TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2013 Volume 28(4): 389–403
doi:10.3846/16484142.2013.866980

THE USE OF AHP AND RANK CORRELATION METHODS FOR DETERMINING THE SIGNIFICANCE OF THE INTERACTION BETWEEN THE ELEMENTS OF A TRANSPORT SYSTEM HAVING A STRONG INFLUENCE ON TRAFFIC SAFETY

Valentinas Podvezko[1], Henrikas Sivilevičius[2]

[1]Dept of Mathematical Statistics, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
[2]Dept of Transport Technological Equipment, Vilnius Gediminas Technical University, Plytinės g. 27, LT-10105 Vilnius, Lithuania

Submitted 31 December 2012; accepted 10 September 2013

Abstract. A system of road transport involves vehicles, roads, traffic participants and freight that therefore closely interact. The interaction between these material elements takes place in an external environment. The process of transportation is aimed at achieving some positive results, which could increase the efficiency of the Transport System (TS). However, negative effects such as a high accident rate cannot be avoided. The road accident rate is determined by the properties of the material elements of the TS and the parameters of their interaction. Their impact on the traffic accident rate cannot be determined by a planned experiment. They also cannot be compared quantitatively, because their units of measurement are different. The paper presents a detailed description of nine types of the interaction between TS elements belonging to three various levels. The data was given to 16 transport engineering specialists as a questionnaire for expert evaluation. The paper offers a logical control methodology for filling in the questionnaire based on the Analytic Hierarchy Process (AHP) and the sequence of calculations of the consistency of expert estimates in the process of determining the weights of the investigated interactions. The Kendall's coefficient of concordance has been used for calculating the weights assigned to the criteria by a group of experts and estimating the consistency of the ranks based on them. Finally, the paper presents a new method for evaluating expert judgements with reference to the use of the correlation analysis of ranks and weights. The significance of the calculated pairwise correlation coefficients has been validated by the Student's t-test and lowest value thus allowing us to consider that the expert opinions about the impact of the interaction of TS elements on the traffic accident rate are consistent.

Keywords: transport, roads, roadway, interaction, elements, traffic safety, AHP method, MCDM method, ranking, weights, concordance.

Reference to this paper should be made as follows: Podvezko, V.; Sivilevičius, H. 2013. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety, *Transport* 28(4): 389–403. http://dx.doi.org/10.3846/16484142.2013.866980

Introduction

The main aims of passenger and freight transportation by road transport are associated with an increase in mobility, a decrease in the dependence of the Transport System (TS) on oil fuel, time and transportation expenses. It is also focuses on increasing vehicle capacity and reliability, the number of transported passengers, the amounts of goods and gained profit. These goals of the transportation process are positive and may lead to an increase in the effectiveness of the TS. However, road traffic produces a number of negative effects such as physical and chemical environment pollution, the emission of greenhouse gases and the deterioration of vehicles and road pavement. The main problem is associated with traffic accidents causing damages to vehicles and goods as well as injuries and deaths to people (drivers, passengers, pedestrians and road workers).

A traffic accident is an accident on the road, as well as in a public or private territory, when a moving vehicle injures or kills people, damages at least one of the

Corresponding author: Henrikas Sivilevičius
E-mail: *henrikas.sivilevicius@vgtu.lt*

vehicles, goods, roadway, its structures or some other things. The so-called 'black spots' appearing on the main and local roads are being eliminated. A 'black spot' is a road section about 500 m long where at least four accidents (involving injured or killed people) have been registered within the period of four years, or the accident rate (density and accident rate coefficient) has reached or exceeded the limit value. As specified in the White Paper (European Commission 2001), an increase in traffic safety has always been one of the most relevant strategic aims of the EU Member States and other countries.

Although vehicle design and road infrastructure are being constantly improved, it is hardly possible to completely avoid road accidents. Traffic collisions often result in serious and even fatal injuries to the involved people (Bartczak *et al.* 2010).

The process of transportation includes vehicles, roads, goods and traffic participants, along with the elements of the external environment interacting between each other (Sivilevičius 2011a). Their interaction and parameters influence traffic safety on the motor road. The influence of various types of interaction on road safety differs to some extent. It can be determined by applying Multi-Criteria Decision-Making (MCDM) methods.

Multi-criteria analysis is a popular tool for selecting the best alternative for the given applications. The used approaches include the Simple Additive Weighting (SAW) method, the Weighted Product Method (WPM), Technique for Order Preference by Similarity to Ideal Colution (TOPSIS), the VIKOR (*VIsekriterijumsko KOmpromisino Rangiranje* – in Serbian) method, the Analytic Hierarchy Process (AHP), Graph Theory and Matrix Representation Approach (GTMA), a method based on the Performance Selection Index (PSI) and the Preference Ranking Organisation METHod for Enrichment Evaluation (PROMETHEE) (Maniya, Bhatt 2010; Podvezko, V., Podviezko, A. 2010; Liou, Tzeng 2012). The method based on the performance selection index is a novel tool for selecting the best alternatives without showing the relative importance of attributes.

The AHP is the technology of multi-criteria decision-making (Chang *et al.* 2010) developed by Saaty (1980). The AHP is used for solving complex decision-making problems in different areas (e.g. civil engineering, transport, social and economic development, project selection and material science). Basically, the AHP is applied for reducing complex decisions on a series of one-to-one comparisons, and, consequently, performing their synthesis. However, calculation takes a very long time and there may be a lack of transparency in the whole decision-making process. Furthermore, the main disadvantages of the AHP are associated with artificial limitation on using the 9-point scale (Chatterjee *et al.* 2011; Saaty 1990) and the phenomenon of rank reversal that occurs when indifferent criteria are added to the decision matrix causing a significant change in the aggregate priorities of the alternatives followed by significant undesirable effects.

Construction is one of the main sectors of industry that is highly important for every person. In the work by Lin *et al.* (2011), the creation of the model for assessing the efficiency of the construction management system is discussed. The results of this investigation may be used for increasing the competitiveness of construction industry. The research performed by Lin *et al.* (2011) describes the developed performance evaluation model for checking the effectiveness of the construction knowledge management system. The results obtained in this research can help with increasing the competitive ability of construction industry.

Bitarafan *et al.* (2012) described the application of the AHP method for weighting significant criteria as well as the novel MCDM method Complex Proportional Assessment of Alternatives with Gray Relations (COPRAS-G) for evaluating alternatives. The obtained results show that construction quality is the most important criterion while large-panel construction is the best way of reconstructing the damaged areas.

The application of the AHP based on a pairwise comparison of the criteria or similar methods may help with solving the problem of the accuracy of expert evaluation. The paper offers (Ginevičius 2011) a new method for determining criteria weights – Factor Relationship (FARE) – based on the relationships between all criteria describing the considered phenomenon.

The problem of selecting a construction site for a waste incineration plant has been considered by Turskis *et al.* (2012). The solution of this problem is closely associated with the need for satisfying requirements for stakeholders, such as investors, inhabitants, contractors, etc. The paper by Turskis *et al.* (2012) presents a description of the problem of siting a waste incineration plant and is related to the satisfaction of requirements formulated by investors, citizens, contractors and other concerned parties. Choosing a construction site, the effort is made to take into account the interests of these various parties thus formulating a multi-criteria problem. In this case, a multiple criterion approach is the most effective while the best results can be obtained by applying both AHP and Fuzzy Additive Ratio Assessment (ARAS-F) methods.

Fouladgar *et al.* (2012a) offered a new fuzzy MCDM method for evaluating maintenance strategies based on the concepts of COPRAS and the AHP. A fuzzy AHP was used for calculating the weights of evaluation criteria. Then, the ranks of alternatives were determined based on the fuzzy sets theory and COPRAS.

Selecting the right contractor for the right project is the most crucial challenge for any construction client. Recently, to assist the owners in making decisions, there has been a trend away from the 'lowest-price wins' principle and subjective judgement to a multi-criteria approach to the selection of contractors for construction projects. In this manner, San Cristóbal (2012) offers using two multi-criteria decision methods – TOPSIS and VIKOR. The obtained results show that one of the contractors has been most highly ranked by both methods.

Fouladgar *et al.* (2012b) deal with the problem of selecting a project portfolio by using fuzzy AHP and VIKOR techniques. Project portfolio selection for making decisions on investment is a critical decision in many companies and organizations. The selection is a sophisticated and multi-criteria problem due to miscellaneous criteria that are often in conflict with each other.

Vidal *et al.* (2011) aim to define a measure of project complexity in order to assist decision-making, notably when analysing several projects in a portfolio, or when studying different areas of a project. They offer a multi-criteria approach to evaluating project complexity thus emphasizing the benefits of this approach and discussing the use of the AHP.

In recent years, multi-criteria methods have been widely used for evaluating various complex phenomena. The weights of nine criteria employed in a complex evaluation of construction contracts and the consistency of expert evaluation were determined based on the application of the AHP method (Podvezko *et al.* 2010).

