DOI: 10.55343/CogSust.20523

The analytic hierarchy process as a cognitive tool for evaluating switch components

Mykola KURHAN
https://orcid.org/0000-0002-8182-7709
Department Transport Infrastructure, Ukrainian State University of Science and Technologies
Dnipro, Ukraine
m.b.kurhan@ust.edu.ua

Dmytro KURHAN
https://orcid.org/0000-0002-9448-5269
Department Transport Infrastructure, Ukrainian State University of Science and Technologies
Dnipro, Ukraine
d.m.kurhan@ust.edu.ua

Serhii BAIDAK
https://orcid.org/0000-0002-7909-8527
Department Transport Infrastructure, Ukrainian State University of Science and Technologies
Dnipro, Ukraine
s.y.baidak@ust.edu.ua

Vladyslav KHMELEVSKYI
https://orcid.org/0009-0000-3221-6955
Department Transport Infrastructure, Ukrainian State University of Science and Technologies
Dnipro, Ukraine
Junkpff@gmail.com

Abstract

The purpose of this study is to improve the approach to the comprehensive evaluation of switch elements by applying the Analytic Hierarchy Process (AHP). This method makes it possible to determine their priority according to safety and efficiency criteria, as well as to justify optimal strategies for modernization and reconstruction under conditions of increasing train speeds. The scientific approach involves the use of AHP with consideration of the specific operational features of switches on high-speed railways. In particular, the study accounts for higher safety and speed requirements, decreasing maintenance costs, and the reduced service life of structural components. A hierarchy of criteria was developed, along with pairwise comparisons, the calculation of weighting coefficients, and an integrated assessment of alternatives. The application of AHP enabled the determination of the priority of each switch type based on the criteria of traffic safety, speed, operational costs, and service life. According to the analysis, the priorities of the main switch elements were established as follows: frog – 0.395; closure curve – 0.234; switch blade – 0.190; switch curve – 0.181. These results confirm that the frog is the most critical element in terms of its overall impact on safety, speed, and maintenance costs, which is primarily due to its structural complexity and high wear rate (especially under dynamic loads). The findings provide a basis for informed decision-making regarding the prioritization of repair or replacement of individual structural elements, considering the operating conditions of high-speed lines.

Keywords

railway switch, traffic safety, service life, Analytic Hierarchy Process (AHP), cognitive processes

DOI: 10.55343/CogSust.20523

1. Introduction

Transport is one of the strategic sectors of the economy, and railway transport plays a key role within it. The modern development of railways is inseparably linked with innovative technologies. However, in addition to technological solutions, there is a growing recognition of the importance of the human factor in ensuring safety and efficiency (Endsley, 1995; Reason, 1990). This is particularly relevant to railway switches, which are among the most critical and complex elements of railway infrastructure.

The problem and relevance of this research arise from the premise that switches are not merely technical objects; they demand a high degree of perceptual accuracy and decision-making from personnel (train drivers, dispatchers, maintenance crews). The human eye and brain must rapidly process visual signals, engineering elements, and information from control systems. The extent to which the design of a switch is intuitive and "cognitively compatible" determines the speed of reaction, the minimization of errors, and, consequently, traffic safety.

In this context, traditional approaches to the evaluation of switch elements, which focus exclusively on engineering criteria (strength, wear resistance), are insufficient. It is essential to consider how design features influence the cognitive processes of operators, which ultimately affect the overall safety of train operations.

The aim of this study is to improve the approach to the comprehensive evaluation of switch elements by integrating cognitive analysis. The Analytic Hierarchy Process (AHP) (Taha, 2017) is applied, which makes it possible to determine the priority of switch elements not only according to classical technical and economic criteria (traffic safety, speed, operational costs, service life), but also with consideration of cognitive complexity and the human factor (Zöldy et al., 2024).

2. Data and methods

Considering the railway switch as a system consisting of the switch blades, switch curve, frog, and closure curve (Table 1), the authors evaluated each element on a scale from 1 to 10. Particular attention is given to how design features influence personnel perception and decision-making. It is essential that the chosen solutions comply not only with general standards but also consider the unique operating conditions and the human factor on railways. Thus, the results of this study contribute to the development of a more "intelligent" and safer railway infrastructure.

