ISSN: 2029-4913 / eISSN: 2029-4921

TECHNOLOGICAL and ECONOMIC DEVELOPMENT of ECONOMY

2024
Volume 30
Issue 5
Pages 1486–1509
https://doi.org/10.3846/tede.2024.21881

MODELING AND SIGNIFICANCE ASSESSMENT OF ROAD CONSTRUCTION PARTICIPANT AND USER BENEFITS USING EXPERT EVALUATION METHODS

Henrikas SIVILEVIČIUS [1], Audrius VAITKUS [2], Donatas ČYGAS [3]✉

[1,2] *Road Research Institute, Vilnius Gediminas Technical University, Vilnius, Lithuania*
[3] *Department of Roads, Vilnius Gediminas Technical University, Vilnius, Lithuania*

Article History:
- received 27 March 2024
- accepted 01 June 2024

Abstract. Human activities are related to obtain economic, technical, social and environmental benefits. The road construction process participants and road users have direct or indirect benefits from elaboration of new infrastructure. The number of the benefits received by individual entities is publicly discussed by politicians, lobbyists, experts and other decision-makers without having quantitative estimates of benefits, i.e., often relying on intuition or considering theoretical reasoning. The paper suggests a system of 19 benefit entities (criteria) assigned the ranks given by experts. The study involved three categories of experts, including 35 road engineers, 36 transport engineers and 61 road users. The values of the concordance coefficients obtained as a result of the conducted research were found significantly higher than critical values and showed that the opinions of the experts in each category were consistent (not contradictory). This made it possible to consider the average of the opinions of the expert group as a reliable result of solving the problem. Rank averages were replaced by the normalized weights of criteria using Average Rank Transformation into Weight-Linear (ARTIW-L) and – Nonlinear (ARTIW-N) methods. The global averages of criterion weights were used employing the Inverse Hierarchy for Assessment Main Criteria Importance (IHAMCI) method thus calculating the normalized weights of the road-related classified entities (three main criteria). The findings prove that road users benefit the most (weight 0.3485), the road construction contractor (weight 0.3325) is in the next position and the road owner (investor) takes the weight equal to 0.3190. The generated research data can be used for justifying the rationality of road investment.

Keywords: road engineers, road users, benefits, modelling, expert evaluation, criteria weighting, inverse hierarchy, opinion consistency.

JEL Classification: B16, C44, H54, L92, O18, R42.

✉Corresponding author. E-mail: ***donatas.cygas@vilniustech.lt***

1. Introduction

Transport is fundamental to our economy and society. Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel (European Commission, Directorate – General for Mobility and Transport, 2011). Infrastructure shapes mobility. No major change in transport will be possible without the support of on adequate network and more intelligence in using it. Overall, transport infrastructure investments have a positive impact on economic growth, create wealth and jobs, and enhance trade, geographical accessibility and the mobility of people. It has to be planned in a way that maximises positive impact on economic growth and minimises negative impact on the environment.

Infrastructure is the most vital part of road transport, improves the national image, the mobility of people and the quality of life. According to US President JF Kennedy, "It is not wealth that built our roads, but roads that built our wealth".

The owner (manager) of infrastructure, the construction contractor and users the vehicles of which carry passengers and goods benefit from the development of transport infrastructure. The size of this benefit is publicly discussed by politicians, economists, experts and other decision-makers giving state investments for the development of road transport infrastructure. The benefits of all road construction participants and users consisting of individual entities are figured out applying expert evaluation methods. The assessment of a sufficiently substantial number of the experts that stand for individual categories and have consistent or insignificantly different opinions allow us to calculate the averages of the significance of the benefits received by the entities. The results of the significance of the benefits gained by road construction participants and users are expressed in the ranks or weights and help advisors and decision makers justify the amount of money distributed from the state budget. The maintenance and development of the abandoned roads require more investment. The statement that road development and maintenance is the most beneficial to the road construction contractor is a claim not supported by research.