The paper by Hashemkhani Zolfani *et al.* (2012a) focuses on using a hybrid MCDM model for selecting a supplier. First, eight evaluation criteria, including cost, quality, distance, the reliability of delivery, reputation, technological level compatibility and development ability were defined. The AHP was initially used for calculating the weight of each criterion. A quality control manager is an important staff member in any organization and, according to Hashemkhani Zolfani *et al.* (2012b), the main task is to select the best candidate for this work. Therefore, the paper suggests a personnel selection system based on AHP and COPRAS-G methods.

The role of materials in an engineering design process has already been well recognized. Designers need to identify materials with specific functionalities in order to find appropriate design concepts satisfying requirements for the products (Chatterjee, Chakraborty 2012). This paper concentrates on the application of four preference ranking-based MCDM methods for solving a gear material selection problem. Ranking and selection of the optimal material is an important stage in the engineering design process (Jahan *et al.* 2012).

The selection of materials is a highly significant MCDM problem involving a large number of factors influencing the selection process (Chatterjee *et al.* 2011). Although a large number of mathematical approaches to evaluation, selection and ranking alternative materials for a given engineering application have become available, this paper explores the applicability and capability of two relatively new MCDM methods, i.e. COPRAS and the Evaluation of Mixed Data (EVAMIX) for material selection.

The selection of a shaft sinking method is a multi-criteria decision making problem. Lashgari *et al.* (2011) suggest using a combination of AHP and TOPSIS methods under a fuzzy environment in order to select a proper shaft sinking method.

Recently, the use of multi-criteria quantitative evaluation methods for solving social and economic problems has grown considerably (Podvezko 2009). In practice, criteria weights are determined assessing the economic development of the state and its regions, the commercial activity and strategic potential of enterprises as well as the effectiveness of particular investment projects. The pairwise comparison of criteria has been widely applied while the most well-known, frequently employed and mathematically grounded technique is the so-called AHP the application of which, in more complicated cases, is considered and some algorithms are offered.

Yu *et al.* (2011) present a comprehensive model for ranking candidate location plans of multiple urban transit hubs, which can effectively capture various aspects of concerns in the transit hub location planning process, including the overall efficiency of the transit network, transfer intensity and proximity to major passenger generators/attractors.

In the paper by Wu *et al.* (2011), the optimization model for determining locations for transit-stop accessibility improvement is described in the framework of a spatial MCDM, which is an application of multi-criteria analysis in a spatial context.

The study by Aghdaie *et al.* (2012) looks at developing a framework for municipalities to prioritize their projects and show the location of a footbridge. The selection of the site for constructing the footbridge may be viewed as a kind of the MADM problem. The purpose of Aghdaie *et al.* (2012) was the use of AHP and COPRAS-G methods for evaluating and selecting the construction sites for new footbridges.

In many cases, tunnelling projects find themselves involved in the situation where unexpected conditions threaten the continuation of a project (Fouladgar *et al.* 2012c). Managers always look for a reliable technique to overcome limitations on finance and time. The TOPSIS method is widely used for solving MCDM problems.

The interaction between the parameters of TS elements has a strong influence on traffic safety determining the accident rate on the road.

There is a need to assess the safety performance of road intersections in a vehicle platoon environment (Wang *et al.* 2011). For this purpose, the considered study attempts to quantify intersection-related accidents and develop countermeasures using the selected data on 3520 calculates in Harbin so that to reduce injuries resulting from such accidents. Employing techniques for linear regression, several different explanatory models were constructed to identify the factors associated with annual average daily traffic, junction numbers and volume (capacity). Therefore, 3 stages were considered in response to diverse risk levels.

Traffic safety mainly depends on vehicles, pedestrians and road infrastructure. On highways, the heaviest traffic accidents are associated with crossing the dividing strips by a vehicle and its collision with side obstacles on the junction or road bridge exit (Prentkovskis *et al.* 2012). The authors of the paper present the analysis of the deformation state of a double-wave guardrail (describing strains and stresses of its elements). The early stage of the design of a safety barrier intended for protecting roadside property against fires and explosions on the road has been studied by Vaidogas and Linkutė (2012). Apart from using rigorous methods, engineering judgement for positioning the barrier within the available area may be required.

Car-to-pedestrian front impacts have been well described in the paper by Kopczyński *et al.* (2011). However, still, a lack of data measuring the performance of a new type of Frontal Protection Systems (FPS) fitted on Sport Utility Vehicles (SUVs) has been noticed.

Ptak *et al.* (2012) describe the evaluation of pedestrian kinematics after a collision with a SUV having a high bumper. Summing up the above research, the authors carried out their own comparison between a lower leg and a dummy model. An increasing number in SUVs has a serious implication on passive pedestrian safety.

Animal-Vehicle Collisions (AVCs) cause hundreds of human and wildlife animal fatalities and tens of thousands of human and wildlife animal injuries in North America (Lao *et al.* 2012). It is estimated that AVCs cause more than $1 billion in property damage each year in the United States. This study is aimed at developing an algorithm combining these two types of data to improve completeness in either set of the obtained information.

Fencing highways is one of the measures to reduce the number of Wildlife Animal – Vehicle Collisions (WVCs) in Lithuania (Balčiauskas, Jasiulionis 2012). Attempting to decrease the number of animals venturing onto roads, trials with the chemical repellent *Wam Porocol*® were conducted.

Pei *et al.* (2012) strive for developing a prediction model for speed distribution in terms of the average travel speed and standard deviation using data on probe vehicles in Hong Kong. The effects of traffic flow, road geometry and weather conditions on speed distribution were defined applying the Markov Chain Monte Carlo (MCMC) simulation approach and the Bayesian method.

Moazami *et al.* (2011) look into prioritization based upon a model, including the effects of all important factors such as the pavement condition index, traffic volume, road width, rehabilitation and maintenance cost. Although the AHP can also be used for decision making, fuzzy modelling allows having more precise choices for the outcome.

Sun and Gu (2011) integrated the advantages of the AHP and fuzzy logic theory to develop a new approach to assessing pavement condition and project prioritization. Roughness, deflection, surface deterioration, rutting and skid resistance were identified as five performance indicators evaluating the pavement condition.

Farhan and Fwa (2009) explores the use of the AHP for the prioritization of pavement maintenance activities. The main goal is to identify an approach that can reflect an engineering judgement of highway agencies and engineers more closely. The study concludes that the absolute AHP is suitable for the pavement maintenance prioritization process.

Wu *et al.* (2008) propose a decision support model for optimizing short-term pavement preservation budgets based on two reliable operation research techniques: goal programming for handling multiple objectives and the AHP for priority setting under multiple criteria.

Perati *et al.* (2012) present a novel method based on percentiles for computing the Hurst parameter, which is an indicator of the intensity of self-similarity. The paper also validates the percentile method along with two other existing methods. The numerical results clearly demonstrate that the analysis presented in this paper can be useful for creating the improved designs of toll plazas.

The paper by Sivilevičius (2011b) presents 9-criteria describing the quality of an operating asphalt mixing plant (AMP), mathematical models for determining their significance through the application of an expert evaluation method as well as the correlation of expert opinions. The ranks of AMP quality criteria were replaced with their weight indices through the application of two different methodologies.

Financial constraints necessitate the trade-off among the proposed railroad project priorities for their implementation while budget allocation should be determined by ranking mechanisms in the government. At present, the central Taiwan government prioritizes funding allocations primarily using the AHP (Cheng *et al.* 2012). This study proposes the Data Pre-Processing Method (DPM) for calculating the correlation coefficient using subjective and objective ranking incidence matrices.

Maskeliūnaitė and Sivilevičius (2012) suggest methods for determining the consistency of respondent and expert judgements by ranking the sets of criteria describing the quality of travelling by an international train. The significance of the considered criteria is based on the pairwise comparison employing the AHP method.

Sivilevičius *et al.* (2012) offer an additive model for calculating the normalized weight coefficients of particular criteria in order to figure out the Comprehensive Quality Index (CQI). The work proposes a multi-criteria mathematical model that may be used for evaluating the significance of the criteria describing the organization and technology of travelling by the international train and for determining its quality.

In the study on the interaction of TS elements with the environment, Louisiana Highway Construction Index (LHCI) values from hurricane impacted areas (GO Zones) were compared with those from Non-GO Zones. When hurricanes Katrina and Rita passed over some areas of the country, highway construction cost jumped about 20% state-wide and 51 37 GO Zone (Cheng, Wilmot 2009).

Hurricanes also happen in Lithuania. Exceeding the design speed of the wind is rather dangerous (Vaidogas, Juocevičius 2011). The authors suggest analysing an extremely high speed of the wind separately considering the maximum annual speed of the wind and data on the hurricane.

1. Evaluation of the Interaction between the Elements of the Transport System

The original model of the interaction between the physical elements of the TS representing 6 interaction levels was offered (Sivilevičius 2011a). The first level represents self-interaction between the TS elements, the second – the interaction between the elements, the third – the interaction between the TS elements and the external environment, the fourth – the interaction between various transport modes, the fifth – the interaction of the TS with national economic and non-production sectors and the sixth – the impact of the TS on the Gross Added Value (GAV). To determine the significance of transportation parameters at various interaction levels, the AHP method was suggested.

