Operational Research in Engineering Sciences: Theory and Applications
Vol. 2, Issue 1, 2019, pp. 27-36
ISSN: 2620-1607
eISSN: 2620-1747
DOI: *https://doi.org/10.31181/oresta1901030k*

EVALUATION OF THE TCIS INFLUENCE ON THE CAPACITY UTILIZATION USING THE TOPSIS METHOD: CASE STUDIES OF SERBIAN AND AUSTRIAN RAILWAYS

Evelin Krmac, Boban Djordjević

University of Ljubljana, Faculty of Maritime Studies and Transport

Received: 05 February 2019
Accepted: 12 March 2019
First online: 19 March 2019

Original Scientific Paper

Abstract: *Increasing train traffic on the railway infrastructure implies the use of enlarged railway network capacity and the corresponding increase in intelligence - i.e. "intelligentization" - of the railway industries. The Train Control Information System (TCIS) as one of the most important railway systems with a significant impact on the overall railway performance in terms of its efficiency and influence upon the railway infrastructure capacity (RIC). In this paper, the model for evaluation of the TCIS influence upon the capacity utilization, based on the TOPSIS method, is proposed as an alternative to the DEA-based models. Indeed, the main drawback of the DEA-based models is that the DEA evaluates alternatives from only one point of view and classifies them as efficient or inefficient while the TOPSIS allows the benchmarking of the alternatives by detecting the best practices based on the ranking of the alternatives. For the purposes of this paper, the TOPSIS based evaluation where years represent alternatives were tested through case studies of Serbian and Austrian railways for the period from 2006 to 2015. Based on the obtained results it can be pointed out that the TOPSIS method can be applied to evaluation and comparison of the influence of different TCIS on the railway capacity (RC) utilization.*

Key Words: *Evaluation, Train Control Information System, Railway, Capacity, Multicriteria Decision-Making*

1. Introduction

According to the European Commission (2016) the railway is a "backbone of the EU transport system" and it is crucial when a rising demand for transport, traffic jams, fuel security, and decarbonisation are considered. Nevertheless, many European rail markets are still facing stagnation and downturns (European Commission, 2016), which suggests the possibility of an increase in the future rail traffic. Many of the railways are already exploiting their maximum capacity, so they will have to implement certain solutions to meet the new demand. As stated in

* Corresponding author.
evelin.krmac@fpp.uni-lj.si (E. Krmac) bbn.djordjevic@gmail.com (B. Djordjević)

(Djordjević and Krmac, 2018), the main challenge of many railways around the world is limited availability of capacity for all trains of their infrastructure related to topological configuration; although in some cases the capacity of infrastructure did not change despite doubling, tripling or quadrupling tracks.

There are many different factors influencing the railway capacity (RC) utilization. Some of the most important are timetable, signaling, nodal capacity constraints, rolling stock, infrastructure, external factors and governance. Signaling, for example, is a kind of the traffic management system (TMS), which is an important class of the Train Control Information Systems (TCIS) that provides for safe running of trains on a given infrastructure. Advanced signaling system such as the European Railway Traffic Management System (ERTMS) can provide for not only a higher level of safety but also for reduction of headways and blocking time of infrastructure (Melody, 2012) (Krmac and Djordjevic, 2017).

Regarding that the factors influencing efficiency of the railway capacity (RC) utilization are many and different as well as that signaling is one of the most important of them, in this paper the focus is on evaluation of the TCIS influence using the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method as an example of the MCDM (Multi-Criteria Decision-Making) techniques. The TCISs were already considered in (Djordjević and Krmac, 2018), where the evaluation of the TCIS impact on the railway utilization was performed using the DEA method. In this paper, the TOPSIS method is introduced as a new approach to evaluation and comparison of the TCIS influence on the RC utilization. The application of the TOPSIS method was performed on real data for Serbian and on partially assumed data for Austrian railways.

The following section presents a survey of the previous papers considering analysis, measurement, evaluation and improvement of the railway capacity (RC) utilization, as well as the MCDM methods application in this field. In Section 3 description of the TOPSIS method with selection of criteria and alternatives is presented. Results of the TOPSIS method are presented in Section 4. Finally, in Section 5 conclusions and proposals for future work are summed up.

2. Literature review

So far, the topic of railway capacity has been frequently discussed by researchers (Bevrani, 2005). Different methods for estimating the railway capacity utilization and different categorizations or classifications of these methods can be found in the referential literature (Melody, 2012).