Table 1. Key parameters and characteristics influencing the choice of switch types

Characteristic	Purpose / Application features
Frog number	– For conventional railways (speed up to 120–140 km/h), frog numbers from 1/9 to 1/14 are used, sometimes 1/18. – For high-speed railways (160 km/h and above), larger frog numbers are applied: 1/18, 1/26, 1/30, 1/38, etc. The higher the frog number (i.e., the smaller the crossing angle), the larger the radius of the diverging curve, which allows higher speeds.
Switch blade design	– Flexible blades: applied on high-speed lines; ensure smoother entry of wheelsets into the diverging track. – Conventional blades: used on general-purpose lines.
Frog type	– With cast manganese insert: a traditional solution used on conventional-speed lines. – With movable-point frog (swingnose crossing): mandatory for high-speed switches; provides continuity of the running surface, reduces impact loads and wear.
Rail type	UIC 60 (or others in the case of mixed or transition sections). The choice depends on integration with the existing track.
Fastening method	Preference is given to fastening on prestressed concrete sleepers, which provide increased stability and durability of the structure.
Manufacturer	– Vossloh Cogifer (France, Germany). – voestalpine Railway Systems (Austria). – Weichenwerk Wörth (Germany). – Dnipro Switch Plant (Ukraine).

Design features of railway switches. Railway switches are key elements of railway infrastructure that provide train routing and direction changes. The main types of switches (cast, movable-point frogs, and crossings with different numbers – 1/9, 1/11, 1/18, etc.) are described in detail in Wang et al. (2024) and Boghani et al. (2021). The authors emphasize that the choice of design largely determines traffic safety, permissible speed, and maintenance costs. For example, Wang et al. (2024) proposes a comprehensive approach to the evaluation and maintenance of switches, incorporating data on wear, speed, loads, and geometric characteristics. Critical components of the design are identified using analytical modelling and monitoring systems. This study is valuable as an example of a multi-criteria analysis compatible with AHP methods. In Boghani et al. (2021), a multi-criteria analysis of switch types is presented, considering speed, comfort, cost, and reliability. The authors apply AHP and sensitivity analysis, presenting it as a practical decision-support tool for switch modernization.

Evaluation criteria for switch elements. Studies (Krmac and Djordjević, 2017; Nyström and Söderholm, 2008) examine the key criteria for evaluating switches: traffic safety, permissible speed, durability of elements, and operational costs. It is noted that in the design and modernization of switches it is necessary to consider not only technical characteristics but also the economic feasibility of using a particular type of switch, depending on the function of the track (mainline, station, etc.).

Methods of modelling and selecting optimal designs. Publications (Polishchuk, 2021; Barkhordari et al., 2019) discuss modern methods of analysis for selecting the optimal switch design. In particular, the application of the Analytic Hierarchy Process (AHP) makes it possible to systematize expert assessment and account for a set of interrelated factors. The studies demonstrate that the use of AHP in combination with pairwise comparison of criteria provides well-grounded decisions at the stage of switch design or replacement.

Experience of different railways. Research (Barkhordari et al., 2021; Saaty and Kułakowski, 2016) analyses the experience of German, Polish, Czech, Hungarian, Ukrainian and other railways in operating switches on high-speed lines. It

DOI: 10.55343/CogSust.20523

is noted that modern switches must be adapted to dynamic loads at speeds above 160 km/h, which places new demands on the design of frogs, switch blades, and control mechanisms.

Regulatory framework and recommendations. Regulatory documents establish requirements for the geometry, materials, laying, and maintenance of switches. Scientific works (Fischer, 2025; Fischer et al., 2025b) provide a comparative analysis of the requirements for elements in accordance with European and national standards, enabling conclusions on the harmonization of regulations.

In Kovalchuk et al. (2018), a comprehensive method for extending the service life of switch frogs is presented, based on consideration of the longitudinal profile of the frog, the magnitude of dynamic forces, and normal stresses.

There are various methods for assessing the reliability of railway track components (e.g. Fischer, 2022; 2023), including the Analytic Hierarchy Process (AHP) (Fischer et al., 2025a). For the AHP, it is necessary to create comparison matrices for each criterion, and then among the criteria themselves. The Saaty scale (Saaty and Shang, 2007; Saaty and Tran, 2007) is used for pairwise comparisons, where: 1 – equal importance, 3 – moderate preference, 5 – strong preference, 7 – very strong preference, 9 – extreme preference; 2, 4, 6, 8 – intermediate values. Reciprocal values (1/3, 1/5, etc.) are applied accordingly. For example, if A is three times more important than B, then B is 1/3 as important as A.