The cost of roads is similar to that of the other funds of production, and thus is not eliminated during the manufacturing process but transferred to the value of transport services. From the user's point of view, the most important are the transport and operational characteristics of the road ensuring uninterrupted, best driving speed, the comfort and safety of road traffic all year round. The most important characteristics of the road also include high conductivity, the ability to drive vehicles with permissible overall dimensions, axle loads and total mass at any time of the year and in any weather conditions. It is also important to ensure a prominent level of service in the transportation process and to meet aesthetic and environmental (ecological) requirements.

The paper is aimed at investigating the significance of the benefits received by the hierarchically structured entities related to roads during the entire life cycle of the road decided by the experts of different categories using multi-criteria decision-making (MCDM) methods.

2. Literature review

The construction sector plays a significant role in national economic development and accounts for a dominant portion of rational economic growth (Niu et al., 2023).

Infrastructure is one of the critical drivers of social and economic prosperity, job creation, and inclusive growth. Core infrastructure covers transport, information and communication, energy, water and sanitation infrastructure (Mačiulytė-Šniukienė et al., 2022). Bases on the study result, it can be stated that the funds allocated to road and internet infrastructure should be directed to the regions where this infrastructure is less development (Mačiulytė-Šniukienė et al., 2022).

Contribution to the growth of transport investments is different from region to region. Magazzino and Mele (2021) have highlighted how transport affects economic growth at the aggregate level. However, the lack of infrastructure maintenance eliminates the positive effects of investments over time in the medium term.

The results of study (Palei, 2015) showed that national competitiveness is influenced basically by the level of institutional development and other seven factors, including infrastructure, in turn infrastructure factor is determined mainly by the quality of roads, railroad infrastructure, air transport and electricity supply. The key institutional traps were singled out that prevent the development of the national economy.

Mostafa and El-Gohary (2014) presents a new model for analysing the sustainability of infrastructure project alternatives from a stakeholder-centric perspective: the stakeholder-sensitive, social welfare-oriented sustainability benefit analysis model. The model evaluates infrastructure project alternatives based on a proposed sustainable construction social welfare function (SC-SWF). The SC-SWF is a measure of the collective social, environmental, and economic benefits to all stakeholders.

Makarova et al. (2022) presents a risk management methodology to ensure the security of the transport infrastructure. Risk analysis when implementing a traffic safety management system includes the identification, risk assessment, risk treatment, development of risk management measures, and risk control.

Innovative contacting techniques such as incentive / disincentive contracting could be one tool for ensuring the timely delivery of transportation projects (Sun et al., 2014). This study reports the results from an examination of complected I/D projects in Missouri. Data shows that I/D projects reduced both mobility and safety road user costs.

Urazán-Bonells et al. (2022) contributes to the state of knowledge about the relationship between investment in the road network and economic growth in Latin American countries, specifically in the tertiary and rural road networks. This study concludes that activities in rural zones are the ones that generate the greatest impact on roadway investment within a region.

Public-private partnerships (PPP) are contractual agreements formed between public agencies and private sector entities to allow for greater participation of the private sector in the delivery of transportation projects (Anastasopoulos et al., 2014). The results show that a number of factors play a role in the determination of cost overrun, including the project size (cost, duration, and length), and specific maintenance and rehabilitation activities.

There has been an overall increase in the level of private-sector investment for the road sector in many developing countries during the past decade. However, there has been limited research on the effect of such increased private-sector participation on road costs (Meduri & Annamalai, 2013).

Cirilovic et al. (2014) presents the development of prediction models for the unit costs of road works that could be applied to strategic planning of road works at the network level. The analysis results showed that the level of corruption and the economic environment in a country have a significant effect on both costs of asphalt concrete and road rehabilitation and reconstruction.

Efficiency of road works is conditioned by selection of machines and synchronizing their operations. Modelling these works using queening theory allows the planner to conduct an in-depth analysis of the system's operation to find the best machine types and their optimal number (Jaśkowski et al., 2015).

Work zone optimum length in the highways' resurfacing is an important factor that should be determined before the start of work. This factor influences the time and cost of the project

(Marzouk & Fouad, 2014). The framework consists of two modules; simulation and optimization. Optimization module optimizes the total costs including direct resurfacing operation, indirect / overhead costs, and the impact of work on road users' costs. The latter costs include queening delay cost, accident cost.

