Article citation info:
BUREIKA G, BEKINTIS G, LIUDVINAVIČIUS L, VAIČIŪNAS G. Applying analytic hierarchy process to assess traffic safety riskof railway infrastructure. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2013; 15 (4): 376–383.

Gintautas BUREIKA
Giedrius BEKINTIS
Lionginas LIUDVINAVIČIUS
Gediminas VAIČIŪNAS

APPLYING ANALYTIC HIERARCHY PROCESS TO ASSESS TRAFFIC SAFETY RISK OF RAILWAY INFRASTRUCTURE

ZASTOSOWANIE PROCESU HIERARCHII ANALITYCZNEJ DO OCENY ZAGROŻENIA BEZPIECZEŃSTWA RUCHU W ODNIESIENIU DO INFRASTRUKTURY KOLEJOWEJ

TheAnalytic Hierarchy Process is described in recent research works as an emerging multicriteria decision-making approach to solving large, dynamic, and complex problems, which reflect real situations, such as strategic planning of management or resources, justification of introducing new technologies or determining the effectiveness of systems' operation. The paper presents an application of the Analytic Hierarchy Process to performance evaluation through a case study of Lithuanian railway traffic safety risk. The results of the performed study show that the application of the Analytic Hierarchy Process method can help railway traffic control managers effectively evaluate the railway infrastructure objects from the perspective of traffic safety risk and make long-term strategic plans for preventing the accidents on railway lines even under difficult economic and transportation conditions. A model for assessing railway infrastructure objectsfrom the perspective of traffic safety risk,developed and realized by the authors for Lithuanian Railways two real lines, is presented. Finally, basic conclusions and recommendations are given.

***Keywords**: railway traffic risk, infrastructure objects, assessing of traffic risk,Analytic Hierarchy Process (AHP) method, coefficient of concordance.*

Najnowsze prace badawcze opisują proces hierarchii analitycznej jako nowy wielokryterialny model podejmowania decyzji służący rozwiązywaniu dużych, dynamicznych i złożonych problemów, które odzwierciedlają rzeczywiste sytuacje, takie jak strategiczne planowanie zarządzania lub zasobów, uzasadnianie wprowadzenia nowych technologii lub określanie efektywności działania systemów. W pracy opisano zastosowanie procesu hierarchii analitycznej do oceny działania, przedstawiając studium przypadku dotyczące bezpieczeństwa ruchu kolejowego na Litwie. Wyniki przeprowadzonego badania wskazują, że stosowanie metody procesu hierarchii analitycznej może pomóc menedżerom ds. sterowania ruchem kolejowym skutecznie oceniać obiekty infrastruktury kolejowej z punktu widzenia zagrożenia bezpieczeństwa ruchu oraz konstruować długoterminowe plany strategiczne mające na celu zapobieganie wypadkom na liniach kolejowych, nawet w trudnych warunkach gospodarczych i transportowych. Przedstawiono model oceny obiektów infrastruktury kolejowej z punktu widzenia zagrożenia bezpieczeństwa ruchu drogowego, opracowany i zrealizowany przez autorów dla dwóch linii Kolei Litewskich. Na zakończenie, podano podstawowe wnioski i zalecenia.

***Słowa kluczowe**:zagrożenie bezpieczeństwa ruchu kolejowego, obiekty infrastruktury, ocena zagrożenia ruchu, metoda procesu hierarchii analitycznej (AHP), współczynnik konkordancji.*

1. Introduction

Traffic safety is one of the main problems facing road and railway operators in many countries of the world.Traffic safety situation in Lithuania, despite the progress made in 2008, is still not good enough compared to the other European Union countries. The effective control and management of railway traffic, ensuring its safety, requires a comprehensive analysis of the state of the railway infrastructure objects and systemization of the obtained data. This would help to develop the effective urgent measures to considerably reduce railway traffic safety risks [1]. Thecomponentof railway infrastructure, causing many problems, associated with the collisions of trains with road vehicles and human injuries and mortalities, is level crossing. A comprehensive analysis of level crossings was performed for the period of several years (2003-2011) in Australia and the risk evaluation model ALCAM was suggested, and practically implemented by its governmental institutions. The experts from Great Britain also pay great attention to increasing traffic safety at railway level crossings with the help of the developed traffic safety control model ALCRM [10]. The Safety Risk Model (SRM), which presents quantitative investigation of the potential accidents resulting from the operation and maintenance of the Great Britain rail network is widely applied too [12]. SRM comprises a total of 120 individual models, each representing a type of hazardous event. Other railway infrastructure components, causing problems to specialists dealing with the problems of railway traffic safety in the Baltic States, Poland and Finland, are railway stations, freight terminals and their sortingtrack yards, pipelines [4, 18, 20].

