TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2011 Volume 26(1): 20–34
doi: 10.3846/16484142.2011.560366

MODELLING THE INTERACTION OF TRANSPORT SYSTEM ELEMENTS

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Received 12 July 2010; accepted 10 January 2011

Abstract. Economy and nonproductive sectors of each country could not function without a transport system (TS). Having analysed research works on the interaction of separate TS elements, it was identified that there is no common model for all types of interaction. TS consists of material (physical) objects: traffic participants and freight to be carried, a transportation process and operations' control. TS classification scheme devised according to systematically selected criteria, showing that several criteria are often applied at the same time in official documents, is presented. Original TS physical elements' interaction model with 6 interaction levels is presented as well. The model is suitable for all modes of transport. Six levels of interaction are distinguished: autointeraction of transport elements, the first level; TS elements' interaction, the second level; TS elements' interaction with external environment, the third level; interaction of transport modes, the fourth level; TS interaction with the country's economy and nonproductive sectors, the fifth level; and TS impact on the country's GAV (Gross Added Value), the sixth level. Properties and factors influencing on the results and parameters of interaction have been systematized. Levels and properties of interaction have been analyzed as well. To evaluate the importance of interaction levels to the parameters of the transportation process, the method of Analytic Hierarchy Process (AHP) has been recommended.

Keywords: transport, elements, interaction, model, system, external environment, AHP method.

1. Introduction

Freedom of movement has been one of the greatest values of humanity, which can be used if a developed transport system (TS) of the country is available. The transport sector was and still remains one of the most important economic driving forces in the country, Lithuania not being an exception as well. (Mačiulis *et al*. 2009). Analysts agree that transport will continue to have a positive impact on the economic growth. The growth of the transport sector, especially road transport, increases congestion and environmental pollution as well as reduces safety. Acts of terror occur in the air and railway transport. Cars are also used for this purpose.

Passenger and freight carriage is a dynamic process since its parameters frequently change in the course of time. The paramers of the carriage process are stochastic; however, their change is usually influenced by concrete conditions, the impact of which may be simulated and forecasted. Dependable forecast requires necessary data. Data are obtained through the simulation of interaction processes, their observation, measuring or reproducing the dynamics of interaction after traffic accidents and catastrophes from devices automatically recording their sequence, i.e. black boxes. It enables to find out the reasons of catastrophes and to reduce their risk.

Separate elements of the system interact in the transportation process. The interaction results (consequences) may be positive and negative as side-effects always occur in the transportation process. The interaction of separate transport modes' elements has been studied by researchers from various countries of the world as well as from Lithuania. Road transport functions in all countries; therefore the interaction of its elements has been studied most thoroughly. Railway transport takes the second place according to the amount of carried freight and passengers. Here we survey some research works where recent findings have been published.

The greatest problems posed by TS are insufficient traffic safety as well as physical and chemical pollution of the environment. To improve traffic safety on the roads, the road or its separate sections' reconstruction or upgrading measures are taken; traffic control, accounting and management measures are improved; vehicles are upgraded; road users are disciplined.

The results of macroeconomic simulation showed that each Litas invested into the Lithuanian transport infrastructure generates approximately a double benefit in 4–5 years.

In most countries, roundabouts have become more and more popular, and it is often considered to be the main type of intersections in urban areas (Antov *et al.* 2009). Accident rates are very low, and traffic conditions and speed reduction possibilities are excellent on them. A driver's behaviour directly depends on the driver's understanding of the road infrastructure, road environment and the conditions inside the vehicle (Pellegrino 2009).

Steel structures covered with ground are usually used in the construction of culverts on local roads or even motorways as well as railway viaducts, and, currently, in the construction of ecological objects or tunnels (the animal crossing situated under and above a highway) (Beben 2008). Prospects of transport road metal structures' elements and their system design are related with probality calculation elements (Jankovski and Atkočiūnas 2008). Animal passages and net fencing on the roadside enable to avoid collision between animals and vehicles.

To simulate the interaction between the vehicle's wheels and road pavement, studies by Luo, Prozzi (2007); Soon *et al.* (2004); Perera, Kohn (2004); Douglas *et al.* (2003); Capuruço *et al.* (2005); Pečeliūnas, Prentkovskis (2006); Prentkovskis *et al.* (2010a) and Park *et al.* (2008) have been conducted.

Frequently, a vehicle's tire interacts with the road surface through an intermediate element. When a layer of water builds between the road surface and the rubber tires of the vehicle, the risk of aquaplaning occurs (Fwa *et al.* 2008, 2009; Ong *et al.* 2005; Beljatynskij *et al.* 2010).

Rubber deposits change the parameters of the wheel's interaction with the road surface (Chen *et al.* 2008). In winter, snow falls on the road surface, which worsens driving conditions (Chen *et al.* 2009; Matsuzawa *et al.* 2009). At present, to protect the road from climatic factors or to clean the road from the accumulated ice layer in an extremely short time, wet salt technology is applied (Žilionienė, Laurinavičius 2007). In winter technical salt is sprayed, which reduces road pavement slipperisness and directly or indirectly pollutes the environment (Baltrėnas, Kazlauskienė 2009). Studded tires used in winter not only intensively deteriorate road pavement but also pollute the air as well (Vaiškūnaitė *et al.* 2009; Laurinavičius *et al.* 2010). Baltrėnas *et al.* (2008a) presents the technique of mathematical simulation of solid particles dispersion in the air. Traffic is the main air pollution source in most cities (Orru *et al.* 2008). To investigate dispersion properties caused by transport pollutants on the motorways (Brannvall, Martinėnas 2007), mathematical distribution based on the physical model is used.

Motor transport has the greatest share in the emission of mobile pollutant sources (Baltrėnas *et al.* 2008b; Lewis *et al.* 2009). It has been set that of CO, NO_x, CH_x, SO_2 directly depend on motor transport's intensity.

The noise level generated on urban roads can be excessive and has a negatyve impact on the urban environment (Krezel and McManus 2010). Due to the engine work and air resistance in the interaction between the wheel and the road surface, noise is generated (Pierce *et al.* 2009; Crocker *et al.* 2004). Noise level may be measured by a natural experiment or a computer simulation (Shukla *et al.* 2009). The authors study possibilities of FHWA model application to prognose the noise level caused by transport and to evaluate it in India. Equivalent noise level spread from streets to the residential territory during the day and night time is modelled in work Vaišis and Januševičius (2009). Sources of noise are evaluated Baltrėnas and Puzinas (2009). Reasons of a higher noise level than that presented in the higienic norms and possible causes of its occurance in the teritory of the enterprise and in the neighbouring residential zone. Research (Leipus *et al.* 2010) of noise level dependence on car speed was performed from 50 km/h to 70 km/h. It was determined during the study that noise level produced by a car moving at a speed of 50 km/h on a road with gravel pavement is higher by 4 dBA than that on a road with asphalt pavement.

Road pavement surface macrotexture impacts on the wheel's tire friction coefficient (Flintsch *et al.* 2009; Jackson *et al.* 2009; El Gendy, Shalaby 2008, Nakatsuji *et al.* 2007; Prowell, Hanson 2005; Li *et al.* 2005).

Road surface roughness and rutting impact on the dynamics of the running vehicle, which influences on traffic safety. The development of road surface defects and their impact on the vehicles may be simulated (Gallivan *et al.* 2004; Coleri *et al.* 2008; Vansauskas, Bogdevičius 2009; Priya *et al.* 2008; Salama *et al.* 2007; Xia 2010). Residual deformations leaving ruts is one of the most frequent defects worsening the road pavement exploitation properties (Radziszewski 2007; Suo, Wong 2009; Kim *et al.* 2009; Haryanto, Takahashi 2007). Heavy, frequently recurrent loads of heavy vehicles' axles have the greatest impact on the road pavement layers' deterioration and deformation (Dawson 2008; Tran, Hall 2007; Papagiannakis *et al.* 2007; Bagamppade, Kiggundu 2007; Wang *et al.* 2009). Machemehl *et al.* (2005) measured the truck tire pressure on the road pavement according to the tire-pavement contact stress data. Based on the theory of the object's collision with the hole's angle obstacle (Viba *et al.* 2009), a vehicle's movement when colliding with the hole's angle obstacle has been investigated. The findings of the study can be used in accident experiments when investigating the interaction between the vehicle and one or several obstacles.

Heavy vehicles cause vibrations in bridge structures (Lee *et al.* 2009). Bridges should be seismically isolated (Han *et al.* 2009). The residual dependability index of road bridge supportive structures overloaded with contingent variable vehicles (Kudzys 2009) has been proposed.

To improve the parameters of the traffic process on the roads, traffic control and management devices as well as road weather information systems are used (Finley *et al.* 2006; Nagata *et al.* 2008). They usually improve drivers' behaviour on the roads (Billot *et al.* 2009). Five main traffic management groups are pointed out (Lundkvist, Isacsson 2008): road lighting, fencing, guardrailing, vertical and horizontal marking as well as traffic lights. When installed on the road, they shall preserve their exploitation properties.

The study (Tampère *et al.* 2009) on evaluating the effect of road charging on social wellness showed that traffic between Brussels and Gent cities has decreased due to the increased travel prices when tolls were introduced on the roads.