Meneses and Ferreira (2013) presents the development and implementation of a Multi-Objective Decision-Aid Tool (MODAT) tested with data from the Estradas de Portugal's Pavement Management System. The MODAT users a multi-objective deterministic section-linked optimisation model with different possible goals: minimisation of agency costs, minimisation of user costs, maximisation of the residual value of pavements, etc.

Choi et al. (2014) develops a conceptual cost production model by combining rough set theory, case-based reasoning, and genetic algorithms to better predict costs in the conceptual planning phase. Rough set theory and qualitative in-depth interviews are to select the proper input attributes for the costs prediction model. Case-based reasoning is then applied to predict road construction costs by considering users' difficulties in the conceptual policy planning phase.

The formulation of scenarios for developing the urban transport infrastructure requires decisions mainly based on the intuition of experts in transport and highly influenced by public interest groups, business entities and political opinions. However, the reached decisions sometimes fail to be the most efficient (Dumbliauskas et al., 2018).

Siverio Lima et al. (2022) applies the Road Network Evaluation Tools (RONET) model to assess the economic impacts of urban pavement maintenance and rehabilitation in the city of Munster, Germany. The results indicate that Muster's current investment program is in line with the "Optimal" budget scenario proposed by RONET.

To ensure a sustainable development of road network, pavement management practices tend to expand the boundary of their life cycle cost analyses to include environmental concerns (Pellecuer et al., 2014). In this context, this study assessed the life cycle environmental benefits of three pavement management strategies applied to a one kilometre long road section located in a densely populated urban are.

Monitoring of critical civil engineering infrastructures has become a priority for public owners and administrative authorities (Bertolini et al., 2023). In the digitalization process of possible pavement's distresses, different developments have been identified to guarantes a better depiction of the road's conditions.

Flexible pavements are one of the vital gears of transportation systems that sustain socio-economic growth for a nation. However, their construction and preservation require large capital investment (Asres et al., 2022). The objective of study by Asres et al. (2022) was to develop a resilience analysis framework, probabilistic life cycle assessment (PLCA) framework and probabilistic life cycle cost analysis (LCCA) framework as the pillars of sustainability.

The impact of the changing climate have caused extensive disruption to the road network in the United Kingdom in recent years. Roads are vital for economic growth and social wellbeing, and a disruption to the network can have disastrous consequences (Begum et al., 2022).

Raffaniello et al. (2022) presents the pavement deterioration models for rutting and thermal cracking in the long-term pavement performance (LTPP) test sections. These models were developed using multiple linear regression considering the pavement service live (age), traffic load (average annual daily truck traffic, AADTT), and climate impact (freezing index, FI).

The condition of the road surface shown by pavement distresses worsens travel conditions (Petkevičius et al., 2019).

The strength and physical properties of the asphalt layer of the road surface are exposed to different temperatures and therefore change.

In determination of flexible pavement layers moduli, the pavement depth temperature should be determined and then the moduli should be corrected into a reference temperature (Solatifar et al., 2018). As direct measurement of pavement temperature is time consuming and is difficult to be determined in trafficked roads. For analysis, design, and rehabilitation purposes of flexible pavement, the temperature profile of asphalt layers should be determined (Sedighian-Fard et al., 2023). The predictive models as an alternative to in-situ measurements, are rapid an easy methods to determine the temperature of asphalt lager at various depths.

Pavement condition evaluation by indicating present performance indicators level should be done timely and accurate at road level and whole network level. Ongoing support of pavement condition under network level, with a long-term strategy, allows to prolong the life of the pavement, improve traffic safety and meet public expectations (Vaitkus et al., 2016).

With a limited amount of funds, it is important to prioritize necessary road repair or reconstruction works. The order (prioritization) of the maintenance of the individual sections of the road is figured out applying the distributive and ideal modes of the Analytic Hierarchy Process (AHP) method (Farhan & Fwa, 2009).

All participants and users of road construction receive benefits; however, their size is likely not the same. These road-related entities are arranged by different categories of experts in line with the benefits they obtain.

3. The model of economic benefits for road construction and using participant

Road construction participants and users look to obtain economic, technical, social and environmental benefits from their activity. The road owner (investor), contractor and users are related (interact) throughout the entire life cycle of the road. The life cycle of the road (LCR) is divided into 3 periods (stages): road design, road construction and road maintenance (use) (Figure 1).

