The Choice Restriction Model of the Mean of Transport due to the Route Capacity

P. Purkart[1], J. Kruntorád[2], T. Javořík[3], L. Týfa[4]

[1]*CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail:* purkapav@fd.cvut.cz
[2]*CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail:* kruntjan@fd.cvut.cz
[3]*CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail:* javorik@fd.cvut.cz
[4]*CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail:* tyfa@fd.cvut.cz

Abstract

Each transport route has a limited capacity; but in the case of railway transport, this characteristic is noticeable. This can lead to a situation where there are more requirements to be placed on the transport route than the route can deal with. This paper describes this issue and offers a possible solution for passenger transport. There may be situations where public transport orderers or carriers have requirements that the infrastructure cannot fully satisfy. By using the modified STEM method, it is possible to determine which requirements to comply with in the way that the capacity of the transport route is utilized optimally with maximum benefits. The example is demonstrated in the real part of the railway infrastructure between Plzeň and Žatec in the Czech Republic.
KEY WORDS: *railway infrastructure capacity, requirements of carriers and orderers, STEM method*, *Plzeň – Žatec railway line, optimization*

1. Introduction

The capacity of the railway infrastructure is a parameter that influences its usability. Not only in the Czech Republic, but in all developed countries, where rail transport is used as the backbone of transport services in regions, its capacity is a major problem, often failing to meet all requirements. This raises the question of how to realize the operation of trains so that this is as effective as possible with regard to the constraining infrastructure [1, 2]. There are no uniform procedures and practically every infrastructure manager solves this issue differently.

This issue is also addressed by CTU in Prague, Faculty of Transportation Sciences, Department of Transportation Systems, which encounters this complication not only in scientific work, but also in solving practical studies for various subjects. To solve the problem, the STEM (Step Method) method is currently being considered and tested.

2. Using the STEM Method

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 the 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 basis of the method is an interactive procedure of searching the compromise solution.

The benefit of the STEM method is, that there is only minimal need for communication between a submitter and a solver (comparing to other methods). The scale method for individual criteria 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 the calculation and decision-making process. The calculation is stopped, if the submitter finds the result acceptable, otherwise the solver must be informed by the submitter to change the criteria or their numbers, the whole calculation is made again.

The STEM method consists of the following steps [4]:

1. The solver calculates optimal solutions for individual criteria (purpose function) separately. The number of calculations fits the number of criteria.
2. The solver calculates the scales of individual criteria according to the formula (1):

$$w_i = \frac{z_{ii} - \min\limits_{i=j...k} z_{ij}}{z_{ii}} \frac{\alpha}{\sqrt{\sum\limits_{i=1}^{n} c_{ij}^2}}, \tag{1}$$

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

Value α comes from Eq. (2):

$$\frac{z - \min z}{z} \frac{\alpha}{\sqrt{c}} = 1 . \tag{2}$$

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

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

There is a form (4) for variable *d*:

$$d = \max_{i=j...k} \left\{ w_i \left(z_{ii} - \sum_{j \in J} c_{ij} X_j \right) \right\} . \tag{4}$$

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

$$w_{ii} \left(z_{ii} - \sum_{j \in J} c_{ij} X_j \right) \leq d . \tag{5}$$

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

$$\min f(x) = \sum_{i=1}^{k} w_{ii} \left(z_{ii} - \sum_{j \in J} c_{ij} X_j \right) . \tag{6}$$

3. The solver presents the results to the submitter. The submitter must modify the criteria or add/remove some of them, if he does not find the results acceptable. The solver goes back to step 2. The solver has found a compromise solution, if the submitter of satisfied with the result. The solution is optimal, if the value $d = 0$ is reached.

3. Modifying the Model and Specific Use

The evaluation criteria for individual lines were established for the modified STEM method as follows [3]:

The daily estimated average number of passengers in the limiting railway section in thousands

The parameter expresses the daily average number of passengers on the route in the limiting section, so in the section with the lowest capacity. The value expresses the passenger numbers of trains on the given line in this section.

The daily estimated average number of passengers on the whole route of the line in thousands

The parameter expresses the daily average number of passengers on the whole route of the line, respectively on the logically limited section of the line. This parameter provides an evaluation of the total line utilization. It is not sufficient to consider the potential only on the limiting section mentioned above, but it is also crucial to assess the potential of the whole line.

The use of critical running speed in a logically limited railway section

Often there are cases where trains run at a slower speed without being able to use the full line parameters. It is the reason why implement this parameter. When the train can develop speed in the limiting section of the railway line according to the critical running speed specified for the line profile, the ratio will be 1 (100%). If this is not achieved, the ratio will decrease. If the line speed is up to 100 km/h on the track in the limiting section and the train is able to develop a maximum speed of only 80 km h, the ratio will logically decrease to 0.8 (80%).