Railway traffic safety control is aimed at protecting people, their health and wealth, as well as improving traffic conditions, reducing harmful effect of rail transport on the environment and ensuring the realization of the general aims, associated with railway traffic safety and the relationship between railway systems of various countries. The control of railway traffic safety is regulated in Lithuania by the Lithuanian Law on Railway Traffic Safety. This law defines the rights and responsibilities of the state institutions, developing and implementing the policy of railway traffic safety, as well as the requirements to and the rights of the managers (carriers), and the investigation and registration of traffic accidents.

The aim of this paper is to present a traffic safety risk evaluation model developed by the authors with respect to various objects of the railway infrastructure, based on qualitative (expert) evaluation.In the considered risk management model, it is suggested to assess the damage made by railway traffic accidents, based on the criteria presented in the Lithuanian law on railway traffic safety.

The study of Japanese scientists [17] was conducted to evaluate the effect of potential risk factors – such as driving without a license, alcohol use, speed, seat belt, and helmet – use on fatality in motor vehicle traffic accidents. Human factors play an important role in the occurrence of railway traffic accidents too. They embrace the violation of traffic rules, ignorance of road signs and signals by train operators, their dazzling, tiredness, intoxication, etc. [6, 7, 15, 18].However, traffic safety specialists emphasize that technical factors, including the provision of fencing, pedestrian and cattle crossings, lighting and signs, visibility, etc., can also increase traffic safety [2, 8, 21].

The application of multicriteria methods, especially,the AHP method, largely depends on calculation of the criteria weights, based on expert evaluation [13, 14]. The results obtained can be used for practical purposes if expert judgments are in good agreement [5].The latter may be determined by the concordance coefficient obtained by ranking the available alternatives. The paper considers a possibility to apply the concordance coefficient in the cases, when expert evaluation is not based on ranking. The calculations reveal the dependence of the agreement of expert estimates on a particular method used. The highest degree of agreement has been obtained by using the direct ranking method. The effect of equally assessed criteria, i.e. the tied ranks, on the concordance coefficient and thereby on the level of expert judgments' agreement is usually insignificant and cannot change the results of rating.

For the reasons discussed above in the presented survey, the AHP method was chosen by the authors. It was applied to the analysis of transport sector, particularly, to the assessment of Lithuanian railway traffic risk. In the railway line environment, these groups of criteria(factors) were evaluated:

1) theintensity of railway and road traffic.
2) the degree of line traffic control (controllable, semi-automatic and fully automatic);
3) ambient conditions (rain, snow, darkness, fog, etc.);
4) other.

The infrastructure of Lithuanian Railways embraces the main lines of 2000 km of length, more than 500 level crossings (located at a distance of 4.2 km from each other), tens of railway stations, bridges, viaducts, several locomotive maintenance depots and one tunnel.In the present paper, all objects of the railway's infrastructure are clearly defined, the comprehensive data referring to them is presented and major criteria describing railway traffic safety are determined. The significance of these criteria is also determined, based on expert evaluation, and they are ranked according to this parameter. After evaluation of factors influence weight on the analysed railway line accident level, the urgent measures of increasing the traffic safety on infrastructure object can be ranked. The authors of the present paper offered the developed model for evaluating safety risk with respect to the objects of Lithuanian railway infrastructure. This model was applied on two Lithuanian Railways real lines situated on the main transport corridor (the IXB trans-European corridor) to investigate the level of traffic risk and recommend vital means to improve the situation on these lines. Suggested estimation process, based on worldwide scientifically grounded methods [3, 5, 7, 9, 11, 16], could be also used for assessing and managing traffic safety on the railways infrastructure objects of various country.

2. Railway infrastructure and identification of risk objects

The operator of Lithuanian railway infrastructure is the State Company "Lithuanian Railways" (the original name – AB "Lietuvosgeležinkeliai"), which manages and regulates the traffic in the railway entire network. The railway sidings are private. Railway traffic is controlled by the State Inspection of Railways subordinate to the Ministry of Transport.