Road pavement surface is constantly influenced by environmental factors (temperature, sun radiation, precipitation water, air oxygen, wind), which change its temperature and asphalt properties (Gui *et al.* 2007). Average daily traffic on the road constantly increases, and on separate sections it varies a lot (Sivilevičius, Šukevičius 2007). Hence, equivalent single-axle load (ESAL) having different deteriorating impact on asphalt pavement varies as well. Erosions caused by transport traffic, the wind and water cause rutting on aggregate road shoulders, break pavement edges, and cross-fall does not meet the needs (Vorobjovas, Žilionienė 2008). After hurricanes Katrina and Rita, the highway contruction cost jumped about 20% statewide and 51% GO Zone (Cheng, Wilmot 2009).

To construct, strengthen and reconstruct a new road pavement, each year more and more hot-mix asphalt (HMA) mixture is produced through the application of more upgraded technologies and equipment (Sivilevičius, Šukevičius 2009). Permitted deviations of components' quantity in HMA mixture are reduced, which enables to pave a maximum duration asphalt concrete layer (Petkevičius, Sivilevičius 2008; Bražiūnas, Sivilevičius 2010).

The homogeneity of the HMA mixture in the road pavement depends on the stochastic technological factors in its production in an asphalt mixing plant, the impact of which is taken into account in HMA mixture grading design model (Sivilevičius, Vislavičius 2008; Sivilevičius *et al.* 2011). During the asphalt pavement life cycle, the impact of vehicles' axle loads, environmental factors, exploitation and defect repair materials accumulate in reclaimed asphalt pavement –RAP) inhomogeneity (Mučinis *et al.* 2009).

To simulate and investigate the intercation between vehicles and guardrails and curb, the studies by Macek, Měšťanová (2009); Sokolovskij *et al.* (2007); Prentkovskis *et al.* (2007, 2009, 2010b) were conducted. According to them, the most important evaluation criteria of guardrails are their safety, economic and ecological aspects. The deformation of road guardrails' metal beam and post when hit by a vehicle has been investigated. To carry out a computer experiment, the mathematical model of the road guardrail has been constructed. Vaidogas (2007) proposed a protective transport structures' design method based on the risk analysis. It is considered that accidents damaging road infrastructure elements is a natural risk analysis object.

Meta-analysis results indicate that the crash rate usually increases during precipitation (Qiu, Nixon 2008). Snow has a greater effect than rain does on crash occurrence: snow can increase the crash rate by 84% and the injury rate by 75%.

It has been identified that (Sathyanarayanan *et al.* 2008; Gibbons, Hankey 2007; Choubane *et al.* 2006) the parameters of horizontal marking and pavement reflection have impact on traffic safety on the roads.

Multi-purpose road variant designing optimization methodology was developed and applied (Brauers *et al.* 2008).

A priority list of the Vilnius city development scenarios, taking the indicators of the city's transport system into account, was identified according to the multi-criteria method (Jakimavičius, Burinskienė 2009). Čygas *et al.* (2009) state that traffic safety measures implemented in Lithuania influence on all elements of the traffic safety system *road user–road–vehicle*. The article (Kapski *et al.* 2007) describes an attempt to apply the theory of catastrophes to the traffic situation development process in a conflict situation, which ends with an accident.

To investigate the interaction of railway transport elements, several models have been constructed as well. The main assets of a railway system are its infrastructural objects and rolling stock (Povilaitienė *et al.* 2006). Rail wear reduction possibilities in curves have been investigated. The mathematical model which takes into account the impact of track width on the rail wear in curves is presented. Turkish researchers Sonmez, Ontepeli (2009) presented the calculation method of the city's railway system pre-design expenses based on the parametric simulation. The proposed method enables to construct parametric design expenses model in the early pre-design stage. The importance of quality criteria has been evaluated through the use of AHP (Analitic Hierarchy Process) method in the paper (Sivilevičius, Maskeliūnaitė 2010) dealing with the improvement of the quality of carrying passengers by railway.

The aim of the work is to construct the model of transport system's elements, to present the levels of their interaction, to work out the method of determining the interaction priority and to reveal its impact on the transportation process properties as well as the country's economy and nonproductive activity sectors.

2. Transport System Elements and their Classification

Transport is a constituent part of the country's infrastructure, which has to satisfy the needs of the people and economy in terms of freight transportation and passenger carriage. The transport sector is an integral service provision economy branch. Transport services are used by all economy and nonproductive activity sectors without any exception.

Transport may be analyzed in a broad or a narrow sense. In a broad sense, the transport system (TS) includes all transport modes (TM) in the country. Each TM consists of three integral parts: transport material (tangible) elements, transportation process (TP) and activity regulation (Fig. 1). Their complex and required properties guarantee proper functioning of TS. In a narrow sense, according to some researchers, only transportation facilities or/ and transport management, economy and logistics are considered to be transport. In their opinion, transport ways are not TE.

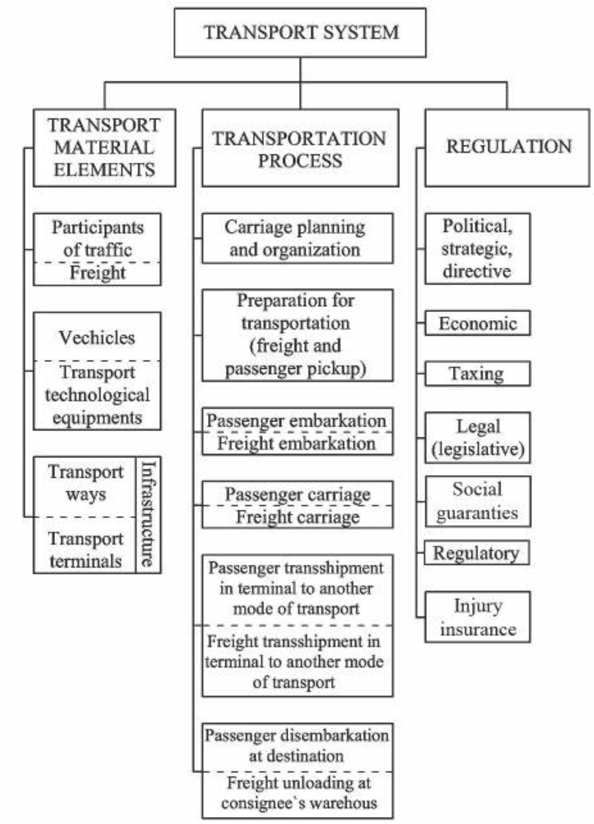

Fig. 1. Composition of transport system

The classification of transport, like other objects, economy and service sectors is a conventional matter as it depends on the selected principles, features and criteria. So far there has been no common strict transport classification system. In different laws, codes and directives it is presented incomplete, varying and is constantly changed. Overall classification is rather complicated and depends on the classification criteria or combinations of properties (Table 1).

Experience shows that transport is usually classified into modes according to the first property, i.e. the type of the way used by vehicles, which carry freight or passengers. Such classification is clear and complies with the administrative dependence and division.

The system of any major TM (road transport, railway transport, air transport, maritime transport, inland water transport) consists of the following (Fig. 1):

– transport material (tangible) elements (traffic users and freight, vehicles and transport technological equipment (TTE), transport ways and terminals, which are called infrastructure);
– TP (planning and organization of carriage, preparation of transportation, passenger embarkation or freight loading, carriage of passengers and freight, passenger or freight transshipment in a terminal, passenger or freight disembarkation at their destination point);

Table 1. Properties (criteria) of transport classification into modes and their names

Classification properties (according to)	Name of transport mode
1. Type of a way used by vehicles	Roadways, railways, tramways, airways, maritime (sea), inland waterways, pipelines, cable ways, technological lines, mining
2. Type of a vehicle	Car, truck, trolleybus, motorcycle, horse-drive, train, tram, hanging cabin, airplane, ship, pump, elevator
3. Type of energy driving a vehicle	Thermal, electric (electromagnetic, electromobile), nuclear, wind, sun (solar), biotransport, gravitational
4. Type of a vehicle's chassis	Wheel, caterpillar, rail, walking, on air cushion, non-chassis
5. Geocentrical position	Space, air, overground, underground, topside, submarine
6. Type of handling	Mechanical, hydraulic, pneumatic, mechatronic, electric, manual, distance (remote), automatic, software
7. Type of work performed	Freight, passenger, technological
8. Purpose	All-purpose (public), non-public (commercial), private, special, production, sports, entertainment
9. Suitability of a vehicle's movement trajectory to the road track	Extremely strict trajectory (pipeline, railway), strict trajectory (road), floating trajectory (air, inland waters, maritime)
10. Carriage distances	Intercontinental, interstate, internal, intercity, suburban, urban, plant, technological interoperational
11. Movement speed	Extremely fast, express, average slow, extremely slow
12. Durability of transported freight properties	Preserving stable freight properties, slightly changing freight properties, changing freight properties

– activity regulation (political, strategic, directive, economic, scientific, legislative, social guaranties, regulatory injury insurance).