The present paper analyses the first three interaction levels of the TS elements influencing the accident rate on the roads and highways (Table 1). The interaction between the TS elements at any level is a complicated phenomenon that cannot be quantitatively evaluated in all cases.

Statistical (historical) data about traffic accidents, which have been collected and processed for a long time, do not provide sufficient information about perpetrators. It is often very difficult or impossible to make an experiment, which would allow determining the influence of a particular interacting element on the accident rate on the road. In this case, experts may help.

All the experts (16), taking part in research were given a description of the levels of the interaction of the TS elements (Table 1). They analysed the situation, then filled in the matrix of pairwise comparison according to AHP requirements and determined the impact of interaction on the accident rate.

The interaction between the TS elements may be direct (Fig. 1) and include one, two or three intermediate elements (Fig. 2).

Table 1. A list of criteria describing the interaction between the elements at various levels of the TS having an impact on the accident rate on the road

Interaction No.	Interaction code	A name and detailed description of the interaction
1	1–1–1 (A)	**The interaction between a traffic participant (freight) and a traffic participant (freight):** cyclist or roller-skater's running into a pedestrian; driver's actions showing disrespect for other participants of traffic; the erratic behaviour of pedestrians at crossings, their collision, poor driver's visibility concerning pedestrians; the effectiveness of the driver training system; the absence of safety reflectors at the dark time of the day on pedestrians or teams of horses in harness pulling a vehicle; carrying uncaged animals in an automobile; unfastened freight falling on a pedestrian or driver; controlling road traffic and drivers by a police patrol; passengers standing in an overcrowded moving bus or trolley-bus.
2	1–2–2 (B)	**The interaction between a motor vehicle and a motor vehicle:** a vehicle not maintaining a safe distance from other vehicles and moving at a high speed, thereby increasing a possibility of collision; the collision of vehicles; hauling a vehicle; passing a vehicle by moving to the opposite traffic lane; sudden braking of a vehicle, moving in dense traffic flow; a motorized infringer of traffic rules chased by a police patrol car or motor cycle; using the parking system; the movement of a vehicle in a traffic jam; the effectiveness of the inspection system of vehicles, poor maintenance of vehicles.
3	1–3–3 (C)	**The interaction between a motor road and a motor road (and its elements):** at-grade intersection of motor roads; the reconstruction of a three-way junction into a roundabout (circular junction); railway crossing; a viaduct (overhead crossing); cyclist tracks, pedestrian paths or side-walks near a motor road; the right side of the roadway specially marked as a cyclist track; the number of slip roads and their visibility
4	II–1–2 (D)	**The interaction between a traffic participant (freight) and a vehicle:** an inattentive, inexperienced or drunk driver poorly driving a vehicle; not fastened safety belts; using a horn; passengers damaging a vehicle's elements; a lack of safety cushions or ineffective safety cushions; children not carried in child safety seats; demonstrating a turn by a driver when intending to change the direction of movement; uncomfortable driving when a vehicle is suddenly braked or accelerated; carrying too heavy, large, not properly fastened or dangerous goods; using a mobile phone without hands-free equipment when driving; running of a vehicle into a bicycle, motor bike, motor cycle or a team of horses in harness pulling a vehicle; the presence of pedestrians at a bus station and in its vicinity; a strike of transport workers; using anti-dazzle fences; other vehicles limiting driver's visibility; dazzling a driver by a long-distance beam of another vehicle; lighting of the roadway by vehicle's head-lights increasing driver's visibility.
5	II–1–3 (E)	**The interaction between a traffic participant (freight) and a motor road (and its elements):** the presence of pedestrians at crossings and on the roadway; pedestrians walking across the prohibited areas of the road or street; driver's orientation on the road; road sections of poor visibility and small radius curves; road signs, horizontal road markings, traffic lights poorly visible or unknown to the driver; slippery sidewalk pavement and pedestrian path surface; poorly visible at-grade intersection; goods dropped from a vehicle on the road; a traffic participant falling down on the roadway, sidewalk or pedestrian path; the elements reducing visibility of the road; using a fixed curved mirror at poorly visible intersection; GPS use in the trip; driver's relaxation at the roadside rest stops; using KOSIS (*Kelių Oro Sąlygų Informacijos Sistema* in Lithuanian) data about the state of the road during the trip.

End of Table 1

Interaction No.	Interaction code	A name and detailed description of the interaction
6	II–2–3 (F)	**The interaction between a vehicle and a motor road (and its elements):** a collision of a vehicle with the road or supporting structures; road pavement damages increasing the dynamics of the vehicle; vibrations and impacts of the vehicle due to the rough, rutted road pavement; smooth, wet road pavement covered with snow or ice and reducing the coefficient of the road grip of a tyre; poor road lighting in the dark; driving on the road sections of small radius curves with or without banked turns; driving over a speed bump or plateau; falling elements of the tunnel; unsuitable tyres, their pressure, a worn-out tread (protector); exceeding the maximum allowable axis load in a vehicle; fuel, oil or cooling liquid leaking out from a vehicle; sound-proofing barriers of a vehicle; deformation of a bridge, viaduct or overpass by a moving vehicle; vehicle's collision with a guardrail or other elements of the road; using fixed or mobile speed indicators; the effectiveness of the work of winter road maintenance agencies; vehicle's re-fuelling at a roadside filing station; using studded tyres or tyres with snow chains; using fixed and axis load and speed indicators in a vehicle; work zones on the road; waiting for passing a border check and customs entry point.
7	III–1–E (G)	**The interaction between a traffic participant (freight) and the environment:** poor visibility on the road for drivers or pedestrians due to fog, rain, snow, tree branches and leaves covering the road elements; toxic gases spreading from dangerous goods carried by a vehicle over the surrounding area; an inappropriate, uncomfortable internal environment in a vehicle (too high or low temperature, poor air conditioning, smoke) negatively affecting a driver and passengers; pedestrian exposure to rain, snow and icicles falling on pedestrians from the roofs of the buildings; unsightly roadside view from the side windows of the vehicle; goods deteriorating due to high or low temperature or rain; traffic participants scattering rubbish around or leaving unattended camp-fires; using KOSIS data on the environment.
8	III–2–E (H)	**The interaction between a vehicle and the environment:** a collision of a vehicle with wild or domestic animals; low or high air temperature; a collision of a vehicle with a building or electrical installation; the amount of oxygen required for fuel, a lack of oxygen in the mountain air; fire in a vehicle; exhaust gases and smoke emitted into the air and increasing greenhouse effect; strong wind, hail, downpour and snow having the impact on a vehicle; noise pollution of the environment by a moving motor vehicle; automobile drag coefficient; strong gusts of the wind complicating its movement from the sides of a vehicle; the use of electric cars; a vehicle body covered with dirt making it poorly visible on the road; a strike of tanker drivers
9	III–3–E (I)	**The interaction between the motor road (or its elements) and the environment:** soil slips, mud flows and drifts on the road after a heavy rain or snow slip as well as rock fragments; earthquake, tsunami; moving along the flooded road section; dust rising into the air from dirt or gravel roads; live wires fallen on the road; karst cavities in the road area or springs near the road; floods caused by heavy rains or snow melting; a bridge over the river, valley, abyss or strait; a road through a settlement, wood or tunnel in the mountain; salt poured on the roadway and found in water, plants, etc.; engineering networks under the road surface; rough terrain predetermining vertical alignment of a road and plan (curve radii); trees, posts and leaves fallen on the road; wild and domestic animals, amphibians, etc., crossing the road and volcanic ashes fallen on the road; the road blocked by people; tall trees growing near the road; padlocks hung on the bridge parapet; the constructed road negatively affecting the vegetation and surroundings; the elements of the infrastructure of the traffic system damaged by people; road signs covered with snow and therefore poorly visible; geothermal heating or the road pavement.