Evaluation of system connection links on the line in a logically defined section

The parameter is set for evaluation of links to other lines, the aim is to determine the importance of the network character of the line. The overall rating of the parameters is the sum of the following points for all interchanges in the logically delimited section of the line. The transfer nodes/points are evaluated as follows:

2 points – railway interchange with system connections to lines in at least three other lines of rail transport directions (at least a crossroad stations, but rather nodal stations) with the possibility of system links to public regular bus transport or city public transport;

1 point – a railway interchange point with system links to lines in at least one or two other directions within the scope of railway transport with the possibility of system links also to public regular bus transport or city public transport; there can be the only system links public regular bus transport or city public transport.

If a line is routed through an important interchange, it receives 2 points for that interchange. It receives 1 point for each interchange point (that is a lower priority interchange). The higher the sum of points, the more frequent and important the links are, and therefore the operation of the line is crucial for the efficient functioning of other public transport lines.

Comparison of travel times of individual car transport and each line in the three most by passengers used routes on the line

The parameter is set to compare the competitiveness of the train line with individual car transport. In the logically delimited section of the line, the three busiest sessions will be selected and the ratio of the travel time of individual automobile traffic in the given section to the travel time using the section of the given line will be determined. For these sessions, the value will be determined separately and then the average of the three values that will be included in the evaluation will be calculated. It follows from the above that if the value exceeds number 1, public transport is on average in a selected session faster than individual car transport.

The Plzeň - Žatec line was chosen for the model test. The line runs from the regional city of Plzeň (Pilsen) in the western part of the Czech Republic to the agglomeration in the Podkrušnohorská pánev in the northern part of the country (cities of Žatec, Chomutov, Most and Jirkov). Especially in the Pilsen agglomeration, the capacity of the railway infrastructure on this line is very restrictive, therefore it was chosen as a test. The STEM method has been modified from the original use primarily for project evaluation, providing evaluation and results for project selection with limited financial possibilities. Newly, the capacity-limiting section of the railway infrastructure has been filled for a given period of time, through which trains should pass such that the benefit for society is maximized.

It is considered that, on the line roughly in the current state of infrastructure, there will be a conflict in the requirements of **public transport orderers**:

- line R (fast train) Plzeň – Most in 120 minute interval;
- line Sp (regional fast train) Plzeň – Žihle in 120 minute interval;
- line Os no. 1 (regional train no. 1) Plzeň – Žihle in 60 minute interval;
- line Os no. 2 (regional train no. 2) Nýřany – Plzeň – Plasy in 60 minute interval.

This line schema ensures the total interval of the last segment of trains in the section Plzeň – Žihle in 60 minutes and in the case of regional trains the total interval of 30 minutes of regional trains in the peak period.

Given the fact that the basic interval of the most sparsely represented train segments is 120 minutes, this value was also chosen as the starting point for determining the length of the evaluation period. We consider even traffic in both directions, so for each direction in this period the capacity of the track is available, including all operations (disturbance and construction of train route, etc.) 60 minutes, if expressed by the number of minutes, not the number of routes, as considered in the model. This value is reduced to **50 minutes** in order not to reach the occupancy rate of 100 %. In this case, it is also considered that during peak periods, the operation of freight trains on this line is minimal, so regular routes are not required for them, otherwise, this value would have to be reduced even more.

It follows from the train timetable diagram that the most fundamentally restrictive section is the **Horní Bříza – Kaznějov** section [**Error! Reference source not found.**]. This section is considered for the calculation, with the following occupancy time for individual lines:

- line R 8 minutes;
- line Sp 9 minutes;
- line Os 10 minutes.

Daily estimated average number of passengers in the limiting railway section in thousands

The estimated number of passengers in the limiting section (Horní Bříza – Kaznějov) and on the whole route of lines were estimated from the experience of the current operation, as the following values in thousand passengers per day (Table).

Table 1

Number of passengers of model lines [in thousand passengers per 24 hours]

Line	Numbers of passengers in the limiting railway section	Number of passengers on the whole route of the line
R	0,9	1,4
Sp	0,8	0,9
Os no. 1	0,5	1,5
Os no. 2	0,3	2,5

The use of critical running speed in a logically limited railway section

For the use of critical running speed, the determined parametres are set in Table 2.

In the case of all connections, the full use of critical running speed is planned.

Evaluation of system connection links on the line in a logically defined section

The individual lines serve the nodes below. The evaluation of individual nodes from the point of view of their significance is summarized in Table 3.