Pipeline transport, technological road transport, and cable road transport may be considered additional modes of transport. The interaction of TS structure model material constituents (elements) is shown in a model (Fig. 2). In case one of the elements is missing, the TP is usually impossible or irrational. In case of exception (sometimes), a vehicle may run idle, i.e. without any freight or passengers. However, such activity is ineffective as it does not create any gross added value (GAV).

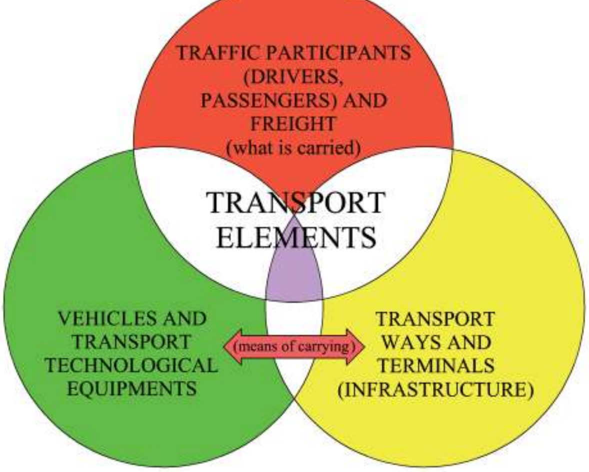

Fig. 2. Model of transport system's material (tangible) constituents (elements)

Other reseachers (Benson, Whitehead 1994) claim that every mode of transport uses four major components, or essential elements of transport. These are the *way*, the *terminal*, the *unit of carriage* and *unit of propulsion*. When classifying transport into modes, researchers do not distinguish inland water transport.

To analyze the structure of TS, the terms and their definitions presented below are important. A TM is the field of activity organizing, implementing, developing and maintaining carriage of freight and/ or passengers on one (the same) structure and purpose natural (water, air) roads or artificial ways (car, railway, pipeline). A transport object (TO) is a material part of a special purpose TS for performing and/ or servicing passenger and freight TP. A transport element (TE) is a transport object of any TM or its TO material constituent.

Traffic participants are people who take part in traffic: drivers, passengers and pedestrians. A driver is a person who drives or teaches how to drive a vehicle, herds animals or birds as well as a horseman. Different minimum age is set for drivers of different categories of road vehicles. A pedestrian is a person who is on the road but not in the vehicle as well as the one who goes in a wheelchair, roller-skate, skateboard, scooter, pushes a bicycle, a moped, pulls (pushes) a sledge, a perambulator or any other type of a trolley. This *first (1) group of physical components* partly includes people working on the road, i.e. traffic controllers, wardens, supervising officials, people who repair or supervise a road, technical traffic control facilities, those who eliminate the consequences of accidents, customs and border crossing points' officers or people working near running vehicles or inside TTE. According to traffic regulations, people working on the road are not considered pedestrians as the road is a working place for them. However, they take part in the traffic process.

A passenger is a person who is waiting for a vehicle or is inside a vehicle, but does not drive it. Freight is an article or an animal suitable (prepared) for transportation or is transported. Properties of freight, especially those of hazardous freight, impact on their transportation technology.

The *second (2) group of transport physical components* includes vehicles and TTE. A vehicle is a device for carrying people and (or) freight. This term in road transport also includes tractors and self-propelled machinery, trailers and semi-trailers. In road transport, the most important vehicle is a car. A car is any motor vehicle using the road and carrying freight and (or) passengers or towing other vehicles. Trolleybuses belong to the category of cars as well. Motorcycles, tractors and self-propelled machinery (TTE) do not belong to the category of cars.

Mobile and stationary equipment used in the loading process in terminals, road, railway, airport maintenance and construction as well as traffic accounting, management and information equipment shall be considered TTE.

Transport ways (TW) are natural and artificial roads with their structures (bridges, jetties, intersections, viaducts, overhead roads, tunnels) and facilities (road signs, guardrails, traffic handling and accounting, lighting, information technologies) as well as terminals to be used by running, sailing, flying, flowing vehicles. Transport ways comprising the *third (3) group of physical components* are also called transport infrastructure. The road is a lane of land or structure's surface used by transport at its full width, including carriageways, intersections, sidewalks, road shoulders, walkways and cycle tracks. Highways and motorways, canals, railways, tramways, tunnels and monorails are similarly constructed (Benson, Whitehead 1994).

A TP is a process of movement of a vehicle with freight, passengers or only with a driver for changing their place. Traffic is the movement of vehicles and/ or pedestrians, horsemen along a set route intended for all or only some types of vehicles.

3. Interaction Model of TS Elements

The TS is investigated as a whole of interrelated integral elements in the external environment, the activities of which are intended for carrying freight and passengers. TS mission is to guarantee sustainable mobility of society members and carriage of goods, maintaining the dynamic development of the country's economy and increasing competitive capability of the country in international markets. The necessity of transport is based on the existence of its three physical components (traffic participants and freight, vehicles and TTE, TW and terminals, i.e. its infrastructure (Fig. 3). The system of three 'supports' survives if all three supports showing transport's material (physical) objects are available.

The following six levels of TS elements, external environment factors as well as economy and nonproductive activity sectors' interaction may be pointed out in the model (Fig. 3): I, II, III, IV, V, VI. The first (I) level consists of autointeraction, written on the top of the model with arrows at the ends of U-shaped bands drawn on a horizontal plane. Freight, traffic participants, vehicles, TTE ① as well as TW and terminals (infrastructure) interact ②.

The second level of interaction (II) consists of the physical interaction of transport material elements. Traffic participants and freight interact with vehicles and TTE. Vehicles and TTE interact with transport infrastructure. TW and terminals (infrastructure) interact with traffic participants and freight. The interaction of the second level is shown by arch-shaped (bent) bands with arrows at the ends drawn on the horizontal plane on the bottom of the model.

Transport functions in the external environment, which is made up of people, energy objects (power plants, its transfer by air and underground lines), plants (flora), buildings, air and its constituent gases (hurricane, tornado, wind), water (rain, shower, steam, mist, ice, snow, cunami), ground (volcano ash formed from the depth of earth, lava, mountains, earthquake formed due to tector plane movement, dirt slumps), animals (fauna). Eight elements comprising physical environment interact with the following TE: traffic participants and freight, vehicles and TTE, TW and terminals (infrastructure). This physical interaction is attributed to the third (III) level. It is illustrated by vertical bands drawn on the sides of the model with bent ends and arrows. Transport should be eco-friendly. Environment may also be internal (inside vehicles) and macroeconomic.

The fourth (IV) level of interaction is comprised of the interaction of TM. TS transport of different modes usually interacts not physically but in organizational, competitive, economic, carriage market division areas. In spring 2010, when the volcano errupted in Iceland, air space was polluted. Due to the cancellation of flights, passengers had to use other modes of transport. The physical interaction of TM is made up of the interaction of different modes' material elements. The fourth level of interaction in the model is illustrated by horizontal circles, corresponding with various TM, on the left side 6 arrows reminding vertical comb teeth.

The following physical parameters impact on the physical interaction of transport and their interaction with the external environment: the state and properties of a material, temperature, noise and vibrations, friction, adhesion, cohesion, time, speed and acceleration, weight, dimensions and shape, lighting, gravitation. The interaction process and its result are influenced by standardization, normative and legal regulation, marketing. Their impact on the interaction is illustrated in the model by a dotted line surrounding 'Transport modes and elements' and 'External environment'.

Transport is an integral part of the country's economy and nonproductive activity sectors. The following economy sectors use transport services: mining, energetics, agriculture, fishery and hunting, foresting, construction, industry, trading, municipal economy, tourism and sports, communications and consignment. The following nonproductive sectors could not exist without it: education and culture, public health, social security, environmental protection, national defence. Its services are used by special and diplomatic services, banking and cash services. Transport interaction with separate economy and nonproductive activity sectors belong to the fifth (V) level. It is illustrated by arrows pointed to the exterior of the model (Fig. 3). The most important result of this level of interaction is its impact on the country's economy, expressed by gross added value (GAV).

The role of transport in generating GAV is of paramount importance. (Fig. 4, VI interaction level). In the Lithuanian transport sector, approximately 5% of the country's employed work; however, during the last seven years they have generated 9.4–11.0% of GAV. Income generated from transport and stocking activities was constantly increasing: from 4.81 billion LTL in 2003 to 9.1 billion LTL in 2009.