3. Results and discussion

After conducting expert analysis, the following justification of the evaluations was obtained.

Switch points (Fig. 1)

- Traffic safety (10): This is the most critical element, where the actual transfer of a train from one track to another takes place. Any defect, wear, improper contact of the switch blade, or malfunction of the actuator may lead to derailment. It is the most vulnerable part of the switch.
- Operating speed (9): The quality of blade-to-stock rail contact and the geometry of the switch points directly affect the smoothness and permissible speed of train passage, especially on the diverging route. Modern flexible switch points allow higher speeds.
- Maintenance costs (9): Switch points are subject to significant dynamic impact and wear. Maintenance costs (adjustment, repair, replacement) are among the highest.
- Service life (8): Due to intensive wear and dynamic loads, the service life of switch points is generally shorter than that of sleepers or the main rail sections.

Figure 1. Switch points of a R65 turnout with a 1/11 crossing, track gauge 1 435 mm (Ukraine)

Switch curve

- Traffic safety (8): The correct radius and absence of defects in the switch curve are important for safe train passage. However, it is not as “active” a switching element as the switch points or the frog.
- Operating speed (10): The radius of the switch curve is the decisive factor for the permissible speed on the diverging route. The gentler the curve (larger radius), the higher the achievable speed.

DOI: 10.55343/CogSust.20523

- Maintenance costs (7): Costs are mainly associated with rail and sleeper wear along the curve, but they are generally lower than for switch points or the frog.
- Service life (7): Rails in the curve are prone to lateral wear, which may somewhat reduce their service life compared to straight track.

Frog (Fig. 2)

- Traffic safety (9): The frog is the point where the wheel flange crosses the rail. Any defect or excessive wear in the frog can cause a derailment. Modern movable-point frogs significantly improve safety.
- Operating speed (8): The type and condition of the frog (particularly the presence of a movable point) strongly influence the permissible train speed. The impact effect when passing over a fixed frog limits speed.
- Maintenance costs (10): The frog is one of the most heavily loaded and most worn elements. Repair, welding, and replacement costs are among the highest in the switch.
- Service life (9): Although the frog is highly susceptible to wear, modern technologies and materials (e.g., high-manganese steel, movable-point designs) can significantly extend its service life.

Figure 2. Frog with guard rail of a R65 switch, 1/11 crossing, track gauge 1 435 mm (Ukraine)

Closure curve

- Traffic safety (7): Similarly to the switch curve, it is important for safe exit from the turnout but is less critical than the active elements.
- Operating speed (7): Its geometry also affects the smoothness of train movement, but it is generally not a decisive factor for the maximum permissible turnout speed.
- Maintenance costs (6): Maintenance costs are comparatively lower than for other elements.
- Service life (6): The service life may be somewhat shorter than that of straight track due to curvature, but longer than that of active elements.

The above evaluations were used as input data for the AHP, where they were compared pairwise to further determine the weighting coefficients of each turnout element according to each criterion (Tables 2-4).

Table 2. Evaluation of turnout elements by criteria (10-point scale)

Turnout element	Traffic safety	Operating speed	Maintenance costs	Service life
Switch points	10	9	9	8
Switch curve	8	10	7	7
Frog (crossing nose)	9	8	10	9
Closure curve	7	7	6	6

Table 3. Pairwise comparison of turnout elements by criteria

Turnout element	Switch points	Switch curve	Frog	Closure curve
		Criterion: Traffic safety		
Switch points (10)	**1**	2	1/3	1/3
Switch curve (8)	1/2	**1**	1/3	1/3
Frog (9)	3	3	**1**	2
Closure curve (7)	3	3	1/2	**1**
		Criterion: Operating speed		
Switch points (9)	**1**	1/2	2	3
Switch curve (10)	2	**1**	3	4
Frog (8)	1/2	1/3	**1**	2
Closure curve (7)	1/3	1/4	1/2	**1**
		Criterion: Maintenance costs		