The investigation and assessment of traffic safety risks associated with railway infrastructure were performed in three stages:

1. The initial stage, which includes the collection (registration) of data on the objects of railway infrastructure and their systemizing, identification of threats, which may result in traffic accidents, expert evaluation of possible damage, the collection of data on the risks associated with the infrastructure objects and determination of the significance of risk factors.
2. Railway traffic risk analysis, when the risk level of an object or a set of objects, chosen based on particular criteria, taking into account the registered risk factors of the considered object or set of objects, is considered.
3. Traffic risk management, which embraces the selection of the required or recommended measures, aimed at reducing risks and associated with a particular object or a set of objects, selected based on particular factors.

At the initial stage of analysis, the data on the objects of Lithuanian Railway infrastructure presenting risk to traffic safety are collected. The risks presented by the following objects of railway infrastructure to railway traffic safety are considered and assessed by the evaluation model:

1) rolling stocks;
2) rails and automatic switches;
3) railway buildings;
4) level crossings;
5) signalling systems and automatic devices;
6) railway stations and terminals.

The main objective ofrailway traffic safety risk evaluation is a basic railway infrastructurecomponent – the railway line. The railway network of the state consists of railway lines, which make the primary chain of the automatic and signalling system of traffic management.

Traffic safety on the railway line depends on the general factors as follows:

1) type of the railway line (single/doubletrack);
2) availability of automatic train traffic control devices;
3) the conditions of track repair performance, with the traffic stopped or active;
4) operational (actual average) speed of the trains;
5) actual number of pairs of trains, running along the railway line per day;
6) the type of the traffic block-system (automatic or semi-automatic system);
7) type of the railway line (crossing – or not – any settlements);
8) the distance to the closest residential building;
9) type of the railway line (passing – or not – any stations);
10) fencing of the railway line;
11) the number of level crossings;
12) visibility of level crossings in both directions;
13) level crossing lighting (present or not present);
14) the number of automatic switches on the railway line;
15) the number of bridges;
16) the number of animal crossings;
17) the number of viaducts and overpasses;
18) the number of viaducts over water;
19) a description of the track largest grade (slope) of the railway line;
20) the smallest radius and length of a horizontal curve;

21) geometric errors of the gauge;
22) the highest superelevation of the rails.

The survey of experts'opinion (specialists in railway traffic safety and train maintenance) allowed the authors to determine the main risk factors for railway line traffic as follows:

1) single-track or double-track railway;
2) geometric errors in the railway track gauge;
3) the number of pairs of trains per day;
4) type and number of level crossings;
5) category of level crossing (intensity of road and train traffic);
6) availability of automatic control devices of train traffic;
7) the largest track grade and the track smallest horizontal curve.

3. Identification of traffic accident threats on railways

The analysis of the data on railway traffic safety risks allowed the authors to identify the main threats as follows:

1) the collision of trains;
2) train derailment;
3) the collision of rolling stock;
4) the derailment of rolling stock;
5) the collision of rolling stock and road vehicles at level crossings;
6) running of rolling stock vehicles over the people at level crossings;
7) the collision of rolling stock and some foreign bodies at level crossings;
8) the collision of rolling stock and people in the area of the railway and its equipment (buildings);
9) the collision of rolling stock and the objects of railway infrastructure;
10) the collision of rolling stock and other objects;
11) fire in the rolling stock;
12) signal passing at danger(SPAD)
13) breakage of the rolling stock wheels;
14) breakage of the rolling stock wheel-sets;
15) spontaneous uncoupling of automatic train carriage coupling;
16) rail breakage;
17) geometric gauge damage;
18) signalling error (erroneous train route design);
19) breakages in signalling, communication, contact systems and power equipment;
20) faults in other engineering equipment.

The threats to railway traffic are constantly revised during the operation of trains and infrastructure objects. Threats are identified by performing the following actions:

1. Investigating railway traffic accidents. It should be determined if the accident was caused by violation of a law regulating railway traffic safety.
2. The investigator of railway safety risks, having found the cause of the traffic accident, should check if this cause had already been registered as the risk factor in the traffic safety evaluation model.

To determine railway traffic safety risks, the potential threat harm (damage) should be determined (Rheinberger et al 2009, Shibata et al 1994). It is found, taking into account the factors given below:

1. Human safety.
2. Direct and indirect financial losses:
   a) due to infrastructure damage;
   b) due to damage to the rolling stock;
   c) due to the harm to the environment;
   d) due to train delay.