Physical interaction of TS material elements may be classified and analyzed in various aspects. From my personal experience and analysis of research works, we recommend to point out the following features and forms of expression:

1) According to the distance between elements (immediacy), the interaction may be as follows:
   - contact (direct) when TS elements directly, without any medium (TS element or environmental element), physically touch each other and interact;
   - noncontact (indirect) when one element (body) does not touch another but impacts another remote element through an intermediate TS or an environmental factor element.
2) According to the utility of the interaction result to theTP, the interaction may be:
   - positive, when it enables to obtain the expected result or approximates to this result;
   - negative, when the result is undesirable and dangerous.
3) According to the change of interaction parameters in the course of time, the interaction may be:
   - static, when the impact of TS's one element on another element does not change in the course of time;
   - dynamic, when TS elements' interaction parameters (size of forces, directions of movement, speed and acceleration, tem-

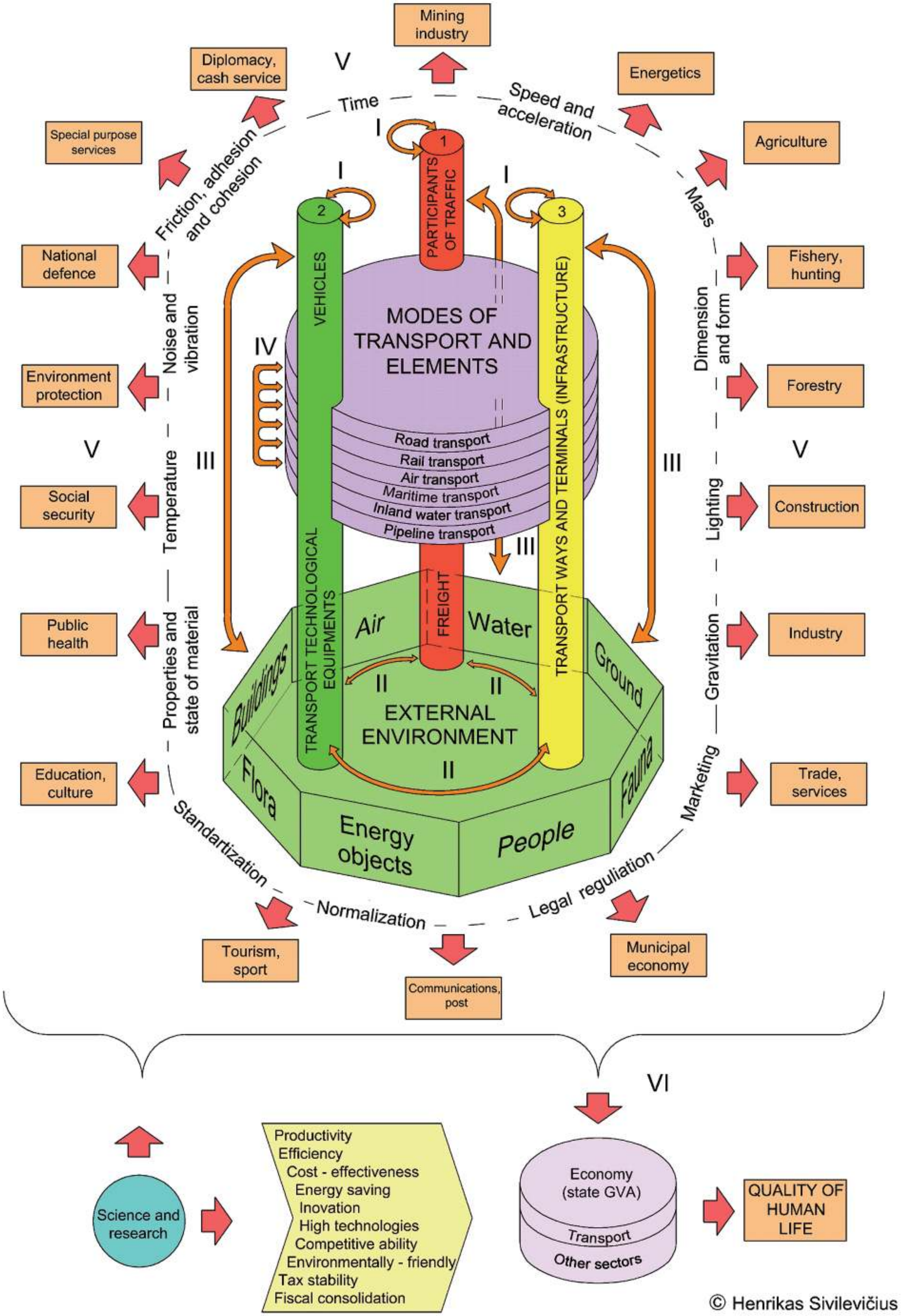

Fig. 3. Model of transport system elements' interaction and its impact on the country's economy and nonproductive activity sectors

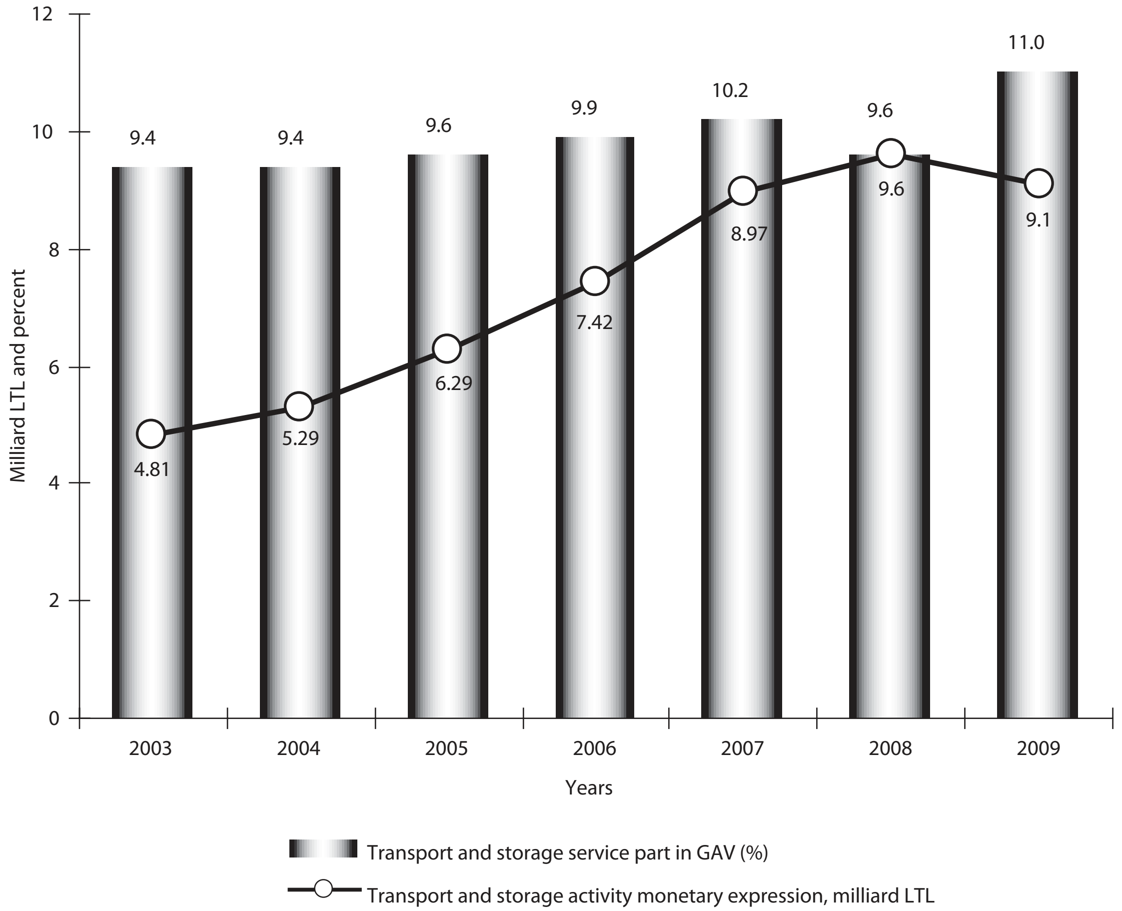

Fig. 4. Transport sector's part in the generation of GAV of the Lithuanian Republic

perature and others) change in the course of time.

4) According to the purposefulness of interaction (the number and origin of purposes), it may be:
   – single-sided (one-direction), when any TS element impacts on another element, not impacting on the first element;
   – double-sided, when interacting TS elements have the same or different impact on each other.
5) According to the duration, the interaction may be:
   – permanent (continuous, constant), when elements' interaction lasts for a long time without any interruptions during the whole transportation cycle;
   – episodic (random, discontinuous), when TS elements interact for a short time during a certain preset or unforecasted time and under certain circumstances.
6) According to the impact on the TP, the interaction may be:
   – passive, when interacting TE do not change the parameters of the TP (and interacting elements);
   – active, when interacting TE change each other's and/ or TP parameters.
7) According to manageability, the interaction may be:
   – uncontrolled, when TS elements' interaction commencement, its duration and completion time as well as parameters cannot be changed with all possible means available;
   – controlled, when a traffic participant (driver, pedestrian, passenger) or a worker may with the help of certain actions or equipment automatically or programmably change the parameters of elements interacting in the TP.
8) According to its eco-friendliness, the interaction may be:
   – ecological, when the consequences of TE' interaction on the environment and traffic participants do not inflict any harm or harm is not significant and does not exceed the permitted one;
   – not ecological, when TE' interaction inflicts significant harm on the environment and traffic users.

Improving the interaction between the TS elements by using research-based decisions.

These eight features may be used to describe any interaction of TE. It is not always expressed numerically. It is difficult to compare interactions if qualitative parameters are not expressed quantatively.

4. Evaluation of TS elements' interaction by AHP method

'Not everything that counts can be counted, and not everything that can be counted counts' (Albert Einstein). It has become common to simulate TS elements' interaction and to calculate its parameters. It is quite complicated to compare different types of interactions; however, it has become possible with the help of modern research achievements. A previous provision that apples cannot be compared to oranges is not correct any more (T. L. Saaty).