DOI: 10.55343/CogSust.20523

Turnout element	Switch points	Switch curve	Frog	Closure curve
Switch points (9)	**1**	2	1/2	3
Switch curve (7)	1/2	**1**	1/3	2
Frog (10)	2	3	**1**	4
Closure curve (6)	1/3	1/2	1/4	**1**
Criterion: Service life				
Switch points (8)	**1**	2	1/2	3
Switch curve (7)	1/2	**1**	1/3	2
Frog (9)	2	3	**1**	4
Closure curve (6)	1/3	1/2	1/4	**1**

Table 4. Pairwise comparison of criteria by importance

Turnout element	Traffic safety	Traffic speed	Operating costs	Service life
Traffic safety	1	5	7	7
Traffic speed	1/5	1	3	3
Operating costs	1/7	1/3	1	2
Service life	1/7	1/3	1/2	1

Traffic safety has an overwhelmingly strong advantage over all other criteria, since it is a fundamental requirement of railway transport. Traffic speed has a moderate advantage over operating costs and service life, as it is a key indicator of the efficiency of modern railway operations. Operating costs have a moderate advantage over service life, because direct expenses for regular maintenance and track repairs are often more tangible and immediate than full replacement of elements due to the end of their service life.

After constructing the matrices (Tables 2–4), the next steps in the Analytic Hierarchy Process (AHP) include: normalization of matrices (calculating the sum of each column and dividing each element by the column sum); calculation of weight coefficients (priority vectors) by averaging the values across rows of the normalized matrices. This provides the weight coefficients for each turnout element under each criterion, as well as the weight coefficients of the criteria themselves. Then, the consistency index *(CI)* and consistency ratio *(CR)* are computed for each matrix (a solution is considered acceptable if $CR < 0.1$).

Based on the obtained evaluations and calculations, the turnout elements are ranked by priority as follows (Fig. 3):

1. Frog (core): 0.395 (highest priority, explained by its critical importance for safety, operating costs, and service life)
2. Closure curve: 0.234 (indicating that even a “less significant” element has a substantial influence within the overall system)
3. Switch (point blades): 0.190
4. Switch curve: 0.181

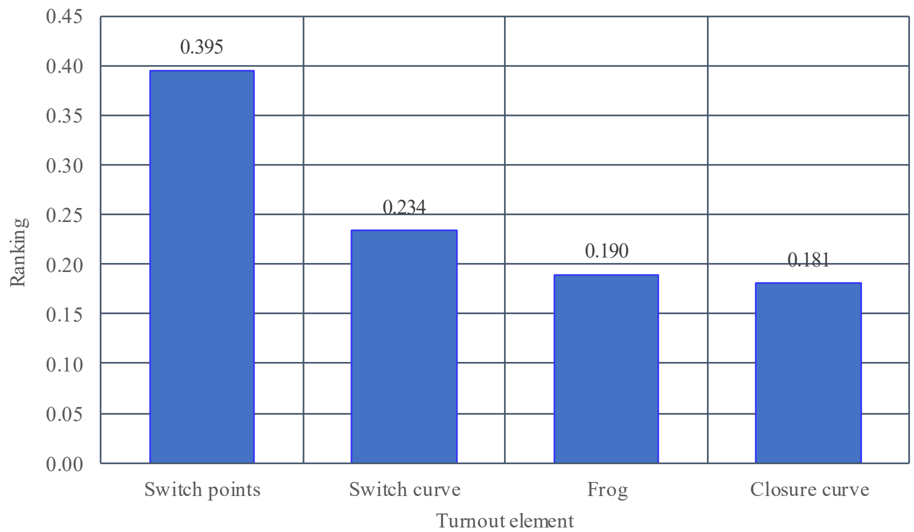

Figure 3. Ranking of turnout elements

This result indicates that the frog is the most critical element in terms of its overall impact on all considered criteria, particularly given the weight of safety. This is entirely logical, as the frog is the most heavily worn and complex section, influencing safety (impact loads), speed (especially with a movable point), and maintenance costs.

The Analytic Hierarchy Process (AHP) allows for the detailed analysis of complex elements such as the frog, breaking them down into sub-elements and conducting alternative design evaluations. For example, frogs may vary in type and design: with a solid nose or a movable nose (Table 1). Railway operating conditions affect the performance indicators of frogs (Table 5).