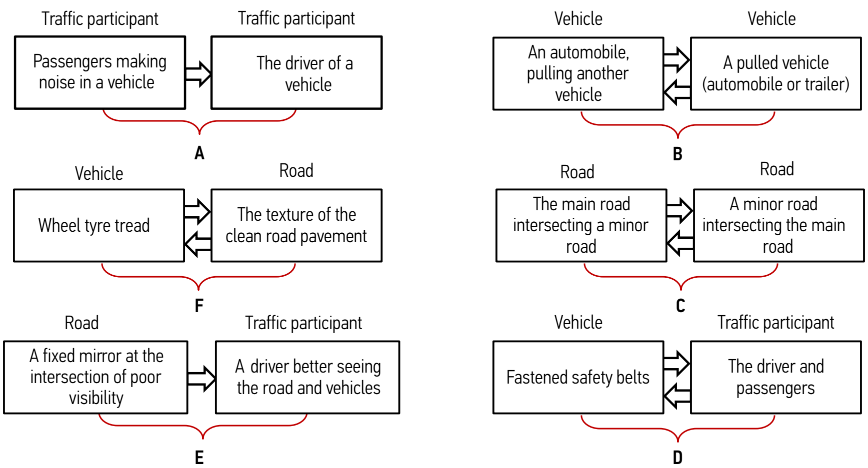

Fig. 1. The examples of a direct unilateral and bilateral interaction between the elements of the traffic system

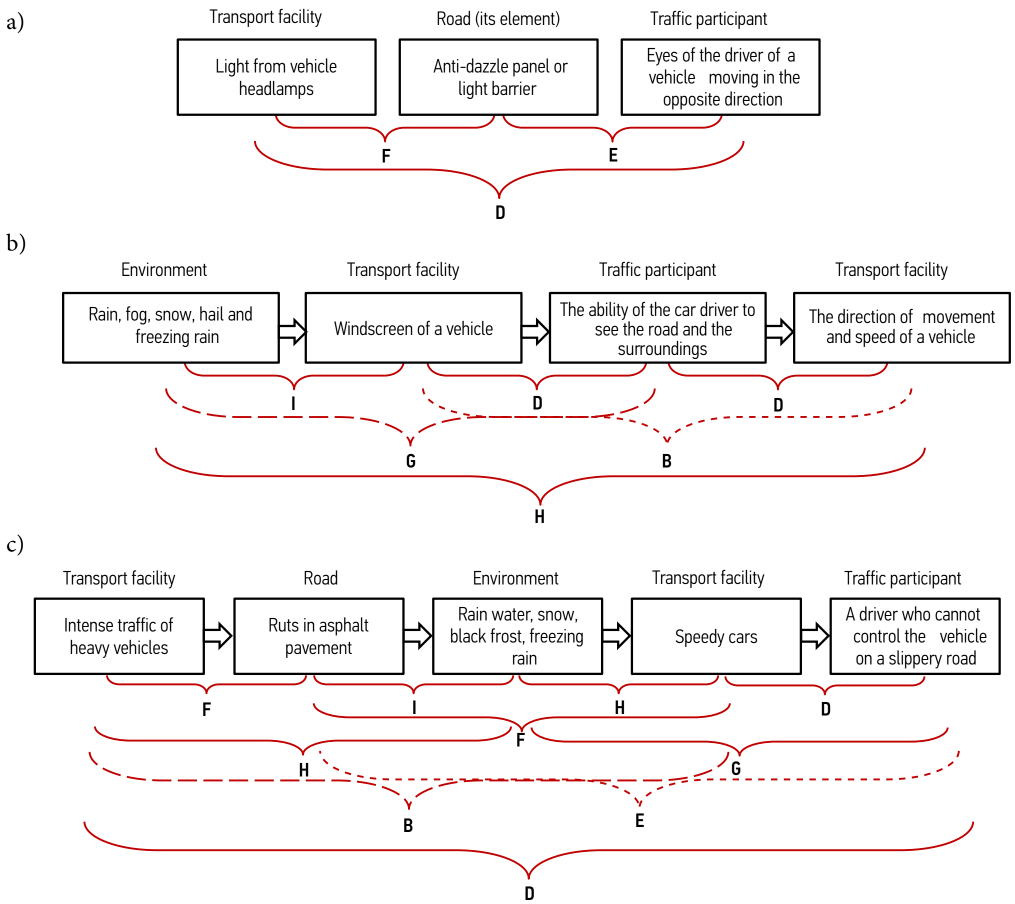

Fig. 2. The examples of the interaction between the elements of the TS and one (a), two (b) and three (c) intermediate elements

2. Logical Control of filling in the Questionnaire by Experts Using the AHP Method and the Consistency of their Estimates

To determine the significance of the criteria used, i.e. to calculate their weight, the method of pairwise comparison developed by T. Saaty – the Analytic Hierarchy Process (AHP) was applied (Saaty 1980). The method is based on the use of pairwise comparison matrix $\mathbf{P} = \left\| p_{ij} \right\|$ $(i, j = 1, 2, \ldots, m)$, where m is the number of compared criteria. The experts compare all criteria R_i and R_j with each other. The matrix elements represent the relationship between the unknown weights ω_i of criteria (interactions) only in the ideal case:

$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{pmatrix} = \begin{pmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_m} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2} & \cdots & \frac{\omega_2}{\omega_m} \\ \vdots & & \ddots & \vdots \\ \frac{\omega_m}{\omega_1} & \frac{\omega_m}{\omega_2} & \cdots & \frac{\omega_m}{\omega_m} \end{pmatrix}. \quad (1)$$

They show the significance of the considered criteria for the evaluated object. The matrix is inverse symmetrical, i.e. $p_{ij} = 1/p_{ji}$. The evaluation scale of 1–3–5–7–9 is employed in the AHP technique (Saaty 1980). The intermediate even numbers may also be used.

The weights in the Saaty's AHP method and vector $\boldsymbol{\omega}$ are normalized components of the eigenvector corresponding to the largest eigenvalue λ_{max} of matrix $\mathbf{P}$:

$$\mathbf{P} \cdot \boldsymbol{\omega} = \lambda_{max} \cdot \boldsymbol{\omega}. \quad (2)$$

The highest eigenvalue of matrix $\mathbf{P}$ and the eigenvector may be calculated using computer programs or one of the suggested algorithms (Saaty 1990; Podvezko 2009; Sivilevičius 2011a).

In using AHP technique, each expert fills in a pairwise comparison matrix-questionnaire. An example of such questionnaire filled in by one of the experts (the first one) is presented in Table 2. The experts performed the pairwise comparison of criteria A, B, C,..., I displayed in Table 1, taking into account their influence on traffic safety.

When filling in the questionnaire, each expert may determine visually if there are any apparent logical contradictions (errors) in the estimates made. In fact, in the ideal case (theoretically), the relationship between any two rows, the elements of the k-th row (ω_k / ω_1, ω_k / ω_2, ..., ω_k / ω_j, ..., ω_k / ω_m) and the elements of the i-th row ($\omega_i / \omega_1, \omega_i / \omega_2$, ..., ω_i / ω_j, ..., ω_i / ω_m) is constant and equal to ω_k / ω_i $(i, j, k = 1, 2, ..., m)$. This relationship is element $p_{ki} = \omega_k / \omega_i$ found at the intersection of the k-th row and in the i-th column of matrix $\mathbf{P}$. If the evaluation scale of 1–3–5–7–9 used by Saaty were replaced with a set of all rational numbers, it would be sufficient to fill in only one row or column of the matrix **P**. Then, with reference to the proportionality of the elements, the whole matrix could be filled (Podvezko 2009). However, even using the scale suggested by Saaty (1980, 1990), it is often possible to see, check or eliminate logical contradictions (errors) found in filling in the rows or columns of the matrix elements.

All the elements in the second row (B) of Table 2 should be, theoretically, three times as large as the respective 1st (A) row elements, whereas the 3-rd (C) row elements should be smaller than the respective 1-st (A) row elements (theoretically 7 times), which would imply that contradictions are absent. In our case, this situation (absence of contradictions) can be observed. There are no logical contradictions in other rows of the questionnaire filled in by this expert either.

However, the experts cannot completely avoid errors. For example, logical contradictions can be observed in the questionnaire filled in by the 6th expert (Table 3). The elements of the last 9-th (I) column should be larger than those of the 8-th (H) column (theoretically 3 times because the main element of the 8-th (H) row of the main diagonal $p_{88} = 1$, whereas the respective 9-th (I) column element $p_{89} = 3$). However, the elements of the last column in rows 1 (A), 2 (B), 4 (D), 5 (E) and 6 (F) are smaller than the elements of the respective 8th (H) column, though, formally, the estimates of this expert are also consistent (Table 4).

Following the rules given below can help an expert with filling in the questionnaire (matrix) of criterion comparison and reducing inconsistency (discordance degree):

1) First, the criteria are ranked according to their significance for the purpose of evaluation. The most significant criterion is assigned the highest rank equal to unity (one), the second most significant is given Rank 2, etc. while the least important criterion – rank m, where m – is the number of the criteria compared.
2) The criteria are written down in the evaluation table (matrix) in the order of their significance according to the ranks obtained.
3) All the elements in the 1st row will be smaller than 1, because the 1st criterion is the most important. All the elements of the matrix above the main diagonal will not be smaller than 1 because each criterion is more important than any criterion below.
4) The 2-nd, 3-rd and other criteria are compared with the remaining criteria. All the elements of the matrix above the main diagonal will not be smaller than 1 because each criterion is more important than those below it.
5) None of the elements in the 2-nd row can be larger than the largest element in the 1st row, because the 1st criterion is the most significant while the elements of the matrix (in an ideal

Table 2. Data on comparing the criteria elicited from expert 1

Criterion	A	B	C	D	E	F	G	H	I	Weights ω_i	Ranks e_{i1}
A	1	1/3	7	1/3	2	3	4	5	7	0.144	3
B	3	1	8	2	4	5	6	7	9	0.302	1
C	1/7	1/8	1	1/9	1/6	1/3	1/3	1/2	2	0.023	8
D	3	1/2	9	1	4	5	7	8	9	0.268	2
E	1/2	1/4	6	1/4	1	2	3	5	8	0.109	4
F	1/3	1/5	3	1/5	1/2	1	1	2	3	0.054	5
G	1/4	1/6	3	1/7	1/3	1	1	2	3	0.048	6
H	1/5	1/7	2	1/8	1/5	1/2	1/2	1	2	0.031	7
I	1/7	1/9	1/2	1/9	1/8	1/3	1/3	1/2	1	0.019	9