Table 2

The use of critical running speed in a logically limited railway section

Line	The use of critical running speed in a logically limited railway section
R	1,00
Sp	1,00
Os no. 1	2 x 1,00 = 2,00 *
Os no. 2	2 x 1,00 = 2,00 *

*For regional trains, the value is multiplied by two, as two trains pass in each direction over a reference period of 120 minutes

Table 3

Evaluation of system connection links of model lines in individual nodes

Line	Nodes - evaluation								
	Nýřany	Plzeň – Jižní P.	Plzeň hl.n.	Plzeň-Bolevec	Třemošná	Horní Bříza	Kaznějov	Plasy	Mladotice
R	-	-	2	0	0	0	1	1	0
Sp	-	-	2	0	0	1	1	1	1
Os no. 1	-	-	2	1	1	1	1	1	1
Os no. 2	1	2	2	1	1	1	1	1	-
Line	**Nodes - evaluation**								
	Žihle	Blatno	Žatec	Chomutov	Most	-	-	-	-
R	1	1	1	2	2				
Sp	1	-	-	-	-				
Os no. 1	1	-	-	-	-				
Os no. 2	-	-	-	-	-				

The values for the individual lines are summed into the model as a whole, and the accumulation of these values is expressed in Table 4. For experimental reasons, the values of the lines that pass through the section twice during the evaluation interval are not multiplied twice.

Table 4

Cumulative evaluation of system connection links of model lines

Line	Cumulative evaluation of system connection links of model lines
R	11
Sp	7
Os no. 1	9
Os no. 2	10

Comparison of travel times of individual car transport and each line in the three most by passengers used routes on the line

The values of the ratio of travel time of individual car transport and trains of the given lines were determined for individual lines from the averages of the following importants routes:

- R: Plzeň – Mostecko, Plzeň – Plasy, Plzeň – Žihle;
- Sp: Plzeň – Kaznějov, Plzeň – Plasy, Plzeň – Žihle;
- Os no. 1: Plzeň – Horní Bříza, Plzeň – Plasy, Plzeň – Žihle;
- Os no. 2: Plzeň – Plasy, Plzeň – Horní Bříza, Plzeň – Nýřany.

The results are summarized in Table 5.

Table 5

Comparison of travel times of individual car transport and each line
in the three most by passengers used routes on the line

Line	Comparison of travel times of individual car transport and each line in the three most by passengers used routes on the line
R	0,80
Sp	0,87
Os no. 1	0,80
Os no. 2	0,87

For these criteria, the model was compiled according to the principles given in chapters 2 and 3 and entered into Xpress (input source code and generated outputs - see Fig. 1).