The life cycle of the road (LCR) starts from the conception of road alignment and the justification of road necessity, research into terrain, soil and water, the process of road design, the evaluation of solutions, the public procurement of works organized by the road engineer and the announcement of the contractor (tender winner). The second stage of the LCR covers road construction works the scope and quality of which are controlled conforming to the requirements specified in the contract and normative documents. The built road is comprehensively evaluated with reference to control tests and inspection to recognize it as suitable for use. The third stage of the LCR begins when the road is put into use (operation). At this time, it is needed to take care of the road (routine maintenance of summer and winter periods) and repair pavement distresses and defects of other elements (cracks, breaks, ruts, crumbly wear layer) occurring on the road surface. Due to the inevitable irrationality of repairing cracks, ruts and local distresses, the asphalt or concrete surface is recycled, and at the end, the reconstruction of the layers of the road surface pavement takes place prior to which the LCR ends. Following reconstruction, the other LCR begins.

The road engineer plans to build a road, distributes investments for road design and construction works and provides adequate funds for road maintenance necessary after road construction works are completed and the road is recognized as suitable for use. The builder of the road (the state, i.e., SC "VIA Lietuva", a municipality, a legal or natural person) only incurs costs during the design and construction period. Prior to the construction of the road, the builder designs a construction project at its own expense E_{RD} (Figure 1a cost point *B*′), prepares tender conditions and announces a public tender for road construction works to be done. A contractor selected from a few applicants agrees to perform all the work provided in the contract and in consonance with the technical project in a high-quality manner for the lowest price. When announcing the winner of the tender for construction works, the criterion for economic utility is used less often in practice.

During the period of road construction (from t_1 to t_2), the road engineer from National Budget gives funds E_{RC} to the contractor for quality work provided in the contract and done on time. Also, the road engineer finances the maintenance work of the other roads of state importance (expenses E_{RM}). The number of works and the price of roads constantly increases due to the fact that roads wear overtime t_{RU} (Figure 1 a, b). The construction contractor incurs road construction costs E_{RC} less than income I_{RC}, which allows to earn profit P_{RC}, i.e., receive economic benefits. When supervising the maintained road, the contractor also goes to expenses E_{RM}, which, being lower than income I_{RM}, allows to bring profit P_{RM}. The expenses of the road engineer for the construction of the road E_{RC} are equal to the income generated by the construction contractor I_{RC} and received for the construction work performed.

When a newly built or reconstructed road is put into operation, the costs of the builder $E_{RD} + E_{RC}$ are continuously returned overtime t_{RU} in the form of the collected taxes subject to the number of the vehicles on the road (traffic intensity), vehicle mass, the amount and price of fuel consumed, the part of the excise revenue, freight vehicles, the number of road taxes and fines for speeding.

The road pays off when $I_{NB} > E_{RD} + E_{RC} + E_{RM}$. The payback period t_{PP} is reduced by increasing traffic intensity of vehicles and by the number of heavy vehicles in particular, the price of fuel, the share of excise duties assigned by the National Budget administered by the Government of the Republic of Lithuania. The road would pay off faster (time from t_2 to t_3 would decrease) if there were no operating costs (Figure 1a, line 1). As for road maintenance, funds E_{RM} are always distributed, which increases the payback time of the road t_{pp} from t_2 to t_4 (Figure 1a, curve 2).

The road users carrying cargo and passenger transportation and the entities earning indirect income have economic benefits I_{RU} that are greater than their incurred costs E_{RU} (Figure 1c). The difference between income I_{RU} and expenses E_{RU} stands for the profit received by road users P_{RU}.