Table 3. Data on comparing the criteria elicited from expert 6

Criterion	A	B	C	D	E	F	G	H	I	Weights ω_i	Ranks e_i
A	1	3	9	1/3	7	7	3	5	3	0.211	2
B	1/3	1	9	1/3	7	7	3	5	3	0.165	3
C	1/9	1/9	1	1/9	1/3	1/3	1/7	1/5	1/5	0.015	9
D	3	3	9	1	9	7	5	7	5	0.325	1
E	1/7	1/7	3	1/9	1	1/3	1/7	1/3	1/5	0.021	8
F	1/7	1/7	3	1/7	3	1	1/5	1/3	1/5	0.029	7
G	1/3	1/3	7	1/5	7	5	1	3	3	0.107	4
H	1/5	1/5	5	1/7	3	3	1/3	1	3	0.063	6
I	1/3	1/3	5	1/5	5	5	1/3	1/3	1	0.064	5

Table 4. The values of consistency indices and ratios referring to data on criterion evaluation provided by all experts

Expert	Consistency index *C.I.*	Consistency ratio *C.R.*
E1	0.050	0.034
E2	0.127	0.088
E3	0.111	0.077
E4	0.134	0.092
E5	0.048	0.033
E6	0.133	0.091
E7	0.066	0.045
E8	0.124	0.086
E9	0.131	0.091
E10	0.135	0.093
E11	0.108	0.075
E12	0.051	0.035
E13	0.062	0.043
E14	0.136	0.094
E15	0.142	0.098
E16	0.119	0.082

case) represent the relationships between the unknown weights of the criteria. All 3-rd row elements cannot be larger than the largest element in the 2-nd row either, etc.

The most significant elements as well as the order of their significances may vary, because each expert refer to his/her personal experience, knowledge, views, etc. of assigning weights (significances) to the considered criteria and determine the relationships between the weights of criteria.

The concordance (consistency) degree of particular estimates of each expert is determined by consistency index *C.I.* and concordance ratio *C.R.* (Saaty 1990).

The consistency index is defined as the ratio (Saaty 1980) as follows:

$$C.I. = \frac{\lambda_{\max} - m}{m - 1}, \quad (3)$$

where: m is the matrix order and the number of the criteria compared.

In practice, the level of the consistency of matrix **P** may be determined if we compare calculated consistency index *C.I.* in the evaluation matrix with randomly generated (against the scale 1–3–5–7–9) index *R.I.* found in the same row of the inversely symmetric matrix (Saaty 1990). The ratio of consistency index *C.I.* calculated in a particular matrix to the mean value of random index *R.I.* is referred to as consistency ratio *C.R.* showing the degree of matrix consistency:

$$C.R. = \frac{C.I.}{R.I.}. \quad (4)$$

The matrix is consistent if consistency ratio *C.R.* is smaller than 0.1 (Saaty 1980). In Table 2, the consistency index of the comparison matrix of the 1st expert *C.I.* = 0.050 and consistency ratio *C.R.* = 0.034 < 0.1, whereas as regards the matrix of the 6-th expert (Table 3), consistency index *C.I.* = 0.133 and consistency ratio *C.R.* = 0.091 < 0.1. This means that the estimates of both experts are consistent.

The comparative analysis of the evaluation results obtained from two experts reveals that the weights (significances) of criteria, as well as their ranks, differ, though the estimates of each expert were consistent. To increase the reliability of the estimates of criterion weight, a group of 16 experts was made.

3. Estimates of Evaluating Groups and Their Consistency

To obtain the final weights of criteria, the questionnaires, including the estimates provided by the experts and containing no serious errors along with the calculated consistency ratio *C.R.* smaller than 0.1 were selected. The values of consistency indices and ratios found in the selected questionnaires of the experts are presented in Table 4.

By applying the AHP method, consistency index *C.I.*, consistency ratio *C.R.* and the weights of criteria ω_i of expert estimates are determined.

The reliability of the results is much higher making the evaluation of groups and founding the average aggregate weight. The consistency of results on the evaluation of groups can be found out using concordance coefficient W (Kendall, Gibbons 1990). The calculation of the coefficient is based on ranking criteria. The AHP method is used only for defining the consistency of the estimates provided by some particular experts. To specify the consistency of the evaluation results of the whole group of the experts, the algorithm offered by (Podvezko 2007) may be used. First, the weights of each criterion ω_i ($i = 1, 2, \ldots, m$) are calculated and, then, the ranks of these criteria are determined. The weights of criteria ω_{ki} calculated for all experts are presented in Table 5 (k is the number of experts; $k = 1, 2, \ldots, q$).

The results obtained in ranking criteria by 16 experts (transport engineering specialists) are displayed in Table 6.

Concordance coefficient W is calculated by the equation:

$$W = \frac{12 \cdot S}{q^2 \cdot m \cdot \left(m^2 - 1\right)}, \quad (5)$$

where: m is the number of criteria; q is the number of experts; S is the sum of the squares of deviations from the sum of ranks $e_i = \sum_{k=1}^{q} e_{ik}$ for the values of each criterion (Table 6, last but one column) from the total mean value $\bar{e} = \frac{\sum_{i=1}^{m} e_i}{m}$:

$$S = \sum_{i=1}^{m} \left(e_i - \bar{e}\right)^2.$$

Concordance coefficient $W = 0.651$ is calculated based on the data given in Table 6.

Table 5. Weights ω_{ki} calculated for evaluation criteria of all experts

Expert	Criterion								
	A	B	C	D	E	F	G	H	I
E1	0.144	0.302	0.023	0.268	0.109	0.054	0.048	0.031	0.019
E2	0.014	0.285	0.070	0.214	0.061	0.168	0.036	0.134	0.019
E3	0.104	0.326	0.154	0.224	0.047	0.076	0.031	0.022	0.016
E4	0.217	0.162	0.029	0.329	0.073	0.110	0.048	0.018	0.014
E5	0.268	0.134	0.062	0.268	0.030	0.132	0.030	0.062	0.017
E6	0.211	0.165	0.015	0.325	0.021	0.029	0.107	0.063	0.064
E7	0.263	0.122	0.055	0.308	0.130	0.058	0.019	0.027	0.018
E8	0.156	0.326	0.073	0.110	0.046	0.223	0.021	0.015	0.031
E9	0.121	0.074	0.040	0.229	0.030	0.182	0.016	0.217	0.021
E10	0.115	0.070	0.043	0.315	0.029	0.181	0.016	0.212	0.019
E11	0.213	0.105	0.161	0.329	0.050	0.072	0.022	0.032	0.016
E12	0.074	0.222	0.025	0.312	0.035	0.155	0.051	0.108	0.018
E13	0.266	0.131	0.061	0.266	0.034	0.131	0.034	0.059	0.017
E14	0.218	0.163	0.036	0.314	0.080	0.100	0.048	0.019	0.022
E15	0.315	0.212	0.181	0.115	0.069	0.043	0.029	0.019	0.016
E16	0.228	0.186	0.020	0.304	0.110	0.044	0.029	0.064	0.015
The average weight $\overline{\omega}_i$	0.183	0.187	0.066	0.264	0.060	0.110	0.037	0.069	0.021
Rank	3	2	6	1	7	4	8	5	9

Table 6. The ranks of criteria e_{ik} assigned by the experts

Criterion	Expert																Sum	Rank e_i
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16		
A	3	9	4	2	1.5	2	2	3	4	4	2	5	1.5	2	1	2	48	3
B	1	1	1	3	4	3	4	1	5	5	4	2	3.5	3	2	3	45.5	2
C	8	5	3	7	5.5	9	6	5	6	6	3	8	5	7	3	8	94.5	6
D	2	2	2	1	1.5	1	1	4	1	1	1	1	1.5	1	4	1	26	1
E	4	6	6	5	7.5	8	3	6	7	7	6	7	7.5	5	5	4	94	5
F	5	3	5	4	3	7	5	2	3	3	5	3	3.5	4	6	6	67.5	4
G	6	7	7	6	7.5	4	8	8	9	9	8	6	7.5	6	7	7	113	8
H	7	4	8	8	5.5	6	7	9	2	2	7	4	6	9	8	5	97.5	7
I	9	8	9	9	9	5	9	7	8	8	9	9	9	8	9	9	134	9

The significance of the concordance coefficient and the consistency of evaluating groups are described by criterion χ^2 (Kendall, Gibbons 1990):

$$\chi^2 = W \cdot q \cdot (m-1) = \frac{12 \cdot S}{q \cdot m \cdot (m+1)}. \qquad (6)$$

If χ^2 calculated by equation (6) is larger than critical $\chi^2_{\alpha,\nu}$ obtained from the table of χ^2 distribution with a degree of freedom $\nu = m - 1$ and significance level α chosen to be about zero, then, the estimates elicited from the experts are considered to be consistent.