Recently, detailed classification of methods and approaches related to the estimation of the railway capacity utilization was presented in the referential literature by (Djordjević and Krmac, 2018). In their paper, methods and approaches are grouped as analytical, optimization, and simulation methods, as well as parametric ones. The factors and parameters which affect the railway capacity utilization are identified and reviewed. Further, the literature review regarding the consideration of the TCIS influence on the capacity consumption is also presented. Moreover, (Djordjević and Krmac, 2018) also introduced a “new approach based on the DEA method for evaluation of the TCIS efficiency in improvement of the railway capacity utilization.”

Considering that the RC utilization is a multidisciplinary area, other MCDM methods for evaluation of the TCIS impact on the railway capacity utilization, besides the DEA method, can be applied. Therefore, in this paper the introduction of the TOPSIS method for that purpose is considered. In order to confirm the novelty of introduction of the TOPSIS for evaluating the TCIS efficiency influence on the RC utilization, the literature is reviewed regarding the application of the TOPSIS in railway engineering.

In the evaluation of high speed transport systems where High-Speed Rail and Transrapid Maglev are presented as alternatives, after determination of the importance of particular criteria using the entropy method, Janic (2003) applied the TOPSIS to the "selection of the preferable alternative (high-speed systems) under given circumstances."

The TOPSIS method with the Multilevel grey evaluation (MGE) was employed by Chen et al. (2014) to evaluate the overall performance of passenger transfer at large transport terminals in different alternatives through a case study on the Beijing South Railway Station in China.

Zhao et al. (2018) used the TOPSIS for the evaluation of China transportation networks. In combination with cargo rates, the TOPSIS was used for three models of transportations - i.e., railway, highway, and national road – to "synthesize the evaluation of indices and three networks" with the aim of ranking the city nodes according to their importance.

The entropy-TOPSIS method was formulated and used by Huang et al. (2018) for the evaluation of operation performance of the urban rail transit system from different perspectives: operator's, passenger's, and government's.

The TOPSIS method was also used for analysis of the Swedish railway's network vulnerability of multi-commodity networks with the aim to identify critical links in the network (Whitman et al., 2017).

Bababeik et al. (2018) utilized the TOPSIS for determination of links priorities or calculation of the links while resolving the problem of "optimal location and allocation of relief trains."

The fuzzy TOPSIS with failure mode and effect analysis was proposed by Jinbao and Xing (2014) "for determination of the closeness coefficient of each failure mode of metro door fault criticality."

For measurement of a service quality of rail transit lines the Fuzzy-TOPSIS in combination with statistical analysis and trapezoidal fuzzy numbers has been adopted by (Aydin, 2017).

3. Methodology

Railway capacity and railway performance analyses often deal with multiple conflicting key indicators, what creates a high degree of complexity. The use of the MCDM can be a potential tool for solving such complexities. As an example of the MCDM methods a special DEA model – i.e., a non-radial DEA model - has been applied in (Djordjević and Krmac, 2018) as a tool for consideration of influence of the TCIS efficiency on the railway capacity utilization. However, the authors pointed out that the DEA evaluates alternatives from only one point of view and classifies them as efficient or inefficient. In order to overcome these disadvantages of the DEA method, in this paper the TOPSIS method, which enables minimization and maximization criteria simultaneously, as well as ranking of the evaluated alternatives, is proposed.

Based on the fact that the non-radial DEA model implies some weaknesses and considers decision-making units (DMUs) only from one point of view, in this paper the TOPSIS method is introduced in order to improve the disadvantage of the DEA method and consider the results of the DEA method obtained in (Djordjević and Krmac, 2018). Regarding their results of the sensitivity analysis, it can be said that the DEA is not the most suitable benchmarking tool in the field of the evaluation of the TCIS efficiency influence on the RC utilization. To overcome this weakness, a TOPSIS could be applied as a MCDM method for benchmarking the alternatives by detecting the best practices based on the ranking of alternatives and on the evaluation of the TCIS influence on improvement of the railway infrastructure capacity (RIC).

The introduction of the TOPSIS method for evaluation of the TCIS influence on the RIC and ranking of alternatives was based on its benefit in terms of the simultaneous consideration of alternatives from different viewpoints - i.e., both pessimistic and optimistic aspects - while the DEA ranking methods utilized input or output oriented aspects.