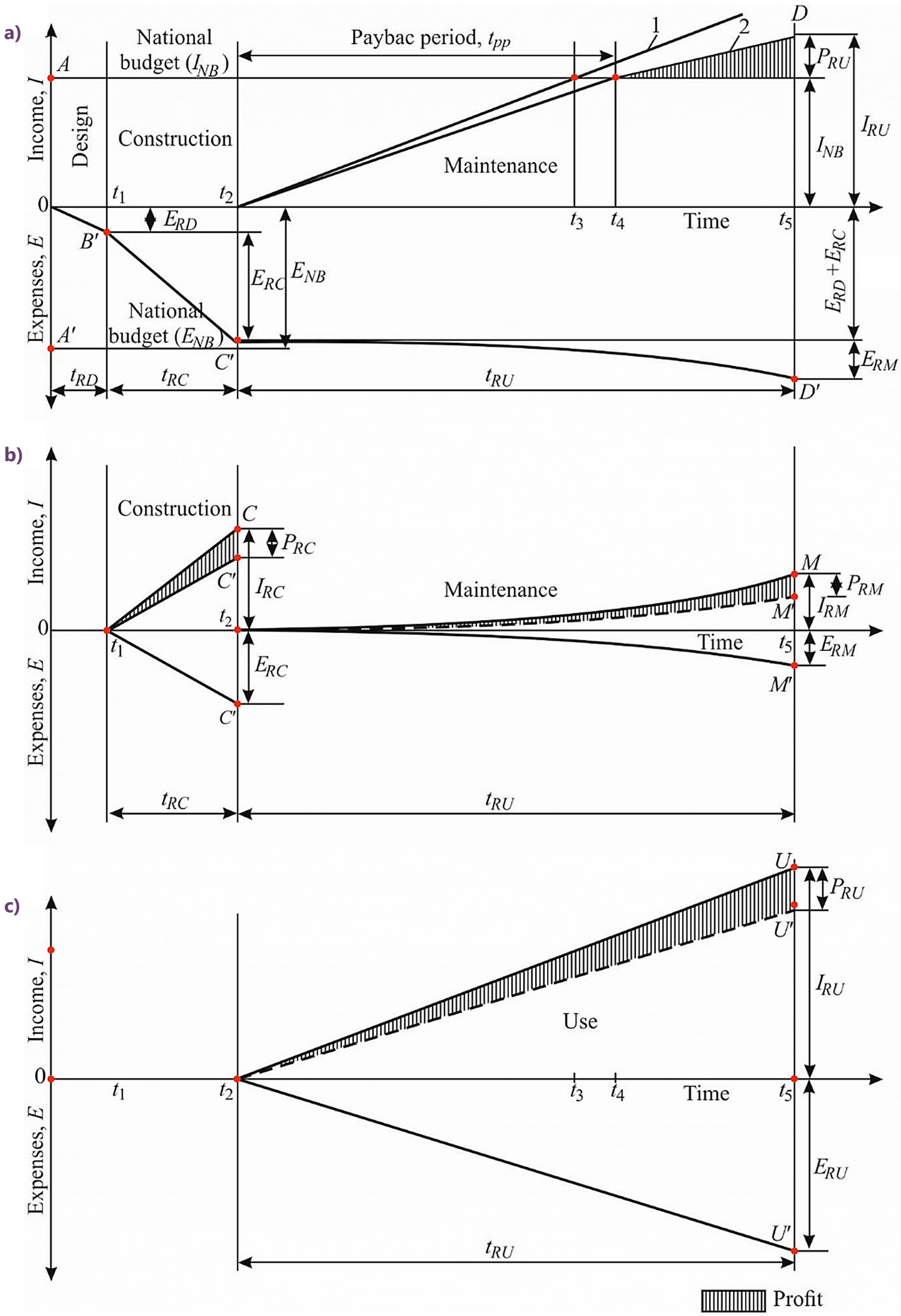

Figure 1. The model of economic benefits for road construction participants and users during road life cycle: a – road contracting authority; b – road building contractor; c – road users

4. The definitions of entity-related roads

Beneficiary entities interact with a road throughout its life cycle. A full description of the entities is given below in random order.

A. **Road researchers and designers.** A researcher and designer of a new or reconstructed road (developers of a technical assignment, a technical project or a work project, co-ordinators, environmental impact assessors) – *RRD*.

B. **Suppliers of road materials.** The manufacturers, distributors and importers of materials, mixtures, constructions and equipment (traffic management, accounting and control, road weather information systems and other Intelligent Transport Systems (ITS)) for road construction, repair and maintenance – *SRM*.