To perform the analysis of railway traffic safety risks, based on the suggested model and taking into account railway infrastructure objects, the following expert information is required:

1. Types of objects.
2. Threats typical of a particular object.
3. Factors, increasing the weight of threat criteria.
4. Relative values of factors, increasing the weight of threat criteria.
5. Factors, decreasing weight of threat criteria (control measures are offered).
6. The level of damage caused by the realized threat.

3.1. The determination of the railway infrastructure objects risk model

The application of the created model was demonstrated by considering two railway lines, representing Lithuanian Railways infrastructure. Their brief description is given below.

The first considered Lithuanian railway line is „Livintai – Gaižiūnai":

1) railway type – a single-track railway;
2) railway track gauge – 1520 mm;
3) distance – 12 km;
4) automatic block system;
5) type of signalling – interlocking system;
6) communication system – analogue, digital;
7) railway traffic intensity – 63 pairs of trains per day;
8) allowable speed on the railway line for freight/ passenger trains – 90/120 km/h;
9) the number of level crossings – 1unit;
10) the type of level crossings – 1 unregulated level crossing (the 3rd category level);
11) road traffic intensity at the level crossing – 12 vehicles/day;
12) the number of switches on the railway line (without railway station switches) – no switches;
13) the smallest radius of the road curve on the railway line – 833 m;
14) the largest track on the railway line – 7,9 ‰.

The second considered Lithuanian railway line "Kaišiadorys-Pravieniškės":

1) railway type – a double-track railway;
2) railway track gauge – 1520 mm;
3) distance – 16 km;
4) automatic block system;
5) type of signalling – interlocking system;
6) communication system – analogue, digital;
7) railway traffic intensity – 43 pairs of trains per day;
8) allowable speed on the railway line for freight/ passenger trains:
9) even route – 80/120 km/h;
10) odd route – 90/120 km/h.
11) the number of level crossings – 1 unit;
12) the type of level crossings – 1 unregulated level crossing (the 3rd category level);
13) road traffic intensity at the level crossing – 1533 vehicles/day;
14) the number of switches on the railway line (without railway station switches) – no switches;
15) the smallest radius of the road curve on the railway line:
    a) even route – 850 m;
    b) odd route – 1373m.
    c) the largest track on the railway line:
    d) even route – 5.8%o;
    e) odd route – 5.5‰.

NOTE. The 3rd category is (51–100) trains and (251–700) vehicles per day according Lithuanian classification of level crossings.

3.2. Threats considered in the risk management model

Three threats common for the railway linewere chosen to reveal the operation of the risk estimation model:

1) Human injury (T1).
2) Derailment (T2).
3) The collision of rolling stock (T3).

For each of these 3 threats, the factors, increasing theweight of criteria, were identified below in the text.

The first threat T1.The factors, increasing the weight of the threat "Human injury" criteria:

1) T1F1 High allowable train speed (more than 100 km/h);
2) T1F2 Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway);
3) T1F3 The railway in the state of track repair (with traffic stopped);
4) T1F4 The railway in the state of track repair (with traffic active);
5) T1F5 Regulated level crossing with low intensity road traffic (up to 500 vehicles per day);
6) T1F6 Unregulated level crossing with low intensity road traffic (up to 500 vehicles per day);
7) T1F7 Regulated level crossing with high intensity road traffic (more than 500 vehicles per day);
8) T1F8 Unregulated level crossing with high intensity road traffic (more than 500 vehicles per day).

The second threat T2. The factors, increasing realization weight of the threat "Derailment"criteria:

1) T2F1 High allowable maximum speed (more than 100 km/h);
2) T2F2 Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway);
3) T2F3 The railway in the state of track repair (with traffic active);
4) T2F4 Passing a switch (switches);
5) T2F5 Railway curves of small radius (up to 700m);
6) T2F6 Railway track grade (a large grade of more than 8 ‰ and length of more than 2 km);
7) T2F7 Irregular straight railway track gauge (lower than 1517 mm or higher than 1525 mm);
8) T2F8 No automatic railway traffic regulating devices (on the passed railway line);
9) T2F9 The ambient temperature (minus 30°C and lower or plus 30°C and higher).