In this particular case (when $S = 10004$; $q = 16$; $m = 9$ and $W = 0.651$), $\chi^2 = 83.37$ is calculated while critical value $\chi^2_{\alpha,\nu}$ obtained from the table of chi-square distribution with a degree of freedom $\nu = m - 1 = 8$ and significance level $\alpha = 0.05$ is equal to $\chi^2_{\alpha,\nu} = 15.51$. Hence, the estimates of the experts are consistent (83.37 >> 15.51).

4. Correlation Analysis of Expert Estimates

The degree of the consistency of the estimates provided by two experts is shown by the correlation coefficient. To determine the consistency of the estimates obtained from the group of experts, concordance coefficient W and the Kendall's theory of concordance (Kendall, Gibbons 1990) are used as described above. It seems to be useful to check the consistency of the estimates in the groups, which was determined by applying the concordance theory of mathematical statistics based on the correlation between all pairs of expert estimates. The values of coefficient correlation r calculated considering the pairs of the estimates provided by all experts are presented in Table 7.

The correlation coefficient $r_{1-k,e}$ of the ranks e_{i1} of the estimates indicated by the first expert and the ranks of the estimates provided by other 15 experts (k is the expert number and k = 1, 2, ..., 16) are calculated applying the equation:

$$r_{1-k,\,e} = \frac{m \cdot \sum_{i=1}^{m} e_{i1} \cdot e_{ik} - \sum_{i=1}^{m} e_{i1} \cdot \sum_{i=1}^{m} e_{ik}}{\sqrt{m \cdot \sum_{i=1}^{m} e_{i1}^2 - \left(\sum_{i=1}^{m} e_{i1}\right)^2} \cdot \sqrt{m \cdot \sum_{i=1}^{m} e_{ik}^2 - \left(\sum_{i=1}^{m} e_{ik}\right)^2}}, \quad (7)$$

where: e_{i1} is the rank assigned by the 1st expert to the i-th criterion; e_{ik} is the rank assigned by the k-th expert to the i-th criterion (Table 6); m is the number of criteria (i = 1, 2, ..., m).

Correlation coefficients $r_{1-k,\,\omega}$ (between weights) and $r_{\Sigma-k,\,\omega}$ showing the correlation between the average values of the calculated weights of all experts and the weights obtained by each expert (see data in Table 5) are calculated in the same way for the calculated criterion weights of the 1st expert and other experts. When making these calculations, e_{i1} and e_{ik} are replaced with criterion weights ω_{i1} and ω_{ik} in equation (7).

To validate a statistical hypothesis about the equality of correlation coefficient values to zero, the Student's t-test was taken and its statistic t was calculated as follows:

$$t = r \cdot \sqrt{\frac{m-2}{1-r^2}}, \quad (8)$$

where: m is the number of criteria; r is a pairwise correlation coefficient.

The hypothesis of the equality of correlation coefficient $r_{\Sigma-k}$ to zero is rejected because the value of Student's t-statistic t = 2.72, calculated by equation (8), corresponds to the lowest value of this coefficient $r_{\Sigma-k,\,\min} = 0.588$ which is higher than critical value $t_{\alpha,\,v} = 1.895$ with significance level $\alpha = 0.05$ and the degree of freedom $v = m - 2 = 7$. Therefore, the correlation coefficient of the compared estimates statistically differs from zero. Correlation coefficients both between ranks $r_{1-k,\,e}$ and weights $r_{1-k,\,\omega}$ have not always been significant (Table 7).

The values presented in the 2nd column (Table 7) refer to correlation coefficients between ranks $r_{1-k,\,e}$ and were obtained by comparing the ranks assigned by other 15 experts (k is the expert number, k = 1, 2, ..., q). The correlation between five (1-st, 4-th, 7-th, 14-th and 16-th) expert estimates (opinions) is sufficiently strong (correlation coefficient is more than 0.83). The correlation between the estimates assigned by 3 experts and the estimates provided by the 1st expert is weak because the values of $r_{1-k,\,e}$ are lower than 0.5. The relationship between the ranks does not reflect the dependence of the estimates well because evaluation, in terms of ranks, is discrete. The values of successive ranks differ in the value of one, though respective weights may match each other. The first expert was randomly chosen implying that any expert of the group could be selected.

The 3rd column (Table 7) displays the values of the coefficient showing the correlation between weights $r_{1-k,\,\omega}$ that are criterion weights calculated employing the AHP method by the 1-st expert and the respective estimates of other 15 experts. This evaluation more accurately reflects the interrelationship between the estimates provided by the experts. The obtained results reveal that the number of experts, the correlation coefficient of weights $r_{1-k,\,\omega}$ of which exceeds 0.8, has increased while the number of correlation coefficient values lower than 0.5 has decreased.

The most important and interesting evaluation results are given in the last (fourth) column of Table 7. They represent the values of correlation coefficient $r_{\Sigma-k,\,\omega}$ between the average weight $\overline{\omega}_i$ and criterion weights ω_{ik} given by individual experts. The consistency of the estimates indicated by the expert group is evident because the correlation coefficient $r_{1-k,\,\omega}$ of 10 experts from 16 exceeds 0.86 while none of expert estimates with the correlation coefficient lower than 0.58 can be found.

Table 7. The estimates of the values of correlation coefficients r provided by all pairs of experts

Experts	$r_{1-k,\,e}$ (between ranks)	$r_{1-k,\,\omega}$ (between weights)	$r_{\Sigma-k,\,\omega}$ (between average weight $\overline{\omega}_i$ and weights assigned by individual experts)
E1	1	1	0.867
E2	0.467	0.711	0.625
E3	0.636	0.857	0.755
E4	0.917	0.819	0.961
E5	0.675	0.655	0.926
E6	0.600	0.769	0.865
E7	0.833	0.726	0.878
E8	0.683	0.611	0.605
E9	0.417	0.269	0.594
E10	0.417	0.367	0.677
E11	0.633	0.609	0.858
E12	0.767	0.801	0.859
E13	0.701	0.655	0.924
E14	0.833	0.828	0.960
E15	0.683	0.510	0.588
E16	0.900	0.870	0.936

The relationship between the weights ω_{ik} of the interaction (criteria) of TS elements assigned by individual experts (E1, E4 and E15) and average weights $\overline{\omega}_i$ assigned to these criteria by all experts are shown graphically in Fig. 3.

The lowest value of pairwise correlation coefficient $r_{\min}$ may be calculated by rearranging equation (8) as follows:

$$r_{\min} = \frac{t_{\alpha,\,v}}{\sqrt{m-2+t_{\alpha,\,v}^2}}. \quad (9)$$

Given significant level α = 0.05 and t-statistic $t_{\alpha,\,v}$ = 1.895 (when the interaction of 9 TS elements are compared), the lowest value of the correlation coefficient allowing us to consider that the variables correlate is equal to 0.582.

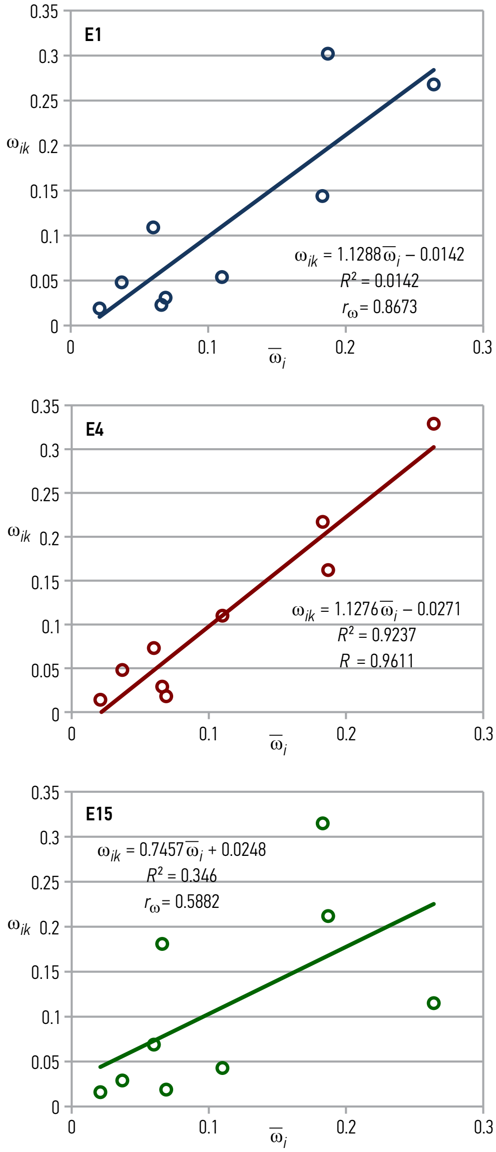

Fig. 3. The relationship between weights ω_{ik} assigned to the relationships of 9 TS elements (criteria) by individual experts (E1, E4, E15) and the average weight of criteria $\bar{\omega}_i$ for all experts

The suggested methodology determining the significance (weight) of criteria (interaction between the TS elements) may be applied to the comparative analysis of traffic safety on motor roads in regions, cities and their districts in various countries. To assess the level of traffic safety, MCDM methods (Podvezko 2011; Zavadskas *et al.* 2012; Ginevičius *et al.* 2012, Bureika 2012) may be successfully used.