3.1 A description of the TOPSIS method

In this part of the paper, the TOPSIS method proposed by Hwang and Yoon (1981) was employed as a decision-making tool to aid decision-makers (DMs) in "trade-offing" all the alternatives. In the literature, this method has received much interest from researchers and practitioners that confirms a wide range of real-world applications across different fields and specific sub-areas (Behzadian et al., 2012). This method is based on the assumption that the selected alternative is at the shortest possible distance from the ideal positive solution and ideal negative solution. As one of the best and most frequently used MCDM methods, it implies the overall assessment, comparison and ranking of alternatives.

Since the DEA divides alternatives into efficient and inefficient with low total discrimination (Djordjević and Krmac, 2018), in this paper the aim of the TOPSIS method is to find the best alternative - i.e., to rank and solve the drawbacks of the DEA method. Consequently, the additional reason for selecting the TOPSIS for evaluation of the TCIS influence on improvement of the RC utilization and for ranking alternatives, is based on the content of the TOPSIS - i.e., decision-makers' (DM) intention to rank alternatives with the best ranking score closer to the positive ideal and to have the greatest distance from the negative ideal solution, as well as the ability to consider alternatives from both pessimistic and optimistic viewpoints - i.e., inputs and outputs like a cost and benefit criterion (Jahantigh et al., 2013), (Lotfi et al., 2011).

The following steps of the TOPSIS method, proposed by Wang et al. (2014) and Delgarm et al. (2016) were performed:

Step 1: Forming decision matrix $X = [x_{ij}]_{n\times m} i = 1,2, \dots, n; j = 1,2, \dots., m$. Within the decision matrix, the alternatives represent years for each case study (see Tables 1 and 2).

Step 2: Performing the normalization of decision matrix X in order to get normalized decision matrix $R = [r_{ij}]_{n\times m}$ by vector normalization method that is presented as

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \tag{1}$$

Step 3: Calculation of the weight normalized decision matrix as

$$V = [v_{ij}]_{n\times m} = [w_i r_{ij}]_{n\times m}, \tag{2}$$

Where w_i is a weight given to criteria from DM and sum of weights $\sum_{i=1}^{n} w_i = 1$. This method is appropriate for decision-making which is based on criteria of different importance.

Different weights were delegated to each criterion only for evaluation of the TCIS influence in terms of the obtained RIC. For each criterion weights were assigned for each case study - i.e., length of *railway network (C1)* (w_1= 0.15), *number of trains (per day) (C2)* (w_2= 0.2), *freight kilometers (C3)* (w_3= 0.2), *passenger kilometers (C4)* (w_4=0.2), *number of failures of whole system* or *its subsystem (C5)* (w_5=0.1), *punctuality of the trains (C6)* (w_6=0.15).

Step 4: Determination of positive ideal and negative ideal solutions is denoted as $A^+$and A^-, respectively. In case of the paper, $A^+$and A^- represent the best and the worst alternative, respectively, demonstrated as

$$A^+ = \left\{\left(\max_i v_{ij} \middle| j\epsilon J_+\right), \left(\min_i v_{ij} \middle| j\epsilon J_-\right) \middle| i = 1, 2, \dots, n\right\} = \{v_1^+, \dots, v_m^+\} \tag{3}$$

$$A^- = \left\{\left(\min_i v_{ij} \middle| j\epsilon J_+\right), \left(\max_i v_{ij} \middle| j\epsilon J_-\right) \middle| i = 1, 2, \dots, n\right\} = \{v_1^-, \dots, v_m^-\}, \tag{4}$$

where$J_+ = \{j_1, j_2, \dots, j_{m_1}\}$, $J_- = \{j_{m_1+1}, j_{m_1+2}, \dots, j_m\}$ and $J_+ \cup J_- = \{1, 2, \dots, m\}$ are benefit and cost criteria, respectively. In this case of the TOPSIS method application, the benefit criteria are represented by *length of railway network (C1), number of trains (per day) (C2), freight kilometers (C3), passenger kilometers (C4),* while the cost criteria include *number of failures of whole system* or *its subsystem (C5),* and *punctuality of the trains (C6)*.

Step 5: Calculation of the separation measure between each alternative by Euclidean distance. The separation of each alternative from the positive ideal is given as

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^+\right)^2}\ , i = 1,2, \dots\dots, n., \tag{5}$$

while the separation from the negative ideal is given as

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, i = 1,2, \dots\dots, n. \tag{6}$$

Step 6: Calculation of relative closeness A_i to positive ideal solution A^+ defined as

$$A_i = S_i^+/(S_i^+ + S_i^-)\,,\ 0 \le A_i \le 1,\ i = 1, 2, \dots, n. \tag{7}$$

If $A_i = 1$ is clear that alternative is the best, and $A_i = 0$ than alternative is the worst. Alternative is closer to the best as A_i approaches 1.