The third threat T3.The factors, increasing the realization weight of the threat „Collision of rolling stock" criteria:

1) T3F1 The use of automatic block system on the railway line;
2) T3F2 The railway in the state of track repair with traffic stopped, when an even train is allowed to run on the odd track or vice versa;
3) T3F3 A single-track railway;
4) T3F4 The use of a parallel gauge (European and wide track gauges) on the railway line;
5) T3F5 High allowable maximum speed (more than 100 km/h);
6) T3F6 Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway);
7) T3F7 Passing a switch (switches);
8) T3F8 No automatic railway traffic regulating devices (on the railway line).

4. Evaluating the factors, which increasing weight the threat criteria, by using the AHP method

Ranking is not the only method of comparing various objects. Experts may evaluate the objects (or the factors describing them) in the units of measurement of a particular scale, as well as in percent, or in any system of points.They may also determine the values of the criterion weights by the method of pairwise comparison. In this case, the sum of the criterion weights should be equal to one. If we wish to apply the concordance coefficient *W* for establishing the level of consistency of experts' judgements, any assessment of the objects should be transformed into ranking. This is not difficult to do because any method shows the significance of the objects as well.

For quantitative evaluation of the weights (significance) of the criteriadescribing the objects, the AHP (*Analytic Hierarchy Process*) pairwise comparison method was applied by Saaty [14] and later widely used by many other scientists [5, 19]. Experts compare all estimated factors (criteria) in pairs.

The pairwise comparison matrix is:

$$A = \begin{Bmatrix} 1 & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_m} \\ \frac{w_2}{w_1} & 1 & \dots & \frac{w_2}{w_m} \\ \dots & \dots & \dots \\ \dots & \dots & \dots \\ \frac{w_m}{w_1} & \frac{w_m}{w_2} & \dots & 1 \end{Bmatrix}; \quad (1)$$

$$a_{ii}=1;\ a_{ij}=\frac{1}{a_{ji}} \text{ and } a_{ij}\neq 0.$$

where m – the number of compared factors (criteria).

T. Saaty devised a consistency test to distinguish the consistent comparisons (with acceptable deviations) from the inconsistent comparison (with unacceptable deviations). The consistency test involves the use of a "consistency ratio": C.R.=(λmax−n)/(n−1)/R.I., where R.I. is a random index whose value depends on RI is presented in the tables (Saaty 1980). If the value C.R.⩾0.1, the decision maker has to redo the pairwise comparison matrix.

An example of determining the values of the weights of threat criteria,using the above-mentioned T. Saaty method and the filled in questionnaire of pairwise comparison of criteria obtained from the experts, is shown in Table 1, in Table 3 and in Table 5.

Applying the T. Saaty's AHP pairwise comparison method, the level of consistency of judgements is determined for each expert. In this case, the level of consistency of judgements of a group of experts based on the concordance coefficient was determined by calculating theT. Saaty weights of the criteria and ranking them according to the decrease of theweights. The method enables us to determine the level of judgements' consistency for an expert. The consistency of 20 experts' judgements was acceptable because the concordance coefficient was less than 0.1.

Evaluating the criteria (factors), increasing weight ofthreatcriteria, the method of pairwise comparison was used. Performing risk analysis of traffic on Lithuanian Railways, aquestionnaire survey of 12 experts of railway traffic control and management and 4 staff members (decision-makers) of the State Company "Lithuanian Railways" was made. Respondents had to compare the criteria determining the weight (sig-

Table 1. The comparison matrix of the factors, increasing the threat "Human injury" (threat T1)

Factors increasing threat realization	Values of comparable coefficients							
	T1F1	T1F2	T1F3	T1F4	T1F5	T1F6	T1F7	T1F8
T1F1. High allowable maximum speed (more than 100 km/h)	1	1/2	1/3	1/6	1/3	1/5	1/4	1/8
T1F2. Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway)	2	1	1/2	1/5	1/2	1/4	1/3	1/6
T1F3. The railway in the state of track repair (with traffic stopped)	3	2	1	1/6	2	1/2	5	1/4
T1F4. The railway in the state of track repair (with traffic active)	6	5	6	1	4	2	4	1
T1F5. Regulated level crossing with low intensity road traffic of up to 500 vehicles per day	3	2	1/2	1/4	1	1/4	1/2	1/8
T1F6. Unregulated level crossing with low intensity road traffic of up to 500 vehicles per day	5	4	2	1/2	4	1	1/2	1/5
T1F7. Regulated level crossing with high intensity road traffic of more than 500 vehicles per day	4	3	1/5	1/4	2	2	1	1/3
T1F8. Unregulated level crossing with high intensity road traffic more than 500 vehicles per day	8	6	4	1	8	5	3	1

nificance) of the criteria at the particular hierarchical level neither with respect to a higher hierarchical level nor to non-structural criteria. Two questionnaires with inconsistent evaluation data were rejected. During the analysis, the factors, increasing the weight of each threat criteria, were compared with each other against the 9-point scale.