Conclusions

1. The variation of traffic accident rate depends on various technical parameters and performance of vehicles, different properties and characteristics of road elements and pavement, the behaviour of traffic participants, types of freight, climate and weather conditions, traffic flows and other factors. Accidents take place during the interaction between moving vehicles, traffic participants, goods, roads and other surrounding elements. The parameters of the material elements of the Transport System (TS) in particular roads differ. They also do not manifest themselves at the same time and are of different importance for traffic. The impact of the interaction of the TS elements on traffic accident rate has been determined by the method referred to as the Analytic Hierarchy Process (AHP) that allowed the authors to calculate the weights of 9 combinations of the interaction between the elements based on expert estimates.
2. A detailed description of the impact of the interaction of the TS elements considered at various levels on the accident rate shows that various factors interact at a particular level or between the levels. The interaction may be direct and include one, two or three intermediate elements. It is difficult, expensive or sometimes even hardly possible to determine the impact of a TS element or its parameters on the accident rate by carrying out a planned experiment. It is not always possible to reliably identify the causes of accidents or factors leading to them and their impact on the accident rate based on statistical (historical) data. The present paper looks at the weight (significance) of the interaction of the TS elements with respect to the accident rate on the road applying the AHP technique based on the knowledge, competence, experience and intuition of transport experts. It has been found that the weights assigned by various experts to the same interaction of the TS elements differ. The estimates presented in 16 questionnaires filled in by the experts are consistent because the calculated consistency ratio *C.R.* is lower than 0.1 (ranging from 0.033 to 0.098) in all pairwise comparison matrices.
3. The consistency of the estimates of all 16 experts determined applying the Kendall's rank correlation method has shown that the opinions of the experts about the impact of the interaction of the TS elements on the accident rate on the road are similar. Concordance coefficient $W = 0.651$, when calculated χ^2 value is equal to 83.37, is considerably higher than critical $\chi^2_{\alpha,\nu}$ value of 15.51, which was determined at significance level $\alpha = 0.05$ and the degree of freedom $\nu = m - 1 = 8$. The interaction (D) between traffic participants (freight) and a vehicle, with the average weight coefficient $\omega_D = 0.264$, is the most significant. The second most significant interaction is between vehicles (interaction B) having $\omega_B = 0.187$. The third most significant interaction is between traffic participants (fright) (interaction A) with the average weight coefficient $\omega_A = 0.183$. Other types of the interaction between the TS elements are of minor importance. According to the experts, the interaction between the motor road (and its elements) and the environment (interaction 1), with the average weight coefficient $\omega_I = 0.021$, has the lowest effect on the accident rate on the road. The priority order of nine types of the interaction between the TS elements was established in the following way: $D \succ B \succ A \succ F \succ E \succ C \succ H \succ G \succ I$.

4. A new method for determining the consistency of expert estimates based on correlation analysis has been offered. The calculation of the correlation coefficients of criterion estimates made by all experts allowed the authors to establish the positive correlation between the ranks assigned to the criteria interaction between the TS elements and the ranks given to them by other 15 experts ($r_{1-k,e}$ ranges from 0.417 to 0.917), between the weights assigned to the criteria by the 1-st expert and other experts ($r_{1-k,\omega}$ ranges from 0.269 to 0.870) as well as between the average weight assigned by the experts to the criteria and weights given to the criteria by each expert ($r_{\Sigma-k,\omega}$ ranges from 0.588 to 0.961). To validate a statistical hypothesis about the equality of the values of the pairwise correlation coefficient to zero, the Student's t-test has been used. The lowest value of the correlation coefficient (r_{min} = 0.582) has been established, which should be exceeded for the variables (ranks or weights) to be considered correlated. It has been found that the estimates provided by the group of experts are undoubtedly consistent (based on the value of $r_{\Sigma-k,\omega}$), because the correlation coefficient of the estimates provided by 10 experts from 16 taking part in research is higher than 0.86 while none of expert estimates has the correlation coefficient lower than 0.582.
5. The developed methodology may be used for a comparative analysis of traffic safety on motor roads in various countries, regions, cities and their districts. MCDM methods are effective for solving evaluation problems similar to those described in this paper.

References

Aghdaie, M. H.; Hashemkhani Zolfani, S.; Zavadskas, E. K. 2012. Prioritizing constructing projects of municipalities based on AHP and COPRAS-G: a case study about footbridges in Iran, *The Baltic Journal of Road and Bridge Engineering* 7(2): 145–153. http://dx.doi.org/10.3846/bjrbe.2012.20

Balčiauskas, L.; Jasiulionis, M. 2012. Reducing the incidence of mammals on public highways using chemical repellent, *The Baltic Journal of Road and Bridge Engineering* 7(2): 92–97. http://dx.doi.org/10.3846/bjrbe.2012.13

Bartczak, B.; Gierczycka-Zbrožek, D.; Gronostajski, Z.; Polak, S.; Tobota, A. 2010. The use of thin-walled sections for energy absorbing components: a review, *Archives of Civil and Mechanical Engineering* 10(4): 5–19. http://dx.doi.org/10.1016/S1644-9665(12)60027-2

Bitarafan, M.; Hashemkhani Zolfani, S.; Arefi, S. L.; Zavadskas, E. K. 2012. Evaluating the construction methods of cold-formed steel structures in reconstructing the areas damaged in natural crises, using the methods AHP and COPRAS-G, *Archives of Civil and Mechanical Engineering* 12(3): 360–367. http://dx.doi.org/10.1016/j.acme.2012.06.015

Bureika, G. 2012. Study of traction rolling-stock using in Lithuanian sector of railway line "Rail Baltica", *Transport Problems – Problemy Transportu* 7(4): 49–56.

Chang, C.-W.; Wu, C.-R.; Chen, C.-C. 2010. Determining the performance of collaborative design systems based on AHP sensitivity analysis, *Journal of Testing and Evaluation* 38(6): 759–766. http://dx.doi.org/10.1520/JTE102608

Chatterjee, P.; Athawale, V. M.; Chakraborty, S. 2011. Materials selection using complex proportional assessment and evaluation of mixed data methods, *Materials & Design* 32(2): 851–860. http://dx.doi.org/10.1016/j.matdes.2010.07.010

Chatterjee, P.; Chakraborty, S. 2012. Material selection using preferential ranking methods, *Materials & Design* 35: 384–393. http://dx.doi.org/10.1016/j.matdes.2011.09.027

Cheng, G.; Wilmot, C. G. 2009. Louisiana highway construction cost trend after hurricanes Katrina and Rita, *Journal of Construction Engineering and Management* 135(7): 594–600. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000015

Cheng, M.-Y.; Su, C.-W.; Tsai, M.-H.; Lin, K.-S. 2012. Data preprocessing for artificial neural network applications in prioritizing railroad projects – a practical experience in Taiwan, *Journal of Civil Engineering and Management* 18(4): 483–494. http://dx.doi.org/10.3846/13923730.2012.699914

European Commission. 2001. *White Paper: European Transport Policy for 2010: Time to Decide*. 119 p. Available from Internet: http://ec.europa.eu/transport/themes/strategies/doc/2001_white_paper/lb_texte_complet_en.pdf

Farhan, J.; Fwa, T. F. 2009. Pavement maintenance prioritization using analytic hierarchy process, *Transportation Research Record* 2093: 12–24. http://dx.doi.org/10.3141/2093-02

Fouladgar, M. M.; Yazdani-Chamzini, A.; Lashgari, A.; Zavadskas, E. K.; Turskis, Z. 2012a. Maintenance strategy selection using AHP and COPRAS under fuzzy environment, *International Journal of Strategic Property Management* 16(1): 85–104. http://dx.doi.org/10.3846/1648715X.2012.666657

Fouladgar, M. M.; Yazdani-Chamzini, A.; Zavadskas, E. K.; Yakhchali, S. H.; Ghasempourabadi, M. H. 2012b. Project portfolio selection using fuzzy AHP and VIKOR techniques, *Transformations in Business & Economics* 11(1): 213–231.

Fouladgar, M. M.; Yazdani-Chamzini, A.; Zavadskas, E. K. 2012c. Risk evaluation of tunneling projects, *Archives of Civil and Mechanical Engineering* 12(1): 1–12. http://dx.doi.org/10.1016/j.acme.2012.03.008

Ginevičius, R. 2011. A new determining method for the criteria weights in multicriteria evaluation, *International Journal of Information Technology & Decision Making* 10(6): 1067–1096. http://dx.doi.org/10.1142/S0219622011004713

Ginevičius, R.; Podvezko, V.; Novotny, M.; Komka, A. 2012. Comprehensive quantitative evaluation of the strategic potential of an enterprise, *Economic Computation and Economic Cybernetics Studies and Research* 46(1): 65–84.