From the model (Fig. 3) and its analysis we can see a lot of possible TS elements' interaction levels and their combinations. Ranking methods enable to determine which interaction is more important to the parameters of the TP and its final result. Complex evaluation and rating of objects (interactions) according to the aim under investigation depend on factual values of indicators and their importance.

Indicators' importance determination methods are classified as subjective if evaluated according to the opinion of specialists (experts). High qualification skills of experts are necessary for subjective evaluation.

As a rule, the more a person knows the situation, the more consistent he is in his solutions. Although an opposite correlation is not necessarily correct, excellent compatibility of solutions does not necessarily mean that a person understands the situation well.

Recently, a popular twin comparison method called Analitic Hierarchy Process (AHP), which was offered by Saaty (2000) and Saaty *et al.* (2003), has been widely used. Twin comparisons enable to increase the compatibility of evaluations. AHP method enables to identify one level hierarchy indicators' significance (importance) in terms of a higher level or hierarchically non-structured significance of indicators. The essence of the method lies in the matrix of twin comparison. An expert compares all evaluated indicators (TS elements' interactions) R_i and $R_j\left(i, j=1,2,\ldots n\right)$, here n – a number of comparative indicators (TS elements' interactions).

The method is convenient as it is easier to compare TS elements' interactions in pairs, but not all at a time. The importance of one TS elements' interaction than that of another is shown as well. The method enables to replace qualitative indicators given to TS elements' interaction by experts by quantative ones.

Suppose that the importance or impact of TS elements' interactions $S_1,\ldots,S_n$ on the parameters of the transportation process shall be compared.

We will study an ideal situation assuming that the importance of our compared interactions is absolutely identical. We will mark this significance by values $\omega_1,\omega_2,\ldots,\omega_n$.

Ratio

$$a_{ij}=\frac{\omega_i}{\omega_j},\ \ i,j=1,2,\ldots,n, \tag{1}$$

shows how many times *i* TS elements' interaction S_i is more important than *j* interaction S_j.

We will write ratios (1) by a square matrix:

$$\mathbf{A}=\begin{bmatrix} \omega_1/\omega_1 & \omega_1/\omega_2 & \ldots & \omega_1/\omega_j & \ldots & \omega_1/\omega_n \\ \omega_2/\omega_1 & \omega_2/\omega_2 & \ldots & \omega_2/\omega_j & \ldots & \omega_2/\omega_n \\ . & . & \ldots & . & \ldots & . \\ . & . & \ldots & . & \ldots & . \\ \omega_i/\omega_1 & \omega_i/\omega_2 & \ldots & \omega_i/\omega_j & \ldots & \omega_i/\omega_n \\ . & . & \ldots & . & \ldots & . \\ . & . & \ldots & . & \ldots & . \\ \omega_n/\omega_1 & \omega_n/\omega_2 & \ldots & \omega_n/\omega_j & \ldots & \omega_n/\omega_n \end{bmatrix}, \tag{2}$$

where: ω_i/ω_j – relative importance of factor i compared to factor j; n – the number of factors in a set.

The relative importance of n factors can be obtained by resolving the following equation:

$$\mathbf{A}\cdot\boldsymbol{\omega}=\lambda_{\max}\cdot\boldsymbol{\omega}, \tag{3}$$

where: $\boldsymbol{\omega}=\left(\omega_1,\omega_2,\omega_3,\ldots,\omega_n\right)^T$ – a vector of relative weights; and $\lambda_{\max}$ – largest eigenvalue of matrix $\mathbf{A}$. If there is no judgement inconsistency, $\lambda_{\max}$ should be equal to n (matrix size).

The AHP method assesses the consistency of each expert's estimates. Consistency index *C.I.* is defined (Saaty *et al.* 2003; Sivilevičius, Maskeliūnaitė 2010; Podvezko 2009) as a relationship:

$$C.I.=\frac{\lambda_{\max}-n}{n-1}. \tag{4}$$

The smaller the consistency index *C.I.*, the higher the consistency of the matrix is. In the ideal case, $C.I.=0$.

Inverse second-order simetrical matrices are always consistent. The relationship between the calculated consistency index *C.I.* of a particular matrix and the average random index *R.I.* is referred to as consistency ratio *C.R.* It determines the degree of the matrix consistency:

$$C.R.=\frac{C.I.}{R.I.}. \tag{5}$$

The value of consistency ratio *C.R.* which is smaller than or equal to 0.1 is acceptable, implying that the matrix is consistent.

5. Numerical simulation influence of TS elements interactions in roadway transport safety

In the road transport (model Fig. 3) as in any other transport mode the following three first TS elements' interaction levels are pointed out:

1. Traffic participants–traffic participants interaction (interaction code I–1–1);
2. Vehicle–vehicle interaction (I–2–2);
3. Transport road–transport road interaction (I–3–3);
4. Traffic participants–vehicle interaction (II–1–2);
5. Traffic participants–transport road interaction (II-1-3);

6. Vehicle–transport road interaction (II–2–3);
7. Traffic participants–environment interaction (III–1–E; E–environment);
8. Vehicle–environment interaction (III–2–E);
9. Transport road–environment interaction (III–3–E).

Interactions of all these levels have impact on traffic safety. TS elements' interaction parameters change in the course of time and frequently have stochastic origin. To identify their impact on traffic safety on the roads, statistical data or expert investigation methods, including AHP method, may be applied.

AHP method is special so that it requires high level thinking of experts. The opinion of a competent expert is much more important than that of several inexperienced (unable to think logically) specialists. Therefore, researchers often interview several experienced experts, e.g. 5 experts (Farhan, Fwa 2009).

The significance of the impact of TS elements' interaction on the number of accidents on the road has been identified according to the opinion of one expert, which enabled to calculate the consistency of a comparative matrix. Using his experience, competence, knowledge and intuition, the expert compared TS elements' interactions with each other (double comparison). He has also taken into consideration the significance of the intensity of criteria (interactions) in terms of each other on a five-point scale (1–3–5–7–9), pointing out how one interaction of TS elements is more important than the other (Table 2).

Double comparison matrix of all TS elements' interactions (Table 2) enables to calculate eigenvector $\boldsymbol{\omega}$ according to the formulas suggested by Podvezko (2009). Its calculation sequence is presented in Table 3.

The consistency of compared matrix is verified (Table 2). Thus, the sum of multiplications $\sum_{j=1}^{9} a_{ij}\omega_j$ is divided by the corresponding criterion calculated value ω_i, presented in Table 3. Calculation results are presented in Table 4.

We find the arithmetic mean of these values, which is equal to the largest eigenvalue of matrix λ_{max}:

$$\lambda_{max} = \frac{1}{m} \cdot \frac{\sum_{j=1}^{n} a_{ij}\omega_j}{\omega_i} = \frac{1}{9}(10.4651 + 10.5380 + 9.9736 + 9.7575 + 9.9984 + 9.8719 + 11.1131 + 10.1841 + 8.2393) = 10.0157.$$

We obtain $\lambda_{max} = 10.02$.

It is known that inverse symmetric n row matrix maximum eigenvalue $\lambda_{max} \geq n$. The closer λ_{max} criteria number n (compared TS elements' interaction number) is, the more consistent result is obtained. In our case, the comparison matrix row or the number of compared TS elements' interactions (criteria) (matrix size) $n = 9$. Hence, 10.02>9. The condition is met.

Now we can calculate consistency index *C.I.* according to the following formula (4):

$$C.I. = \frac{\lambda_{max} - n}{n-1} = \frac{10.02 - 9}{9-1} = 0.127 .$$

The ratio of matrix consistency index *C.I.* and random index *R.I.* found in the publication (Saaty 2000), is obtained according to the following formula (5):

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.127}{1.45} = 0.08756 .$$

A matrix is considered consistent if the value of ratio *C.R.* is smaller than 0.1. In our case 0.088<0.1; therefore, the matrix of the presented digital sample is consistent.

6. Conclusions

1. The functioning of the transport system (TS) is related to various interactions of its elements. A number of research works are dedicated to investigate the interaction of separate material elements of various transport modes (TM), the analysis of which showed that a model common for all interactions does not exist.