When the data elicited from experts were processed and the consistency of experts' judgements was validated by methods presented in the papers of Sivilevičius et al (2010), the comparison matrices and values of the threat increasing factors were obtained in this research work.

4.1. Risk threat "Human injury"

The values of comparison matrix's factors, increasing the weight of the Threat "Human injury", are presented in Table 1.

Table 2. The weight values of the factors, increasing the threat "Humaninjury" (threat T1)

Threat increasing factors	Weight value
T1F1. High allowable maximum speed (more than 100 km/h)	0.021
T1F2. Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway)	0.047
T1F3. The railway line in the state of track repair (with train traffic stopped)	0.077
T1F4. The railway line in the state of track repair (with train traffic active)	0.311
T1F5. Regulated level crossing with low intensity road traffic of up to 500 vehicles per day	0.033
T1F6. Unregulated level crossing with low intensity road traffic of up to 500 vehicles per day	0.101
T1F7. Regulated level crossing with high intensity road traffic of more than 500 vehicles per day	0.064
T1F8. Unregulated level crossing with high intensity road traffic of more than 500 vehicles per day	0.345

Table 3. The weight values of the factors, increasing the threat "Derailment" (threat T2)

Threat increasing factors	Weight value
T2F1. High allowable maximum speed (more than 100 km/h)	0.031
T2F2. Intense train traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway)	0.026
T2F3. The railway line in the state of track repair (with train traffic active)	0.220
T2F4. Passing a switch (switches)	0.120
T2F5. Railway track curves of small radius (up to 700m)	0.112
T2F6. Railway track grade (a large grade of more than 8 %o and length of more than 2 km)	0.029
T2F7. Irregular straight railway track gauge (lower than 1517 mm or higher than 1525 mm)	0.346
T2F8. No automatic railway traffic regulating devices (on the passed railway line)	0.068
T2F9. The ambient temperature (minus 30°C and lower or plus 30°C and higher)	0.047

Table 4. The weight values of the factors, increasing the threat "Collision of rolling stock" (threat T3)

Threat increasing factors	Weight value
T3F1. The use of automatic block system on the railway line	0.079
T3F2. The railway in the state of track repair (with train traffic stopped, when an even train is allowed to run on the odd track, or vice versa);	0.224
T3F3. A single-track railway	0.184
T3F4. The use of a parallel gauge (European and wide track gauges) on the railway line	0.239
T3F5. High allowable maximum speed (more than 100 km/h)	0.037
T3F6. Intense railway traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway)	0.076
T3F7. Passing a switch (switches)	0.113
T3F8. No automatic train traffic regulating devices (on the passed railway line)	0.048

Table 5. The assessment of the weight of the threat "Collision of rolling stock" criteria on the railway lines

Threat increasing factor	Weight of criteria	Infrastructure line (section)		
		"Livintai–Gaižiūnai"	"Kaišiadorys–Pravieniškės"	"Kaišiadorys-Pravieniškės"(railway under track repair)
T3F1. The use of automatic block system on the railway line	0.079	0.079	0,079	0.079
T3F2. The railway in the state of track repair (with traffic stopped, when an even train is allowed to run on the odd track or vice versa);	0.224	-	-	0.224
T3F3. A single-track railway	0.184	0.184	-	-
T3F4. The use of a parallel gauge (European and wide track gauges) on the railway line	0.239	-	-	-
T3F5. High allowable maximum speed (more than 100 km/h)	0.037	0.037	0.037	0.037
T3F6. Intense train traffic (more than 50 pairs of trains per day on a double-track and more than 24 pairs of trains on a single-track railway)	0.076	0.076	-	-
T3F7. Passing a switch (switches)	0.113	-	-	-
T3F8. No automatic railway traffic regulating devices (on the passed railway line)	0.048	0.048	-	-
The numerical value of threat weight of criteria	1.0	0.424	0.116	0.340
Threat realization weight of criteria	-	**Medium**	**Low**	**Medium**

Based on the data of the comparison matrix, presented in Table 1, and the validation of consistency of the compared coefficients, the weight values of the factors describing the threat "Human injury"are given in Table 2.