DOI: 10.55343/CogSust.20523

Table 5. Operational performance depending on frog type and grade

Performance indicator	Movable nose vs. Solid	Frog grade
1. Traffic safety	Frogs with a movable nose provide a significantly higher level of safety at high speeds, as they eliminate the impact section. Therefore, in pairwise safety comparisons, they have a much higher priority than solid frogs, especially for grades intended for high-speed traffic.	For the same design, a 1/18 frog is safer for high-speed passage than a 1/9 frog due to the gentler angle, although 1/9 may be sufficiently safe at lower speeds.
2. Operating speed	Frogs with a movable nose allow much higher speeds on the diverging track compared to solid frogs of the same grade. This is their key advantage.	This is a decisive factor. A 1/18 frog (especially with a movable nose) will allow significantly higher speeds than a 1/9 or 1/11 frog.
3. Maintenance costs	Movable-nose frogs are significantly more expensive to manufacture and install, and their maintenance is more complex (though less frequent under proper operation) than that of solid frogs. However, solid frogs for high-speed lines experience greater wear, requiring frequent welding and repairs, which are also costly. Overall, movable noses may have higher initial costs but lower operating costs per tonnage at high speeds.	Frogs with gentler grades (1/18) are physically larger and more expensive, but they distribute loads better, which may reduce wear.
4. Service life	Movable-nose frogs, due to smoother wheel passage, provide a longer service life for the frog and adjacent rails compared to solid frogs at high speeds. Impacts on solid frogs cause micro-deformations and accelerate wear.	For high speeds, gentler frogs (1/18) generally have a longer service life than steeper ones (1/9) under the same loads, as dynamic impacts are lower.

The generalized ranking of turnout frogs is presented in Table 6 and Fig. 4.

Table 6. Generalized ranking of turnout frogs

Frog type	Speed	Cost	Wear	Service life	Generalized rating
1/18 movable	0.482	0.096	0.482	0.444	0.376
1/11 movable	0.272	0.161	0.272	0.222	0.232
1/9 cast	0.088	0.466	0.088	0.222	0.216
1/11 cast	0.158	0.277	0.158	0.111	0.176

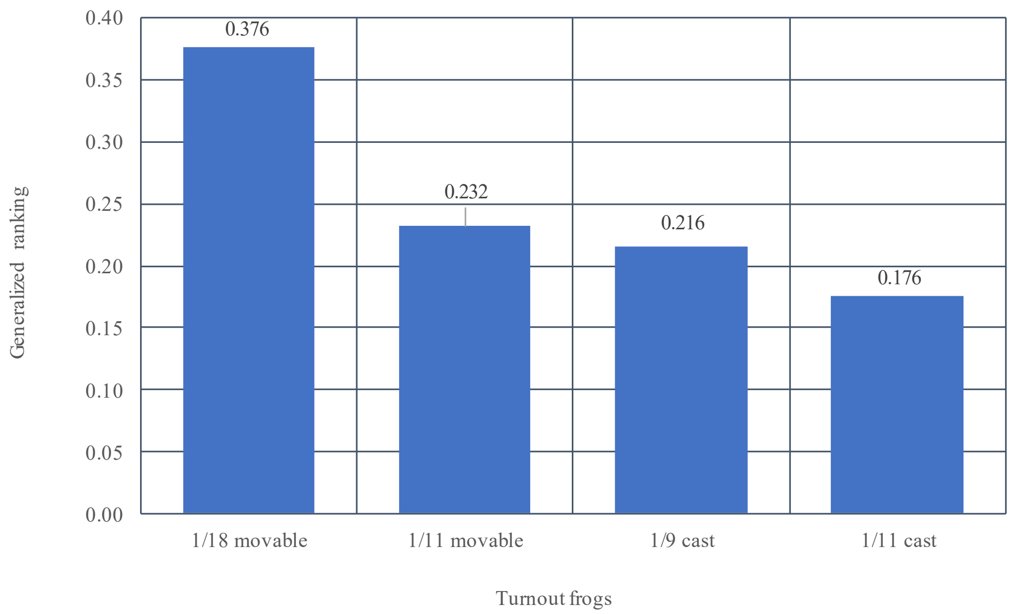

Figure 4. Ranking of frog designs

Figure 4 shows that the 1/9 frog has a higher overall rating than the 1/11 frog. In the pairwise comparison matrix for the "Speed" criterion, the 1/9 frog has poorer characteristics and received a lower score than the 1/11 frog for this criterion. However, for other criteria (such as cost, wear, and service life), the 1/9 frog received higher values, meaning it is cheaper, experiences less wear, and has a simpler design (see Tables 6 and 7).