Hashemkhani Zolfani, S.; Chen, I.-S.; Rezaeiniya, N.; Tamošaitienė, J. 2012a. A hybrid MCDM model encompassing AHP and COPRAS-G methods for selecting company supplier in Iran, *Technological and Economic Development of Economy* 18(3): 529–543. http://dx.doi.org/10.3846/20294913.2012.709472

Hashemkhani Zolfani, S.; Rezaeiniya, N.; Aghdaie, M. H.; Zavadskas, E. K. 2012b. Quality control manager selection based on AHP- COPRAS-G methods: a case in Iran, *Ekonomska Istraživanja – Economic Research* 25(1): 88–104.

Jahan, A.; Bahraminasab, M.; Edwards, K. L. 2012. A target-based normalization technique for materials selection, *Materials & Design* 35: 647–654. http://dx.doi.org/10.1016/j.matdes.2011.09.005

Kendall, M.; Gibbons, J. D. 1990. *Rank Correlation Methods*. 5th edition, Oxford University Press. 272 p.

Kopczyński, A.; Ptak, M.; Harnatkiewic, P. 2011. The influence of frontal protection system design on pedestrian passive safety, *Archives of Civil and Mechanical Engineering* 11(2): 345–364. http://dx.doi.org/10.1016/S1644-9665(12)60148-4

Lao, Y.; Wu, Y.-J.; Wang, Y.; McAllister, K. 2012. Fuzzy logic–based mapping algorithm for improving animal-vehicle collision data, *Journal of Transportation Engineering* 138(5): 520–526. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000351

Lashgari, A.; Fouladgar, M. M.; Yazdani-Chamzini, A.; Skibniewski, M. J. 2011. Using an integrated model for shaft sinking method selection, *Journal of Civil Engineering and Management* 17(4): 569–580. http://dx.doi.org/10.3846/13923730.2011.628687

Lin, L.-K.; Chang, C.-C.; Lin, Y.-C. 2011. Structure development and performance evaluation of construction knowledge management system, *Journal of Civil Engineering and Management* 17(2): 184–196. http://dx.doi.org/10.3846/13923730.2011.576833

Liou, J. J. H.; Tzeng, G.-H. 2012. Comments on "Multiple criteria decision making (MCDM) methods in economics: an overview", *Technological and Economic Development of Economy* 18(4): 672–695. http://dx.doi.org/10.3846/20294913.2012.753489

Maniya, K.; Bhatt, M. G. 2010. A selection of material using a novel type decision-making method: preference selection index method, *Materials & Design* 31(4): 1785–1789. http://dx.doi.org/10.1016/j.matdes.2009.11.020

Maskeliūnaitė, L.; Sivilevičius, H. 2012. Expert evaluation of criteria describing the quality of travelling by international passenger train: technological, economic and safety perspectives, *Technological and Economic Development of Economy* 18(3): 544–566. http://dx.doi.org/10.3846/20294913.2012.710178

Moazami, D.; Behbahani, H.; Muniandy, R. 2011. Pavement rehabilitation and maintenance prioritization of urban roads using fuzzy logic, *Expert Systems with Applications* 38(10): 12869–12879. http://dx.doi.org/10.1016/j.eswa.2011.04.079

Pei, X.; Wong, S. C.; Li, Y. C.; Sze, N. N. 2012. Full Bayesian method for the development of speed models: applications of GPS probe data, *Journal of Transportation Engineering* 138(10): 1188–1195. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000428

Perati, M. R.; Raghavendra, K.; Koppula, H. K. R.; Doodipala, M. R.; Dasari, R. 2012. Self-Similar behavior of highway road traffic and performance analysis at toll plazas, *Journal of Transportation Engineering* 138(10): 1233–1238. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000427

Podvezko, V. 2011. The comparative analysis of MCDA methods SAW and COPRAS, *Inzinerine ekonomika – Engineering Economics* 22(2): 134–146. http://dx.doi.org/10.5755/j01.ee.22.2.310

Podvezko, V. 2009. Application of AHP technique, *Journal of Business Economics and Management* 10(2): 181–189. http://dx.doi.org/10.3846/1611-1699.2009.10.181-189

Podvezko, V. 2007. Determining the level of agreement of expert estimates, *International Journal of Management and Decision Making* 8(5/6): 586–600. http://dx.doi.org/10.1504/IJMDM.2007.013420

Podvezko, V.; Podviezko, A. 2010. Dependence of multi-criteria evaluation result on choice of preference functions and their parameters, *Technological and Economic Development of Economy* 16(1): 143–158. http://dx.doi.org/10.3846/tede.2010.09

Podvezko, V.; Mitkus, S.; Trinkūnienė, E. 2010. Complex evaluation of contracts for construction, *Journal of Civil Engineering and Management* 16(2): 287–297. http://dx.doi.org/10.3846/jcem.2010.33

Prentkovskis, O.; Tretjakovas, J.; Švedas, A.; Bieliatynskyi, A.; Daniūnas, A.; Krayushkina, K. 2012. The analysis of the deformation state of the double-wave guardrail mounted on bridges and viaducts of the motor roads in Lithuania and Ukraine, *Journal of Civil Engineering and Management* 18(5): 761–771. http://dx.doi.org/10.3846/13923730.2012.731252

Ptak, M.; Rusiński, E.; Karliński, J.; Dragan, S. 2012. Evaluation of kinematics of SUV to pedestrian impact – lower leg impactor and dummy approach, *Archives of Civil and Mechanical Engineering* 12(1): 68–73. http://dx.doi.org/10.1016/j.acme.2012.03.016

Saaty, T. L. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill (Tx). 287 p.

Saaty, T. L. 1990. How to make a decision: the analytic hierarchy process, *European Journal of Operational Research* 48(1): 9–26. http://dx.doi.org/10.1016/0377-2217(90)90057-I

San Cristóbal, J. R. 2012. Contractor selection using multicriteria decision-making methods, *Journal of Construction Engineering and Management* 138(6): 751–758. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000488

Sivilevičius, H. 2011a. Modelling the interaction of transport system elements, *Transport* 26(1): 20–34. http://dx.doi.org/10.3846/16484142.2011.560366

Sivilevičius, H. 2011b. application of expert evaluation method to determine the importance of operating asphalt mixing plant quality criteria and rank correlation, *The Baltic Journal of Road and Bridge Engineering* 6(1): 48–58. http://dx.doi.org/10.3846/bjrbe.2011.07

Sivilevičius, H.; Maskeliūnaitė, L.; Petkevičienė, B.; Petkevičius, K. 2012. The model of evaluating the criteria, describing the quality of organization and technology of travel by international train, *Transport* 27(3): 307–319. http://dx.doi.org/10.3846/16484142.2012.724448

Sun, L.; Gu, W. 2011. Pavement condition assessment using fuzzy logic theory and analytic hierarchy process, *Journal of Transportation Engineering* 137(9): 648–655. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000239

Turskis, Z.; Lazauskas, M.; Zavadskas, E. K. 2012. Fuzzy multiple criteria assessment of construction site alternatives for non-hazardous waste incineration plant in Vilnius City, applying ARAS-F and AHP methods, *Journal of Environmental Engineering and Landscape Management* 20(2): 110–120. http://dx.doi.org/10.3846/16486897.2011.645827

Vaidogas, E. R.; Juocevičius, V. 2011. A critical estimation of data on extreme winds in Lithuania, *Journal of Environmental Engineering and Landscape Management* 19(2): 178–188. http://dx.doi.org/10.3846/16486897.2011.579452

Vaidogas, E. R.; Linkutė, L. 2012. Sitting the barrier aimed at protecting roadside property from accidental fires and explosions on road: a pre-optimisation stage, *The Baltic Journal of Road and Bridge Engineering* 7(4): 277–287. http://dx.doi.org/10.3846/bjrbe.2012.37

Vidal, L.-A.; Marle, F.; Bocquet, J.-C. 2011. Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects, *Expert Systems with Applications* 38(5): 5388–5405. http://dx.doi.org/10.1016/j.eswa.2010.10.016

Wang, Y.-G.; Bai, H.; Xiang, W.-S. 2011. Traffic safety performance assessment and multivariate treatments for intersection locations, *The Baltic Journal of Road and Bridge Engineering* 6(1): 30–38.
http://dx.doi.org/10.3846/bjrbe.2011.05

Wu, W.; Gan, A.; Cevallos, F.; Hadi, M. 2011. multiobjective optimization model for prioritizing transit stops for ADA improvements, *Journal of Transportation Engineering* 137(8): 580–588.
http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000244

Wu, Z.; Flintsch, G. W.; Chowdhury, T. 2008. Hybrid multiobjective optimization model for regional pavement-preservation resource allocation, *Transportation Research Record* 2084: 28–37. http://dx.doi.org/10.3141/2084-04

Yu, J.; Liu, Y.; Chang, G.-L.; Ma, W.; Yang, X. 2011. Locating urban transit hubs: multicriteria model and case study in China, *Journal of Transportation Engineering* 137(12): 944–952.
http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000275

Zavadskas, E. K.; Sušinskas, S.; Daniūnas, A.; Turskis, Z.; Sivilevičius, H. 2012. Multiple criteria selection of pile-column construction technology, *Journal of Civil Engineering and Management* 18(6): 834–842.
http://dx.doi.org/10.3846/13923730.2012.744537