As was gained according AHP analyses, the threat factors T1F4 and T1F8 are the most determining factors of weight of threat T1 "Human injury" criteria.

4.2. Risk threat "Derailment"

The values of comparison matrix's factors, increasing the weight of the threat „Derailment" criteria, were estimated. Based on the comparison matrix of the coefficients, given and the validation of the presented data, the values of the factors, increasing the weight the threat "Derailment" criteria, are obtained. They are presented in Table 3.

As is seen in Table 3, the threat factors T2F3 and T2F7 are the most determining factors of the weight of the threat T2 "Derailment" criteria.

4.3. Risk threat „Collision of rolling stock"

The values of comparison matrix's factors, increasing the weight of the threat "Collision of rolling stock" criteria, were estimated by realization of comparison matrix. Based on solved comparison matrix of the coefficientsand the validation of the presented data, the values

Table 6. Assessment of the threat "Collision of rolling-stock" risk level

Name	Railway line		
	"Livintai–Gaižiūnai"	**"Kaišiadorys–Pravieniškės"**	**"Kaišiadorys–Pravieniškės" (railway under track repair)**
Threat	Medium	Low	Medium
Damage	High	High	High
Risk	High	Medium	High

Table 7. Comparison of traffic risk levels of two Lithuanian railway lines

Risk of threat „Human injury“	Railway line	
	“Livintai–Gaižiūnai”	“Kaišiadorys–Pravieniškės”
Risk of the threat „Human injury”	Low	Medium
Risk of the threat „Derailment“	Low	Low
Risk of the threat „Collision of rolling stock“	High	Medium
Total risk (determined based on the highest risk level)	High	Medium

of the factors, increasing the weight of the threat “Collision of rolling stock”, are obtained. They are presented in Table 4.

As is seen in Table 4, the threat factors T3F2 and T3F4 are the most determining factors of the weight of the threat T3 “Collision of rolling stock” criteria.

4.4. Risk assessment of the threat “Collision of rolling stock” in real lines of Lithuanian Railways

The results of the weight of the threat “Collision of rolling stock”criteria obtained for the considered infrastructure objects (railway lines) are presented in Table 5.

By calculating traffic risk level of the particular threats on the particular railway lines, the total risk of an object can be assessed. The comparative analysis of the risk level on the railway lines “Livintai-Gaižiūnai”and

“Kaišiadorys-Pravieniškės” (not during the track repair) is presented Table 7.

Finally, as is seen in Table 7, the risk of the threat “Derailment” has the low level on both analysed railway lines.

7. Discussion &conclusions

The authors developed the model of railway traffic risk management, focussing on the objects of railway infrastructure. This model may be used by railway managers for improving traffic safety strategy, establishing the priority of the required (urgent) measures and their correction.

The suggested railway traffic risk management model provides the information about the particular factors causing traffic risks and allows an identification of the areas or objects to be improved for vital railway traffic safety.The suggested model enables for ranking basic railway infrastructure objects such as railway lines, according to their riskiness to traffic safety, and helps to determine the “weakest points“ and to plan the organizational measures, required for eliminating the threats.First, all infrastructure objects, presenting considerable risk to railway traffic according to the results obtained by using the created model, were ranked. Then, the level of risk at all infrastructure objects was reduced to the “medium” and, finally, to “low” level.

The analysis of the threat “Human injury“ has shown that the factor T1F8, associated with unregulated level crossing with high intensity road traffic up to 500 vehicles per day and found on the estimated railway line highly increases the weight of the considered threat realization criteria. The elimination of this factor would allow traffic accident threat to be reduced to the “low” level, thereby decreasing the risk of the threat “Human injury” to the “low”. The threat factors T2F3 and T2F7 are the most influential factors of the threat T2 “Derailment” criteria.The analysis of the threat “Collision of rolling stock” injury“ has shown that the factors T3F2 and T3F4 are the most determining,

Respondents of 16 questionnaires had to compare the criteria determining the weight (significant) of the traffic safety criteria. The largest eigenvalue λmax, C.I. (consistency index) and C.R. (consistency ratio) were calculated to ensure the sufficient reliability of presented traffic risk assessment.Limitations of applying this suggested model are to asses only the objects of entire railway infrastructure with identically the same signalling, automation and traffic management systems. The comprehensive (complex) traffic risk evaluation index of railway infrastructure object should be created for the future improvement the applicability of traffic risk management model.

