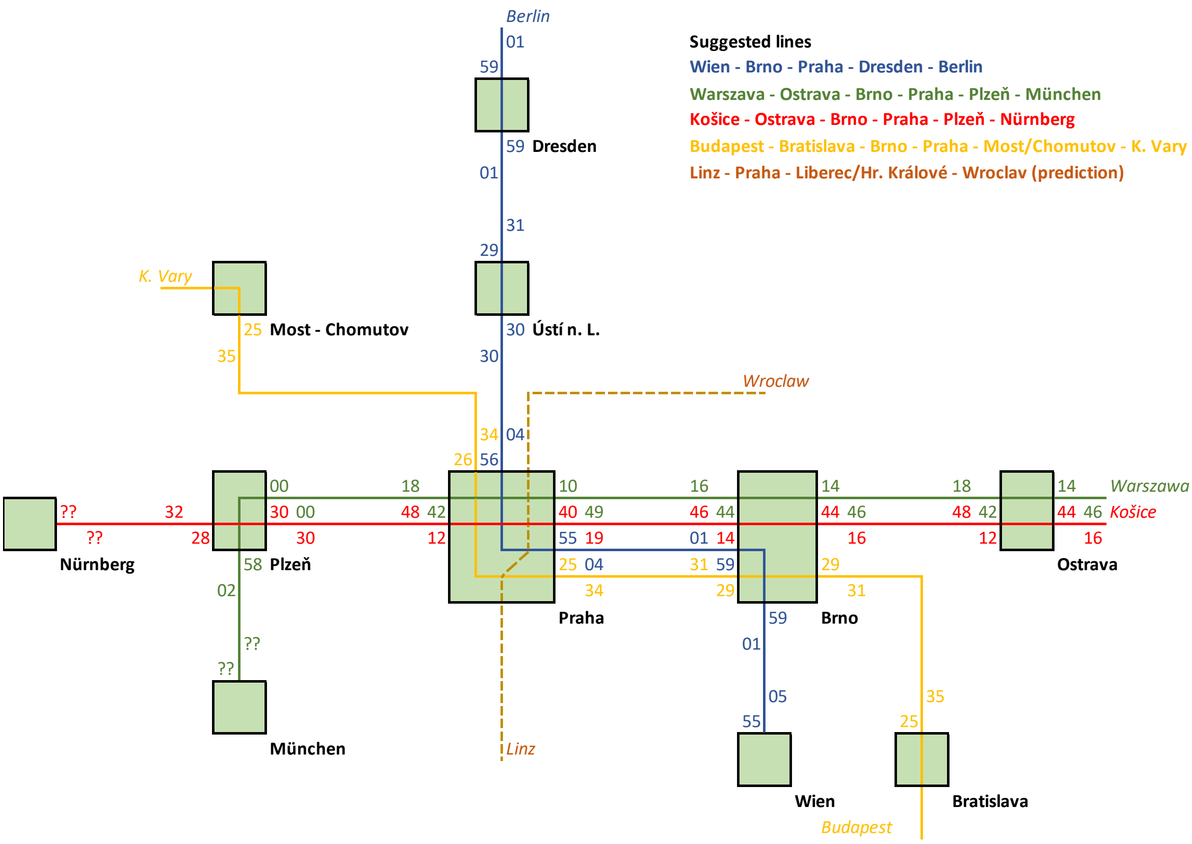

Fig. 2. Network graphics of possible line routing in the international transportation

4. CONCLUSION

It is obvious from the calculation, according to evaluation criteria, that the top priorities of construction have sections Praha – Brno and Brno – [Slovakia/Austria]. While the plans of Správa železnic contains the section Praha – Ústí nad Labem – [Germany], result of this paper prefers a construction of the section Praha – Plzeň – [Germany]. It is also possible to assume that in the section Praha - Ústí nad Labem - [Germany], the railway already uses its potential partially, so its construction was not identified as a priority in the model.

It is obvious that the **number of long-distance transport lines transferred,** , which in the case of the route through Pilsen is relatively significant (lines Ex6, R16 and R26), **has** the significant influence on the calculation according to the STEM. This fact has significantly increased the priority of the construction of the RS through Plzeň than through Ústí nad Labem.

We can expect smaller or bigger impacts from building the RS network on almost every line, however our main goal should be total passenger increase in public transportation, balanced use of railway network, reduction of travel times between the cities and reduction of environmental damages from the individual car transportation. It is necessary to point out, that high-speed railway transportation has to be attractive and affordable. Otherwise, our goals cannot be reached.

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