Step 7: Ranking the alternatives according to A_i, where a higher value of A_i denotes a better solution in terms of the TCIS influence on improvement of the RIC.

3.2 Application of the TOPSIS method to evaluation of the TCIS efficiency on the obtained RIC

3.2.1 Selection of criteria

Based on the factors that affect RC, reviewed by (Djordjević and Krmac, 2018), available data, and the fact that other indicators can also be used for RC description, adequate criteria for the evaluation of the TCIS influence on the obtained RIC were selected. The obtained railway capacity is presented based on the required capacity and spare capacity. Spare capacity might absorb variations from day to day or a future traffic increase (Nystrom, 2009).

Regarding that railway transportation can be viewed as a production process, the *length of railway network (C1)* and *number of trains per day (C2)* were selected as timetable indicators. The *number of trains per day* also represents one of the main indicators of the infrastructure capacity, which is related to the infrastructure availability (Patra et al., 2010). As outputs of railway transportation as production process, the *realized freight (tkm) kilometers (C3)* and *passenger kilometers (C4)* (Boysen, 2012) were included as criteria in the TOPSIS method. On the liberalized railway markets higher values of *C1* and *C2* produce higher capacity. Therefore, "capacity is the maximum amount that can be produced in relation to the limiting constraints from infrastructure, rolling stock or staff" (Boysen, 2012). According to (Djordjević and Krmac, 2018) two more criteria were selected: criteria that is closely related to the functioning of the TCIS – the *number of failures of the whole system or its subsystem (C5)*, and criteria *punctuality of the trains (C6)*, which is the result of system failures and is related to the infrastructure availability (Patra et al., 2010).

3.2.2 Selection of alternatives and case studies

The second important stage of the TOPSIS methodology is the selection of alternatives. At the beginning of the TOPSIS method application and the analysis of the results of the model, the TCIS used at Serbian and Austrian railways were considered as case studies. Because the railways of Serbia and Austria are significantly different in terms of length of the network and volume of the transport, they were not compared. Hence, in the study these case studies were evaluated separately while years as alternatives were jointly considered for each case study. So, the alternatives of the selected case studies represent years. For each Serbian alternative real data were used. Data for criteria such as *number of trains (per day)* and *punctuality of the trains* were collected from planned and realized timetables, data of the *number of failures* were collected from the Serbian railways evidence, while *realized freight and passenger kilometers* and *length of railway network* data were extracted from Serbian statistics (Djordjević and Krmac, 2018).

Real data for the Austrian case, published by (OBB, 2016), were used only for 2015 and were collected for *length of railway network* and *number of trains (per day)* while Eurostat data for *freight and passenger kilometers* was used. However, because of missing data for *number of failures* and unavailability of data for other years, these data were assumed. The data for Serbian case study are presented in Table 1 while those for Austrian case study in Table 2. Since the data for each case study were not collected from the same source, there is a doubt in terms of the data and results accuracy.

Table 1. Data used for the TOPSIS method – Serbian case study

Alternatives/DMUs	Serbian case					
	C1	C2	C3	C4	C5	C6
2006	3819	1.510	684110	4232	55	40%
2007	3819	1.515	687002	4551	43	55%
2008	3819	1.502	583071	4339	38	60%
2009	3819	1.430	522033	2967	35	65%
2010	3819	1.431	521933	3522	39	60%
2011	3819	1.431	540911	3611	34	70%
2012	3819	1.430	539727	2769	23	80%
2013	3819	1.433	612495	3022	34	70%
2014	3819	1.420	452963	2988	27	80%
2015	3739	1.436	508678	3249	30	80%

Table 2. Data used for the TOPSIS method – Austrian case study

Alternatives/DMUs	Austrian case					
	C1	C2	C3	C4	C5	C6
2006	9646*	6.327*	110778	8907	8	90%*
2007	9646*	6.329*	115526	9167	7	95%*
2008	9646*	6.345*	121579	10365	7	95%*
2009	9646*	6.332*	98887	10184	9	80%*
2010	9646*	6.340*	107670	10263	10	85%*
2011	9646*	6.340*	107587	10778	7	95%*
2012	9646*	6.339*	100452	11211	6	96%*
2013	9646*	6.330*	95449	11804	8	90%*
2014	9646*	6.335*	98281	11981	7	95%*
2015	9646	6.340	97642	12104	5	96.3%

*- denotes assumed data

4. Results of the TOPSIS method

Both the railway capacity (RC) analysis and the railway performance analysis often deal with multiple conflicting key performance indicators (KPIs) (Bevrani, 2015). These complexities can be a subject of the MCDM. As the main MCDM method in our case, the TOPSIS method, which enables minimization and maximization criteria simultaneously as well as ranking of evaluated alternatives, is proposed.