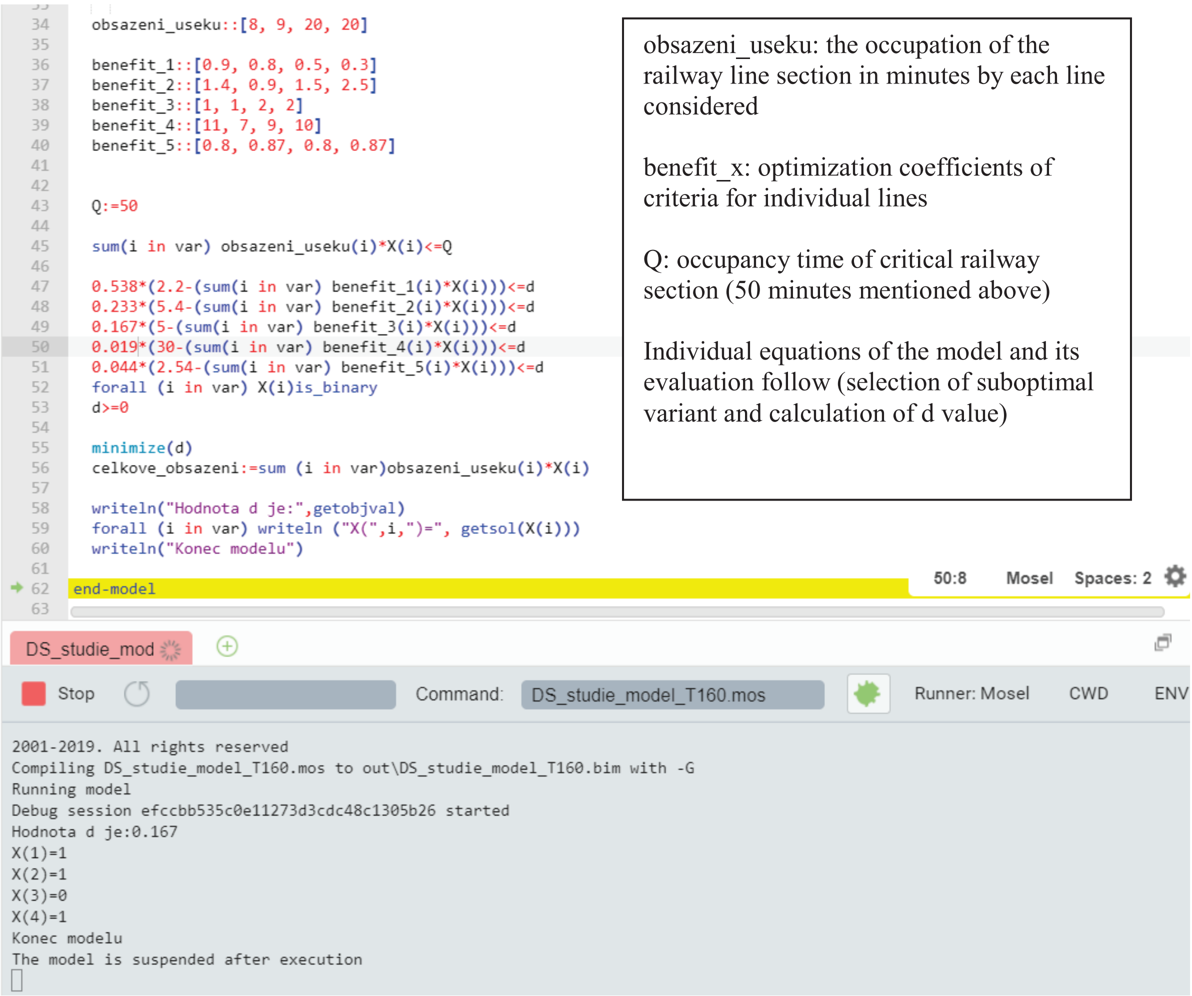

Fig. 1 Specific example of a model in Xpress environment

4. Conclusion

Linear optimization was performed with the result that lines R (fast train), Os no. 1 (regional train no. 1) and Os no. 2 (regional train no. 2) should be operated on the railway infrastructure. This combination seems to be the most effective according to the STEM method. The value of the coefficient d reached 0.167, which means that a compromise solution was found, not a global optimum. In terms of traffic on this line, the result achieved by the model is logical. For the number of passengers transported in all operating sections of these lines, the global optimum has been reached, because these are cumulatively the lines with the highest expected numbers of passengers. However, it is evident the model's complexity, because the line Sp (regional fast train) has been eliminated, which in the limiting railway section has the second highest expected number of passengers out of all four lines. It is clear from this case that a compromise solution has been reached overall.

The above form of research shows that the STEM method can be modified not only for the problem of railway infrastructure capacity, but also for solving other tasks by the computational way. In the above task, the method achieves relatively satisfactory results, but it will be the next mission of the research team to test other methods and compare the results achieved by them. So far, the STEM method has been used intensively.

However, the evaluation criteria must be chosen carefully and responsibly, otherwise, the method will not give satisfactory results. However, if this is done, it may be an appropriate tool for deciding or assessing situations that are optimal or possibly suboptimal solutions is not obvious.

Acknowledgment

All the facts presented in this article are based on the results of the research on the CTU Faculty of Transportation Sciences, Department of Transport Systems. This research was supported by the Grant Agency of the Czech Technical University in Praha, grant No. SGS18/150/OHK2/2T/16 Railway track parameters for transportation service optimization and No. SGS20/138/OHK2/2T/16 Design and optimal use of railway infrastructure parameters.

References

1. **Hansen, I.A.; Pachl, J.** 2008. Railway timetable and traffic. Hamburg: DVV Media Group GmbH - Eurailpress.
2. **Pachl, J.** 2004. Systemtechnik des Schienenverkehrs: Bahnbetrieb planen, steuern und sichern, mit Beispielen. 4. überarb. und erw. Aufl. Stuttgart: B.G. Teubner.
3. **Purkart, P.** Optimal cooperation of public transport segments. Praha: Defense date 2019-12-06. Doctoral Minimum. CTU FTS. Department of Transportation Systems. Supervised by L. TÝFA.
4. **Teichmann, D.; Dorda, M.** 2015. Comparison of Two Selected Methods In Evaluating Of Investments in Transport Infrastructure. In: Finance and Performance of Firms in Science, Education and Practice : proceedings of the 7th International Scientific Conference : April 23-24, 2015, Zlín, Czech Republic. Zlín: Tomas Bata University in Zlín, 2015. pp. 1524-1536.
5. Public available operational documents (timetables etc.) of Správa železnic, state organization (Czech state railway infrastructure manager