Table 7. Advantages and disadvantages of frog nose designs

Frog type	Advantages	Disadvantages
Solid nose	Lower maintenance, simpler design	Limited speed, higher wear
Movable nose	Higher speed, reduced rail wear	More complex design, higher cost

Thus, the highest overall priority was assigned to the 1/18 movable-nose frog, indicating the best balance among the evaluated criteria. The lowest priority was assigned to the 1/11 solid-nose frog. These results can be used to make informed decisions when selecting frog designs during the design or modernization of turnouts.

In this study, a comprehensive approach was applied to the evaluation of turnout elements, integrating classical technical and economic indicators with cognitive analysis. This methodology shows how engineering decisions affect the perception and decision-making speed of personnel, which is critically important for ensuring safety at high speeds.

DOI: 10.55343/CogSust.20523

Using the Analytic Hierarchy Process (AHP), the priority of criteria for high-speed operations was justified. It was shown that traffic safety has an overwhelmingly strong advantage, highlighting its key role in the context of cognitive safety. It was also established that traffic speed moderately outweighs operating costs, which in turn have a greater impact than service life, reflecting the operational significance of each factor for railway infrastructure efficiency.

Based on the calculations, the priority of turnout elements was determined as follows: frog (0.395), closure curve (0.234), switch (point blades) (0.190), and switch curve (0.181). This result is supported by both technical and cognitive concentration.

4. Conclusion

The authors have refined the methodology for comprehensive evaluation of turnout elements by integrating cognitive analysis with the Analytic Hierarchy Process (AHP). This approach extends traditional engineering criteria (safety, speed, costs, service life) to incorporate the specifics of human factors and cognitive perception in high-speed railway operations. The main findings of the study are as follows:

- Based on expert analysis and AHP calculations, traffic safety was identified as the highest-priority factor for high-speed operations. Importantly, this safety depends not only on the technical excellence of the design but also on how intuitive and predictable the behavior of turnout elements is for both drivers and maintenance personnel.
- The calculated weight coefficients for the main turnout components showed that the frog (0.395) is the most critical element. This high priority is due not only to its complex design and high wear but also to its direct impact on visual perception and train dynamics, requiring increased attention and rapid decision-making from the driver.
- The study considered cognitive risks associated with specific turnout elements. For example, higher operating speeds can shift priority to the switch (point blades) as the element demanding the greatest concentration and cognitive processing from the driver at the moment of route setting. This confirms the hypothesis that priorities depend on operational conditions.
- The proposed methodology allows not only the evaluation but also the design of turnouts considering their "cognitive compatibility. " The results of the study can be applied for:
  1. Developing optimal maintenance strategies that account for potential human-factor-related risks.
  2. Making informed choices of frog types, particularly considering their influence on visual perception and driver reaction time.
  3. Determining priorities for major repairs on high-speed lines, where cognitive safety is a decisive factor.

Acknowledgement

The research results presented in this article were obtained as part of the scientific work carried out by the staff of the Ukrainian State University of Science and Technologies, entitled "Study of the Condition and Prospects for the Development of Railway Track Facilities". The paper was supported by the SZE-RAIL Research Team. The research has not received any financing for the article process charge.

References

Barkhordari, P., Galeazzi, R., Tejada, A., Santos, I. (2019). Identification of behavioural models for railway turnouts monitoring. *arXiv*. 1910.06582. DOI: 10.48550/arXiv.1910.06582

Barkhordari, P., Galeazzi, R., Blanke, M. (2021). Monitoring of Railpad Long-term Condition in Turnouts Using Extreme Value Distributions. *arXiv*. DOI: 10.48550/arXiv.2101.02567