Therefore, the TOPSIS method with both viewpoints - i.e., pessimistic and optimistic - is used in order to evaluate and rank alternatives. Moreover, in this paper, the TOPSIS is employed with the aim of checking the results of the non-radial DEA model applied in (Djordjević and Krmac, 2018). The results of the TOPSIS method are calculated using Excel environment and are summarized in Table 3.

In terms of Serbia, the best influence of the TCIS on the obtained RIC was in 2007, while in Austria the best impact of the TCIS on capacity was in 2008 (see Table 3).

From Table 3 the rank for other alternatives/years in terms of the TCIS influence on the obtained RIC may be seen.

Table 3. Results of the TOPSIS method

Alternatives/DMUs	Serbian case		Austrian case	
	Ci	Rank	Ci	Rank
2006	0.6223	3	0.4588	6
2007	0.6942	1	0.5981	2
2008	0.6233	2	0.6158	1
2009	0.3574	9	0.3441	10
2010	0.4335	5	0.3758	9
2011	0.4436	4	0.4892	4
2012	0.3904	7	0.4737	5
2013	0.4203	6	0.4401	7
2014	0.3388	10	0.4350	8
2015	0.3625	8	0.5215	3

However, considering the characteristics and the process, the results of the TOPSIS method were different from expected in comparison with the results obtained by the non-radial DEA model in (Djordjević and Krmac, 2018). For instance, for the Serbian case study, Alternative 2007 was ranked as 1 by the TOPSIS and also had the best value of efficiency obtained by the non-radial DEA model, while for 2012 with efficiency 1 the rank was 7. Also for the Austrian case study, the results of the TOPSIS method were different from the results of the non-radial DEA model. For example, Alternative 2008 had a rank of 1 and had also obtained the best efficiency by the non-radial DEA model. However, the year 2015 with a rank of 3 by the TOPSIS had an efficiency score of 1 by the non-radial DEA method. The reason for differences in the results should be found in the fact that the DEA considered inputs for a given level of outputs while the TOPSIS method differed thusly; seeking the best alternatives, closest to the ideal positive solution and furthest from the negative. Another reason for differences in the results is the involvement of weights for each criterion, not only for variables in the goal function in the non-radial DEA model.

5. Conclusion

Increasing train traffic on the railway infrastructure, such as the state of railways in EU, implies the use of enlarged railway network capacity. To realize all necessary changes and increase speed, capacity and higher overall performance, the railway industries have to move towards so-called "intelligentization" creating "modern railway transport" (Li et al., 2003). In terms of railway, according to Fantechi et al. (2014), "one such example of complex systems refers to the TCIS which is characterized by a large number of components of various kinds (mechanical, electrical, computer, etc.) that have different types of interactions (local, simultaneous, etc.) which are interconnected and operate in synergy with each other." In order to evaluate the TCIS efficiency influence on the RIC, the non-radial DEA model was introduced in (Djordjević and Krmac, 2018). However, based on the disadvantages of the DEA method described above, in this paper the TOPSIS method, which allows ranking of considered alternatives and enables their evaluation from pessimistic and optimistic point of view, was introduced. The evaluation where years represent alternatives was tested through case studies of Serbian and Austrian railways for the period from 2006 to 2015. While data for Serbian railways were real, those for Austrian railways were mainly assumed. Based on the obtained results it can be pointed out that the TOPSIS method can be applied to evaluation and comparison of the influence of different TCISs on the RC utilization.

As future work, the proposed method can be applied to a comprehensive and accurate set of real data, using different variables or criteria, along with the performance of validity check. The proposed method could also be applied on the micro level, - i.e., the evaluation of the TCIS influence on the capacity utilization for a particular line. Likewise, it could also be applied to other concepts of capacity.