Table 2. Significance of TS elements' interaction to the accident rate in road transport criteria double comparison matrix

Interaction code by Fig. 3	I-1-1	I-2-2	I-3-3	II-1-2	II-1-3	II-2-3	III-1-E	III-2-E	III-3-E
I-1-1	1	1/9	1/7	1/9	1/7	1/9	1/5	1/9	1/3
I-2-2	9	1	5	1	5	3	7	5	7
I-3-3	7	1/5	1	1/3	1	1/3	3	1/3	7
II-1-2	9	1	3	1	5	1	7	3	9
II-1-3	7	1/5	1	1/5	1	1/5	3	1/3	5
II-2-3	9	1/3	3	1	5	1	7	1	9
III-1-E	5	1/7	1/3	1/7	1/3	1/7	1	1/7	5
III-2-E	9	1/5	3	1/3	3	1	7	1	7
III-3-E	3	1/7	1/7	1/9	1/5	1/9	1/5	1/7	1

Table 3. Calculation sequence and results of eigenvector ω

Calculation step	TS elements' intersection (criterion) mark (code)								
	I–1–1	I–2–2	I–3–3	II–1–2	II–1–3	II–2–3	III–1–E	III–2–E	III–3–E
Step one	ω_1''	ω_2''	ω_3''	ω_4''	ω_5''	ω_6''	ω_7''	ω_8''	ω_9''
Calculated elements a_{ij} from each row of Table 2 E.g., first row a_{ij} elements multiplication	$\omega_i'' = \prod_{j=1}^{9} a_{ij}$								
Table 2 each row multiplication	$\omega_1'' = 1 \cdot \frac{1}{9} \cdot \frac{1}{7} \cdot \frac{1}{9} \cdot \frac{1}{7} \cdot \frac{1}{9} \cdot \frac{1}{5} \cdot \frac{1}{9} \cdot \frac{1}{3} = 0.000000207$								
	0.000000207	165375	1.08888	25515	0.28	2835	0.001157	264.6	0.00004319
Step two n degree root is calculated from each row calculated ω_i'' $(n=9)$	ω_1'	ω_2'	ω_3'	ω_4'	ω_5'	ω_6'	ω_7'	ω_8'	ω_9'
E.g., from obtained row second element 9th degree root	$\omega_i' = \sqrt[9]{\omega_i''} = \sqrt[9]{\prod_{j=1}^{9} a_{ij}}$								
Root of all criteria multiplications a_{ij} 9-th degree	$\omega_2' = \sqrt[9]{165375} \approx 3.8004$								
	0.1808	3.8004	1.0095	3.0878	0.8681	2.4189	0.4717	1.8586	0.3274
Step three Summed all calculated ω_i'	$\sum_{i=1}^{9} \sqrt[9]{\prod_{j=1}^{9} a_{ij}} = \sum_{i=1}^{9} \sqrt[9]{\omega_i'}$								
For the sum of all components	$0.1808 + 3.8004 + 1.0095 + 3.0878 + 0.8681 + 2.4189 + 0.4717 + 1.8586 + 0.3274 = 14.0232$								
Step four Each element ω_i' is divided by the sum of all elements	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	ω_7	ω_8	ω_9
	$\omega_i = \frac{\sqrt[9]{\prod_{j=1}^{9} a_{ij}}}{\sum_{i=1}^{9} \sqrt[9]{\prod_{j=1}^{9} a_{ij}}}$								
E.g., first criterion's ω_1' is divided by the obtained sum, etc.	$\omega_1 = \frac{0.1808}{14.0232} = 0.0129, \ldots, \omega_9 = \frac{0.3274}{14.0232} = 0.02335$								
	0.0129	0.2710	0.0720	0.2202	0.0619	0.1725	0.0336	0.1325	0.0234
All criteria elements' normalized ω_i values (eigenvector)	$\sum_{i=1}^{9} \omega_i = 1.0000$								
Rank of criterion	9	1	5	2	6	3	7	4	8

Table 4. Calculated values of the highest eigenvalues λ_{max} components

TS elements interaction code	$\sum_{j=1}^{9} a_{ij}\omega_j$	$\frac{\sum_{j=1}^{9} a_{ij}\omega_j}{\omega_i}$
I–1–1	0.1350	10.4651
I–2–2	2.8558	10.5380
I–3–3	0.7181	9.9736
II–1–2	2.1486	9.7575
II–1–3	0.6189	9.9984
II–2–3	1.7029	9.8719
II–1–E	0.3734	11.1131
III–2–E	1.3494	10.1841
III–3–E	0.1928	8.2393

2. Transport system objects (elements) classified according to the set new criteria enable to reveal its structure more accurately and simplifies the process of analysis.
3. An original model showing six levels of TS elements' interaction is presented. It reveals the relationship of its material elements' interaction, the interaction with the external environment and the interaction among TM and the interaction with the country's economy and nonproductive activity sectors. Interaction expression properties, which reveal its qualitative aspects and differences, are systematized.
4. Separate levels of TS elements' interaction differently influence on the parameters of the transportation process (TP). We recommend to use the Analytic Hierarchy Process (AHP) method to evaluate the

importance of different interactions to the parameters of the TP. The effect of the interaction of the TS elements of various levels on traffic safety on the road demonstrated by a numerical model proved the effectiveness of using AHP method for establishing the priority of various interaction forms.

References

Antov, D.; Abel, K.; Sürje, P.; Rõuk, H.; Rõivas, T. 2009. Speed reduction effects of urban roundabouts, *The Baltic Journal of Road and Bridge Engineering* 4(1): 22–26. doi:10.3846/1822-427X.2009.4.22-26

Bagamppade, U.; Kiggundu, B. M. 2007. Influence of truck load channelization on stripping in asphalt mixtures, *Construction and Building Materials* 21(8): 1628–1635. doi:10.1016/j.conbuildmat.2006.06.027

Baltrėnas, P.; Kazlauskienė, A. 2009. Sustainable ecological development reducing negative effects of road maintenance salts, *Technological and Economic Development of Economy* 15(1): 178–188. doi:10.3846/1392-8619.2009.15.178-188

Baltrėnas, P.; Morkūnienė, J; Vaitiekūnas, P. 2008a. Mathematical simulation of solid particle dispersion in the air of Vilnius city, *Journal of Environmental Engineering and Landscape Management* 16(1): 15–22. doi:10.3846/1648-6897.2008.16.15-22

Baltrėnas, P.; Vaitiekūnas, P.; Vasarevičius, S.; Jordaneh, S. 2008b. Automobilių išmetamų dujų sklaidos modeliavimas [Modelling of motor transport exhaust gas influence on the atmosphere], *Journal of Environmental Engineering and Landscape Management* 16(2): 65–75 (in Lithuanian). doi:10.3846/1648-6897.2008.16.65-75

Baltrėnas, P.; Puzinas, D. 2009. Jūrų uosto teritorijos ir gyvenamosios zonos triukšmo sklaidos modeliavimas taikant programą Cadna A [Modeling of noise dispersion in the seaport territory and residential zone using Cadna A program], *Journal of Environmental Engineering and Landscape Management* 17(3): 148–153 (in Lithuanian). doi:10.3846/1648-6897.2009.17.148-153

Beben, D. 2008. Numerical analysis of a soil-steel bridge structure, *The Baltic Journal of Road and Bridge Engineering* 4(1): 13–21. doi:10.3846/1822-427X.2009.4.13-21

Beljatynskij, A.; Prentkovskis, O.; Krivenko, J. 2010. The experimental study of shallow flows of liquid on the airport runways and automobile roads, *Transport* 25(4): 394–402. doi:10.3846/transport.2010.49

Benson, D.; Whitehead, G. 1994. *Elements of Transport and Logistics*. Pearson Education Ltd. 250 p.

Billot, R.; El Fouzi, N.-E.; De Vuyst, F. 2009. Multilevel assessment of the impact of rain on drivers' behavior: standardized methodology and empirical analysis, *Transportation Research Record* 2107: 134–142. doi:10.3141/2107-14

Brannvall, E.; Martinėnas, B. 2007. The pecularities of fine particles dispersion over the roadside, *The Baltic Journal of Road and Bridge Engineering* 2(1): 39–44.

Brauers, W. K. M.; Zavadskas, E. K.; Peldschus, F.; Turskis, Z. 2008. Multi–objective decision-making for road design, *Transport* 23(3): 183–193. doi:10.3846/1648-4142.2008.23.183-193

Bražiūnas, J.; Sivilevičius, H. 2010. The bitumen batching system's modernization and its effective analysis at the asphalt mixing plant, *Transport* 25(3): 325–335. doi:10.3846/transport.2010.40

Capuruço, R. A. C.; Hegazy, T.; Tighe, S. L.; Zaghloul, S. 2005. Full-car roughness index as summary roughness statistic, *Transportation Research Record* 1905: 148–156. doi:10.3141/1905-17

Choubane, B.; Gokhale, S.; Fletcher, J. 2006. Feasibility of accelerated pavement testing to evaluate long-term performance of raised pavement markers, *Transportation Research Record* 1948: 108–113. doi:10.3141/1948-12

Chen, J.-S.; Huang, C.-C.; Chen, C.-H.; Su, K.-Y. 2008. Effect of rubber deposits on runway pavement friction characteristics, *Transportation Research Record* 2068: 119–125. doi:10.3141/2068-13

Chen, S. S.; Lamanna, M. F.; Tabler, R. D.; Kaminski, D. F. 2009. Computer-aided design of passive snow control measures, *Transportation Research Record* 2107: 111–120. doi:10.3141/2107-12

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. doi:10.1061/(ASCE)CO.1943-7862.0000015

Coleri, E.; Tsai, B.-W.; Monismith, C. L. 2008. Pavement rutting performance prediction by integrated Weibull approach, *Transportation Research Record* 2087: 120–130. doi:10.3141/2087-13

Crocker, M. J.; Hanson, D.; Li, Z.; Karjatkar, R.; Vissamraju, K. S. 2004. Measurement of acoustical and mechanical properties of porous road surfaces and tire and road noise, *Transportation Research Record* 1891: 16–22. doi:10.3141/1891-03

Čygas, D.; Jasiūnienė, V.; Bartkevičius, M. 2009. Assessment of special plans ant technical designs with regard to traffic safety, *Journal of Civil Engineering and Management* 15(4): 411–418. doi:10.3846/1392-3730.2009.15.411-418