References

1. Cacciabue PC. Human error risk management methodology for safety audit of a large railway organisation. Applied Ergonomics 2005; 36 (6): 709–718.
2. Chang H. Ju L. Effect of consecutive driving on accident risk: a comparison between passenger and freight train driving. Accident Analysis and Prevention 2008; 40 (6): 1844–1849.
3. Davey J, Wallace A, Stenson N, Freeman J. The experiences and perceptions of heavy vehicle drivers and train drivers of dangers at railway level crossings. Accident Analysis and Prevention 2008; 40 (3): 1217–1222.
4. Lama A, Smirnovs J, Naudžuns J. Road traffic safety in the Baltic States. The Baltic Journal of Road and Bridge Engineering 2006; 1 (1): 63–68. DOI:http://www.bjrbe.vgtu.lt/volumes/pdf/Volume1_Number1_08.pdf
5. Lin H. An application of fuzzy AHP for evaluating course website quality. Computers Education 2010; 54 (4): 877–888.
6. Lobb B. Trespassing on the tracks: a review of railway pedestrian safety research. Journal of Safety Research 2006; 37 (4): 359–365.
7. McCollister GM, Pflaum A. A model to predict the probability of highway rail crossing accident. In Proc. of the Institution of Mechanical Engineering. Part F – Journal of Rail and Rapid Transit 2007; 221 (3): 321–329.
8. Olejnik K. Critical analysis of the current traffic regulations concerning visibility from the position of a vehicle driver. Quarterly Motor Transport distributed by Motor Transport Institute, Warsaw, Poland 2003; 2: 69–80.
9. Podofillini L, Zio E, Vatn J. Risk-informed optimisation of railway tracks inspection and maintenance procedures. Reliability Engineering & System Safety 2006; 91 (1): 20–35.
10. Review of Network Rail’s All Level Crossing Risk Model (ALCRM). Project Leader: Dr Shane Turner. RSU/08/16 2008; 84.
11. Rheinberger CM, Bründl M, Rhyner J. Dealing with the white death: avalanche risk management for traffic routes. Risk Analysis: An Official Publication Of The Society For Risk Analysis 2009; 29 (1): 76–94.
12. RSSB. Learning from operational Experience. Annual Report 2011/2012. London 2012: 69.

13. Saaty TL. Decision-making with the AHP: Why is the principaleigenvector necessary? European Journal of Operational Research 2003; 145(1): 85–91.
14. Saaty TL. The analytic hierarchy process, McGraw-Hill, New York 1980.
15. Savage I. Does public education improve rail-highway crossing safety? Accident Analysis and Prevention 2006; 38(2): 310–316.
16. Shedden P, Scheepers R, Smith W, Ahmad A. Incorporating a knowledge perspective into security risk assessments. VINE: The Journal of Information& Knowledge Management Systems 2011; 41(2): 152–166.
17. Shibata A, Fukuda K. Risk factors of fatality in motor vehicle traffic accidents. Accident Analysis & Prevention 1994; 26(3): 391–397.
18. Silla A, Kallberg V-P. The development of railway safety in Finland. Accident Analysis and Prevention 2012; 45: 737–744.
19. Sivilevičius H, Maskeliūnaitė L. The criteria for identifying the quality of passengers' transportation by railway and their ranking using AHP method. Transport 2010; 25(4): 368–381.
20. Szybka J, Broniec Z, Pilch R. Forecasting the failure of a thermal pipeline on the basis of risk assessment and exploitation analysis. Esploatacja i Niezawodnosc – Maintenance and Reliability 2011; 4: 5–10.
21. Tey LS, Ferreira L, Wallace A. Measuring driver responses at railway level crossings. Accident Analysis and Prevention 2011; 43: 2134–2141.

Gintautas BUREIKA, Ph.D., D.Sc., Assoc. Prof.
Lionginas LIUDVINAVIČIUS, Ph.D.
Gediminas VAIČIŪNAS, Ph.D., D.Sc., Assoc. Prof.
Railway Transport Department
Vilnius Gediminas Technical University
J. Basavičiaus str. 28, 03224 Vilnius, Lithuania
E-mails: gintautas.bureika@vgtu.lt, lionginas.liudvinavičius@vgtu.lt
gediminas.vaiciunas@vgtu.lt

Giedrius BEKINTIS, M.Sc.
UAB "Synergy Consulting", Ltd
Saltoniškių g.9, LT-08105, Vilnius, Lithuania
info@synergy.lt