References

Aydin, N. (2017). A fuzzy-based multi-dimensional and multi-period service quality evaluation outline for rail transit systems. Transport Policy, 55, 87–98.

Bababeik, M., Khadem, N., & Chen, A. (2018). Increasing the resilience level of a vulnerable rail network: The strategy of location and allocation of emergency relief trains. Transportation Research Part E, 119, 110-128.

Behzadian, M., Otaghsara, K. S., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. Expert Systems with Applications, 39, 13051–13069. doi:10.1016/j.eswa.2012.05.056

Bevrani, B. (2015). Capacity Determination and Expansion Models for Rail Networks . Queensland University of Technology.

Boysen, H. E. (2012). General model of railway transportation capacity. WIT Transactions on The Built Environment, 127.

Chen, S., Leng, Y., Mao, B., & Liu, S. (2014). Integrated weight-based multi-criteria evaluation on transfer in large transport terminals: A case study of the Beijing South Railway Station. Transportation Research Part A, 66, 13-26.

Delgarm, N., Sajadi, B., & Delgarm, S. (2016). Multi-objective optimization of building energy performance and indoor thermal comfort: A new method using artificial bee colony (ABC). Energy and Buildings, 131, 42-53. doi:10.1016/j.enbuild.2016.09.003

Djordjević, B., &Krmac, E. (2018). Application of Multicriteria Decision-Making Methods in Railway Engineering: A Case Study of Train Control Information Systems (TCIS). In A. Hessami, Modern Railway Engineering (pp. 153-185). Rijeka: INTECH.

European Commission. (2016). Commission Staff Working Document: A European Strategy for Low-Emission Mobility. Brussels: European Commission.

Fantechi, A., Flammini, F., & Gnesi, S. (2014). Formal methods for railway control systems. International Journal on Software Tools for Technology Transfer, 16, 643-646.

Huang, W., Shuai, B., Sun, Y., Wang, Y., &Antwi, E. (2018). Using entropy-TOPSIS method to evaluate urban rail transit system operation performance: The China case. Transportation Research Part A, 111, 292-303.

Hwang, C. L., & Yoon, K. (1981). Multiple Attribute Decision Making Methods and Applications. Berlin.

Jahantigh, M., Lotfi, H. F., & Moghaddas, Z. (2013). Ranking of DMUs by using TOPSIS and different ranking models in DEA. International Journal of Industrial Mathematics, 5(3), 217-225.

Janic, M. (2003). Multicriteria Evaluation of High-speed Rail, Transrapid Maglev and Air Passenger Transport in Europe. Transportation Planning and Technology, 26(6), 491-512.

Jinbao, R., & Xing, Z. (2014). Fault Criticality Evaluation of Metro Door based on modified FMEA. Proceedings of the 33rd Chinese Control Conference. Nanjing, China.

Krmac, E., &Djordjevic, B. (2017). An evaluation of train control information systems for sustainable railway using the analytic hierarchy process (AHP) model. European Transportation Research Review, 9-35. doi:10.1007/s12544-017-0253-9

Lotfi, H. F., Fallahnejad, R., & Navidi, N. (2011). Ranking Efficient Units in DEA by Using TOPSIS Method. Applied Mathematical Sciences, 5(17), 805-815.

Melody, K. S. (2012). Railway Track Capacity: Measuring and Managing. University of Southampton, Faculty of Engineering and the Environment

Nystrom, B. (2009). Use of Availability Concepts in the Railway System. International Journal of Performability Engineering, 5(2), 103-118.

OBB. (2016). OBB in numbers: We move Austria forward.

Patra, A. P., Kumar, U., & Kraik, P.-O. L. (2010). Availability target of the railway infrastructure: an analysis. Reliability and Maintainability Symposium (RAMS). doi:10.1109/RAMS.2010.5448035

Wang, B., Nistor, I., Murty, T., & Wei, Y.-M. (2014). Efficiency assessment of hydroelectric power plants in Canada: A multi criteria decision making approach. Energy Economics, 46, 112-121. doi:10.1016/j.eneco.2014.09.001.

Whitman, M. G., Barker, K., Johansson, J., & Darayi, M. (2017). Component importance for multi-commodity networks: Application in the Swedish railway. Computers & Industrial Engineering, 112, 274-288.

Zhao, L., Zhao, Y., Hu, Q., Li, H., & Stoeter, J. (2018). Evaluation of consolidation center cargo capacity and locations for China railway express. Transportation Research Part E, 117, 58-81.