Dawson, A. R. 2008. Rut accumulation and power law models for low-volume pavements under mixed traffic, *Transportation Research Record* 2068: 78–86. doi:10.3141/2068-09

Douglas, R. A.; Woodward, W. D. H.; Rogers, R. J. 2003. Contact pressures and energies beneath soft tires: modeling effects of central tire inflation–equipped heavy-truck traffic on road surfaces, *Transportation Research Record* 1819B: 221–227. doi:10.3141/1819b-28

El Gendy, A.; Shalaby, A. 2008. Image requirements for three-dimensional measurements of pavements macrotexture, *Transportation Research Record* 2068: 126–134. doi:10.3141/2068-14

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

Finley, M. D.; Ullman, B. R.; Trout, N. D. 2006. Motorist comprehension of traffic control devices for mobile operations, *Transportation Research Record* 1948: 37–44. doi:10.3141/1948-05

Flintsch, G. W.; De León Izeppi, E.; McGhee, K. K.; Roa, I. A. 2009. Evaluation of international friction index coefficients for various devices, *Transportation Research Record* 2094: 136–143. doi:10.3141/2094-15

Fwa, T. F.; Kumar, S. S.; Anupam, K.; Ong, G. P. 2009. Effectiveness of tire-tread patterns in reducing the risk of hydroplaning, *Transportation Research Record* 2094: 91–102. doi:10.3141/2094-10

Fwa, T. F.; Kumar, S. S.; Ong, G. P.; Huang, C. J. H. 2008. Analytical modeling of effects of rib tires on hydroplaning, *Transportation Research Record* 2068: 109–118. doi:10.3141/2068-12

Gallivan, V. L.; Huber, G. R.; Flora, W. F. 2004. Benefits of warranties to Indiana, *Transportation Research Record* 1891: 221–228. doi:10.3141/1891-26

Gibbons, R. B.; Hankey, J. 2007. Wet night visibility of pavements markings, *Transportation Research Record* 2015: 73–80. doi:10.3141/2015-09

Gui, J. (G.); Phelan, P. E.; Kaloush, K. E.; Golden, J. S. 2007. Impact of pavement thermophysical properties on surface temperatures, *Journal of Materials in Civil Engineering* 19(8): 683–690. doi:10.1061/(ASCE)0899-1561(2007)19:8(683)

Han, K.-B.; Hong, S.-N.; Park, S.-K. 2009. Seismic performance evaluation of retrofitted bridge by isolation bearings, *The Baltic Journal of Road and Bridge Engineering* 4(3): 134–142. doi:10.3846/1822-427X.2009.4.134-142

Haryanto, I.; Takahashi, O. 2007. Use of secant shear modulus for rutting potential assessment of Indonesian wearing course mixtures, *The Baltic Journal of Road and Bridge Engineering* 2(3): 95–100.

Jackson, N. M.; Choubane, B.; Holzschuher, C. 2009. Practical approach to measuring and reporting friction and macrotexture at variable test speeds, *Transportation Research Record* 2094: 103–111. doi:10.3141/2094-11

Jakimavičius, M.; Burinskienė, M. 2009. Assessment of Vilnius city development scenarios based on transport system modelling and multicriteria analysis, *Journal of Civil Engineering and Management* 15(4): 361–368. doi:10.3846/1392-3730.2009.15.361-368

Jankovski, V.; Atkočiūnas, J. 2008. *MATLAB* implementation in direct probability design of optimal steel trusses, *Mechanika* (6): 30–37.

Kapski, D.; Leonovič, I.; Ratkevičiūtė, K. 2007. Theoretical principles of forecasting accident rate in the conflict sections of the cities by the method of potential danger, *The Baltic Journal of Road and Bridge Engineering* 2(3): 133–140.

Kim, Y.-R.; Park, H. M.; Aragão, F. T. S.; Lutif, J. E. S. 2009. Effects of aggregate structure on hot mix asphalt rutting performance in low traffic volume local pavements, *Construction and Building Materials* 23(6): 2177–2182. doi:10.1016/j.conbuildmat.2008.12.007

Krezel, Z. A.; McManus, K. 2010. Environmentally friendly sound absorbing noise barrier made from concrete waste–further developments, *International Journal of Pavement Research and Technology* 3(4): 223–227.

Kudzys, A. 2009. The structural safety assessment of the overloaded members of highway bridges, *The Baltic Journal of Road and Bridge Engineering* 4(4): 149–155. doi:10.3846/1822-427X.2009.4.149-155

Laurinavičius, A.; Miškinis, D.; Vaiškūnaitė, R.; Laurinavičius, A. 2010. Analysis and evaluation of the effect of studded tyres on road pavement and environment (III), *The Baltic Journal of Road and Bridge Engineering* 5(3): 169–176. doi:10.3846/bjrbe.2010.24

Lee, Y.-S.; Kim, S.-H.; Skibniewski, M. J. 2009. Analytical and experimental approach for assessing vibration serviceability of highway bridges due to heavy vehicle traffic, *The Baltic Journal of Road and Bridge Engineering* 4(3): 123–133. doi:10.3846/1822-427X.2009.4.123-133

Leipus, L.; Butkus D.; Januševičius, T. 2010. Research on motor transport produced noise on gravel and asphalt roads, *The Baltic Journal of Road and Bridge Engineering* 5(3): 125–131. doi:10.3846/bjrbe.2010.18

Lewis, P.; Rosdorf, W.; Frey, H. C.; Pang, S.-H.; Kim, K. 2009. Requirements and incentives for reducing construction vehicle emissions comparison of nonroad diesel engine emissions data sources, *Journal of Construction Engineering and Management* 135(5): 341–351. doi:10.1061/(ASCE)CO.1943-7862.0000008

Li, S.; Zhu, K.; Noureldin, S.; Harris, D. 2005. Identifying friction variations with the standard smooth tire for network pavement inventory friction testing, *Transportation Research Record* 1905: 157–165. doi:10.3141/1905-18

Lundkvist, S.-O.; Isacsson, U. 2008. Condition assessment of road equipment– State-of-the-art, *The Baltic Journal of Road and Bridge Engineering* 3(2): 84–92. doi:10.3846/1822-427X.2008.3.84-92

Luo, R.; Prozzi, J. A. 2007. Effect of measured three-dimensional tire–pavement contact stress on pavement response at asphalt surface, *Transportation Research Record* 2037: 115–127. doi:10.3141/2037-11

Macek, D.; Měšťanová, D. 2009. Multi-criteria evaluation of crash barrier systems types, *The Baltic Journal of Road and Bridge Engineering* 4(3): 108–114. doi:10.3846/1822-427X.2009.4.108-114

Machemehl, R. B.; Wang, F.; Prozzi, J. A. 2005. Analytical study of effects of truck tire pressure on pavements with measured tire–pavement contact stress data, *Transportation Research Record* 1919: 111–120. doi:10.3141/1919-12

Mačiulis, A.; Vasilis Vasiliauskas, A.; Jakubauskas, G. 2009. The impact of transport on the competitiveness of national economy, *Transport* 24(2): 93–99. doi:10.3846/1648-4142.2009.24.93-99

Matsuzawa, M.; Takechi, H.; Kajiya, Y.; Ito, Y.; Igarashi, M. 2009. How drivers perceive visibility in blowing show: human subject experiments on visibility-viewing videos of blowing snow, *Transportation Research Record* 2107: 143–149. doi:10.3141/2107-15

Mučinis, D.; Sivilevičius, H.; Oginskas, R. 2009. Factor determining the inhomogeneity of reclaimed asphalt pavement and estimation of its components content variation parameters, *The Baltic Journal of Road and Brigde Engineering* 4(2): 69–79. doi:10.3846/1822-427X.2009.4.69-79

Nagata, Y.; Hagiwara, T.; Araki, K.; Kaneda, Y.; Sasaki, H. 2008. Application of road visibility information system to winter maintenance, *Transportation Research Record* 2055: 128–138. doi:10.3141/2055-15

Nakatsuji, T.; Hayashi, I.; Ranjitkar, P.; Shirakawa, T.; Kawamura, A. 2007. Online estimation of friction coefficients of winter road surfaces using the unscented Kalman filter, *Transportation Research Record* 2015: 113–122. doi:10.3141/2015-13

Ong, G. P.; Fwa, T. F.; Guo, J. 2005. Modeling hydroplaning and effects of pavement microtexture, *Transportation Research Record* 1905: 166–176. doi:10.3141/1905-19

Orru, H., Kaasik, M.; Antov, D.; Forsberg, B. 2008. Evolution of traffic flows and traffic-induced air pollution due to structural changes and development during 1993–2006 in Tartu (Estonia), *The Baltic Journal of Road and Bridge Engineering* 3(4): 206–212. doi:10.3846/1822-427X.2008.3.206-212

Papagiannakis, A. T.; Zelelew, H. M.; Muhunthan, B. 2007. Wavelet analysis of energy content in pavement roughness and truck dynamic axle loads, *Transportation Research Record* 2005: 153–159. doi:10.3141/2005-16