Boghani, H. C., Ambur, R., Blumenfeld, M., Saade, L., Goodall, R. M., Ward, C. P., Plášek, O., Gofton, N., Morata, M., Roberts, C., Dixon, R. (2021). Sensitivity enriched multi-criterion decision making process for novel railway switches and crossings − a case study. *European Transport Research Review*, 13, 6. DOI: 10.1186/s12544-020-00467-x

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors*. 37(1), 32–64. DOI: 10.1518/001872095779049543

Fischer, S. (2022). Geogrid reinforcement of ballasted railway superstructure for stabilization of the railway track geometry–A case study. *Geotextiles and Geomembranes*. 50(5), 1036–1051. DOI: 10.1016/j.geotexmem.2022.05.005

Fischer, S. (2023). Evaluation of inner shear resistance of layers from mineral granular materials. *Facta Universitatis, Series: Mechanical Engineering*. Online first. DOI: 10.22190/FUME230914041F

Fischer, S. (2025). Investigation of the Settlement Behavior of Ballasted Railway Tracks Due to Dynamic Loading. *Spectrum of Mechanical Engineering and Operational Research*. 2(1), 24–46. DOI: 10.31181/smeor21202528

Fischer, S., Kurhan, M., Kurhan, D. (2025a). Innovative Technologies and Cognitive Factors for Enhancing Safety of Train and Car Movement at Level Crossings. In Zöldy, M. (ed.), *Proceedings of the 3rd Cognitive Mobility Conference. COGMOB 2024. Lecture Notes in Networks and Systems*. 1258. Springer, Cham. 1–13. DOI: 10.1007/978-3-031-81799-1_1

Fischer, S., Hermán, B., Sysyn, M., Kurhan, D., Szürke, S. K. (2025b). Quantitative analysis and optimization of energy efficiency in electric multiple units. *Facta Universitatis, Series: Mechanical Engineering*, 23(2), 351–375. DOI: 10.22190/FUME241103001F

DOI: 10.55343/CogSust.20523

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

Kovalchuk, V., Sysyn, M., Sobolevska, J., Nabochenko, O., Parneta, B., Pentsak, A. (2018). Theoretical study into efficiency of the improved longitudinal profile of frogs at railroad switches. *Eastern-European Journal of Enterprise Technologies*. 4(1) (94), 27–36. DOI: 10.15587/1729-4061.2018.139502

Nyström, B., Söderholm, P. (2008). Selection of maintenance actions using the analytic hierarchy process (AHP): decision-making in railway infrastructure. *Structure and Infrastructure Engineering*. 6(4), 467–479. DOI: 10.1080/15732470801990209

Polishchuk, O. (2021). Models and methods of complex evaluation of complex network and hierarchically network systems. Dissertation abstract for Technical Sciences Doctor Degree, specialty 01.05.04 – System analysis and theory of optimal decisions. Taras Shevchenko National University of Kyiv, Ministry of Education and Sciences of Ukraine. *arXiv*. DOI: 10.48550/arXiv.2104.13852

Reason, J. (1990). *Human Error*. Cambridge University Press, Cambridge. DOI: 10.1017/CBO9781139062367

Saaty, T. L., Kułakowski, K. (2016). Axioms of the analytic hierarchy process (AHP) and its generalization to dependence and feedback: The analytic network process (ANP). *arXiv preprint*, 1605.05777. DOI: 10.48550/arXiv.1605.05777

Saaty, T. L., Shang, J. S. (2007). Group decision-making: Head-count versus intensity of preference. *Socio-Economic Planning Sciences*, 41(1), 22–37. DOI: 10.1016/j.seps.2005.10.001

Saaty, T. L., Tran, L. T. (2007). On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process. *Mathematical and Computer Modelling*, 46(7–8), 918–925. DOI: 10.1016/j.mcm.2007.03.022

Taha, H. A. (2017). *Operations research: An introduction*. 10th edition. Pearson Education Limited, Harlow..

Wang, P., Yang, L., Wang, S., Zhang, H., Han, L., Jing, G. (2024). Evaluation and maintenance method for general speed railway turnouts based on multi-source data. *Construction and Building Materials*. 451, 138896. DOI: 10.1016/j.conbuildmat.2024.138896

Zöldy, M., Baranyi, P., Török, Á. (2024). Trends in Cognitive Mobility in 2022. *Acta Polytechnica Hungarica*. 21(7), 189–202. DOI: 10.12700/APH.21.7.2024.7.11