Park, D.-W.; Martin, A. E.; Jeong, J.-H.; Lee, S.-T. 2008. Effects of tire inflation pressure and load on predicted pavement strains, *The Baltic Journal of Road and Bridge Engineering* 3(4): 181–186. doi:10.3846/1822-427X.2008.3.181-186

Pečeliūnas, R.; Prentkovskis, O. 2006. Influence of shock-absorber parameters on vehicle vibrations during braking, *Solid State Phenomena* 113: 235–240. doi:10.4028/www.scientific.net/SSP.113.235

Pellegrino, O. 2009. An analysis of the effect of roadway design on driver's workload, *The Baltic Journal of Road and Bridge Engineering* 4(2): 45–53. doi:10.3846/1822-427X.2009.4.45-53

Perera, R.; Kohn, S. 2004. Effects of variation in quarter-car simulation speed on international roughness index algorithm, *Transportation Research Record* 1889: 144–151. doi:10.3141/1889-16

Petkevičius, K.; Sivilevičius, H. 2008. Necessary measures for ensuring the quality of hot mix asphalt in Lithuania, *The Baltic Journal of Road and Bridge Engineering* 3(1): 29–37. doi:10.3846/1822-427X.2008.3.29-37

Pierce, L. M.; Mahoney, J. P.; Muench, S.; Munden, H. J.; Waters, M.; Uhlmeyer, J. 2009. Quieter hot-mix asphalt pavements in Washington State, *Transportation Research Record* 2095: 84–92. doi:10.3141/2095-09

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

Povilaitienė, I.; Kamaitis, I. Z.; Podagėlis, I. 2006. Influence of gauge width on rail side wear on track curves, *Journal of Civil Engineering and Management* 12(3): 255–260.

Prentkovskis, O.; Prentkovskienė, R.; Lukoševičienė, O. 2007. Investigation of potential deformations developed by elements of transport and pedestrian traffic restricting gates during motor vehicle–gate interaction, *Transport* 22(3): 229–235.

Prentkovskis, O.; Beljatynskij, A.; Prentkovskienė, R.; Dyakov, I.; Dabulevičienė, L. 2009. A study of the deflections of metal road guardrail elements, *Transport* 24(3): 225–233. doi:10.3846/1648-4142.2009.24.225-233

Prentkovskis, O.; Sokolovskij, E.; Bartulis, V. 2010a. Investigating traffic accidents: a collision of two motor vehicles, *Transport* 25(2): 105–115. doi:10.3846/transport.2010.14

Prentkovskis, O.; Beljatynskij, A.; Juodvalkienė, E.; Prentkovskienė, R. 2010b. A Study of the deflections of metal road guardrail post, *The Baltic Journal of Road and Bridge Engineering* 5(2): 104–109. doi:10.3846/bjrbe.2010.15

Priya, R.; Srinivasan, K. K.; Veeraragavan, A. 2008. Sensitivity of design parameters on optimal pavement maintenance decisions at the project level, *Transportation Research Record* 2084: 47–54. doi:10.3141/2084-06

Prowell, B. D.; Hanson, D. I. 2005. Evaluation of circular texture meter for measuring surface texture of pavements, *Transportation Research Record* 1929: 88–96. doi:10.3141/1929-11

Qiu, L.; Nixon, W. A. 2008. Effects of adverse weather on traffic crashes: systematic review and meta-analysis, *Transportation Research Record* 2055: 139–146. doi:10.3141/2055-16

Radziszewski, P. 2007. Modified asphalt mixtures resistance to permanent deformations, *Journal of Civil Engineering and Management* 13(4): 307–315.

Saaty, T. L. 2000. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*. 1st edition. RWS Publications. 477 p.

Saaty, T. L.; Vargas, L. G.; Dellmann, K. 2003. The allocation of intangible resources: the analytic hierarchy process and linear programming, *Socio-Economic Planning Sciences* 37(3): 169–184. doi:10.1016/S0038-0121(02)00039-3

Salama, H. K.; Haider, S. W.; Chatti, K. 2007. Evaluation of new mechanistic-empirical pavement design guide rutting models for multiple-axle loads, *Transportation Research Record* 2005: 112–123. doi:10.3141/2005-13

Sathyanarayanan, S.; Shankar, V.; Donnell, E. T. 2008. Pavement marking retroreflectivity inspection data: a Weibull analysis, *Transportation Research Record* 2055: 63–70. doi:10.3141/2055-08

Shukla, A. K.; Jain, S. S.; Parida, M.; Srivastava, J. B. 2009. Performance of FHWA model for predicting traffic noise: a case study of metropolitan city, Lucknow (India), *Transport* 24(3): 234–240. doi:10.3846/1648-4142.2009.24.234-240

Sivilevičius, H.; Maskeliūnaitė, L. 2010. The criteria for identifying the quality of passengers' transportation by railway and their ranking using AHP, *Transport* 25(4): 368–381. doi:10.3846/transport.2010.46

Sivilevičius, H.; Podvezko, V.; Vakrinienė, S. 2011. The use of constrained and unconstrained optimization models in gradation design of hot mix asphalt mixture, *Construction and Building Materials* 25(1): 155–122. doi:10.1016/j.conbuildmat.2010.06.050

Sivilevičius, H.; Šukevičius, Š. 2007. Dynamics of vehicle loads on the asphalt pavement of European roads which cross Lithuania, *The Baltic Journal of Road and Bridge Engineering* 2(4): 147–154.

Sivilevičius, H.; Šukevičius, Š. 2009. Manufacturing technologies and dynamics of hot-mix asphalt mixture production, *Journal of Civil Engineering and Management* 15(2): 169–179. doi:10.3846/1392-3730.2009.15.169-179

Sivilevičius, H.; Vislavičius, K. 2008. Stochastic simulation of the influence of variation of mineral material grading and dose weight on the homogeneity of hot-mix asphalt, *Construction and Building Materials* 22(9): 2007–2014. doi:10.1016/j.conbuildmat.2007.07.001

Sokolovskij, E.; Prentkovskis, O.; Pečeliūnas, R.; Kinderytė-Poškienė, J. 2007. Investigation of automobile wheel impact on the road border, *The Baltic Journal of Road and Bridge Engineering* 2(3): 119–123.

Sonmez, R.; Ontepeli, B. 2009. Predesign cost estimation of urban railway projects with parametric modeling, *Journal of Civil Engineering and Management* 15(4): 405–409. doi:10.3846/1392-3730.2009.15.405-409

Soon, S.-C.; Drescher, A.; Stolarski, H. K. 2004. Tire-induced surface stresses in flexible pavements, *Transportation Research Record* 1896: 170–176. doi:10.3141/1896-17

Suo, Z.; Wong, W. G. 2009. Nonlinear properties analysis on rutting behaviour of bituminous materials with different air void contents, *Construction and Building Materials* 23(12): 3492–3498. doi:10.1016/j.conbuildmat.2009.07.004

Tampère, C.; Stada, J.; Immers, B. 2009. Calculation of welfare effects of road pricing on a large scale road network, *Technological and Economic Development of Economy* 15(1): 102–121. doi:10.3846/1392-8619.2009.15.102-121

Tran, N. H.; Hall, K. D. 2007. Development and influence of statewide axle load spectra on flexible pavement performance, *Transportation Research Record* 2037: 106–114. doi:10.3141/2037-10

Vaidogas, E. R. 2007. Risk oriented design of protective highway structures, *The Baltic Journal of Road and Bridge Engineering* 2(4): 155–163.

Vaišis, V.; Januševičius, T. 2009. Modelling of noise level in the northern part of Klaipėda city, *Journal of Environmental Engineering and Lanscape Management* 17(3): 181–188. doi:10.3846/1648-6897.2009.17.181-188

Vaiškūnaitė, R.; Laurinavičius, A.; Miškinis, D. 2009. Analysis and evaluation of the effect of studded tyres on road pavement and environment (II), *The Baltic Journal of Road and Bridge Engineering* 4(4): 203–211. doi:10.3846/1822-427X.2009.4.203-211

Vansauskas, V.; Bogdevičius, M. 2009. Investigation into the stability of driving an automobile on the road pavement with ruts, *Transport* 24(2): 170–179. doi:10.3846/1648-4142.2009.24.170-179

Viba, J.; Liberts, G.; Gonca, V. 2009. Car rollover collision with pit corner, *Transport* 24(1): 76–82. doi:10.3846/1648-4142.2009.24.76-82

Vorobjovas, V.; Žilionienė, D. 2008. Evaluation of shoulders functions on Lithuanian regional roads, *The Baltic Journal of Road and Bridge Engineering* 3(4): 213–218. doi:10.3846/1822-427X.2008.3.213-218

Wang, H.; Zhang, Q.; Tan, I. 2009. Investigation of layer contributions to asphalt pavement rutting, *Journal of Materials in Civil Engineering* 21(4): 181–185. doi:10.1061/(ASCE)0899-1561(2009)21:4(181)

Xia, K. 2010. A finite element model for tire/pavement interaction: application to predicting pavement damage, *International Journal of Pavement Research and Technology* 3(3): 135–141.

Žilionienė, D.; Laurinavičius, A. 2007. De-icing experience in Lithuania, *The Baltic Journal of Road and Bridge Engineering* 2(2): 73–79.