C. **Machinery and equipment manufacturers.** The manufacturers, sellers and repairers of machinery and equipment needed for producing materials and mixtures, performing work on the construction site and supporting roads – *MEM*.

D. **Material and construction carriers.** The carriers of soil, materials, mixtures, construction structures, products and other elements (providers of transport services for the construction contractor and subcontractors) – *MCC*.

E. **Road building contractor and subcontractors.** The construction contractor and subcontractors performing works won by the tenders in line to the projects approved by the Road Maintenance and Development Programme (RMDP) at the construction site – *RBC*.

F. **Owner in road construction.** A road engineer investing funds in construction (client, the owner of the forthcoming road) – the state or its representative institution (SC "VIA Lietuva"), a municipality, a legal or natural person – *ORC*.

G. **Institution of production-based activities.** National institutions and joint-stock companies performing manufacturing activities (industry, construction, agriculture, mining, forestry, etc.) and transporting raw materials, manufactured products, equipment and employees – *IPA*.

H. **Road side property owners.** The owners of the plots of land to be bought or taken for public use and the owners of the plots of roadside business enterprises found next to the road and at the site of road construction, the owners selling or renting real estate and providing services for road users – *RSPO*.

I. **Trade and service institutions.** The institutions performing trade, tourism, public catering, health care, leisure, special and other types of service activities – *TSI*.

J. **People having a better living standard determined by higher GDP.** The residents of the country improving the personal quality of life due to the increasing share of the gross domestic product (GDP) created in the road transport sector and reducing environmental pollution through driving on higher quality roads – *PBLS*.

K. **Increased mobility on behalf of citizens.** The residents using the road to increase personal mobility, to shorten and cheapen the journey between countries, cities, towns, settlements and single farms (homesteads), to promote geographical accessibility and to travel more safely due to a better quality of roads – *IMC*.

L. Specialists involved in road building. People working in the road construction and maintenance sector, reducing the number of the unemployed nationwide and thus improving the quality of personal and family life – *SRB*.

M. Professional training and certification. Training, qualification improvement and certification institutions for those working in the fields of road construction, including universities, colleges, vocational training centers, the organizers of special lectures, Construction Production Certification Center – *PTC*.

N. Organizers of public procurement. The institutions arranging and executing public procurements for the construction of road transport infrastructure (road building) – *OPP*.

O. Transportation and logistics institutions. The entities of the institutions (Lithuanian National Road Carriers' Association *Linava*, Lithuanian National Association of Freight Forwarders and Logistics *Lineka*, Lithuanian Logistics Association, ITS Lithuania, etc.) performing transportation, warehousing and coordination services in road construction (in other sectors of production and non-production activity) among other states and within the country – *TLI*.

P. Consultants, experts, scientists. Road construction advisers, project experts and structural engineers, project execution managers, scientists, technical supervisors of the construction site, legislative drafters – *CES*.

Q. Road vehicle manufacturers. The manufacturers and sellers of road vehicles (cars, motorcycles, bicycles, etc.) and vehicle-related parts, repairers, technical inspection performers – *RVM*.

R. Road traffic supervisors. The institutions supervising, regulating and controlling road traffic, protecting the environment from traffic pollution and ending the consequences of traffic accidents – *RTS*.

S. Fuel and power vendors. The suppliers and sellers of fuel, lubricants and electricity for vehicles, road construction and maintenance machinery and equipment – *FPV*.

The above introduced nineteen entities, hereinafter referred to as criteria, are compared with each other thus assigning them a priority considering their ranks or weights. Also, the significance by weight of the benefits of the entities falling into 3 hierarchically structured categories is assessed. The groups of the entities consist of a road owner or an investor, the road construction contractor and subcontractors and road users, hereinafter referred to as the main criteria.

5. The interaction model of the entities

The road developer manages funds for the design, construction and maintenance of the road. These investments in construction consist of the state budget, municipal funds, corporate and private funds, support from European Union (EU) repayable funds and bank loans (Figure 2). The road engineer (F) designs the road (A) at its own expense and conducts public procurement (N). These three entities (F, A and N) form the first main criterion.

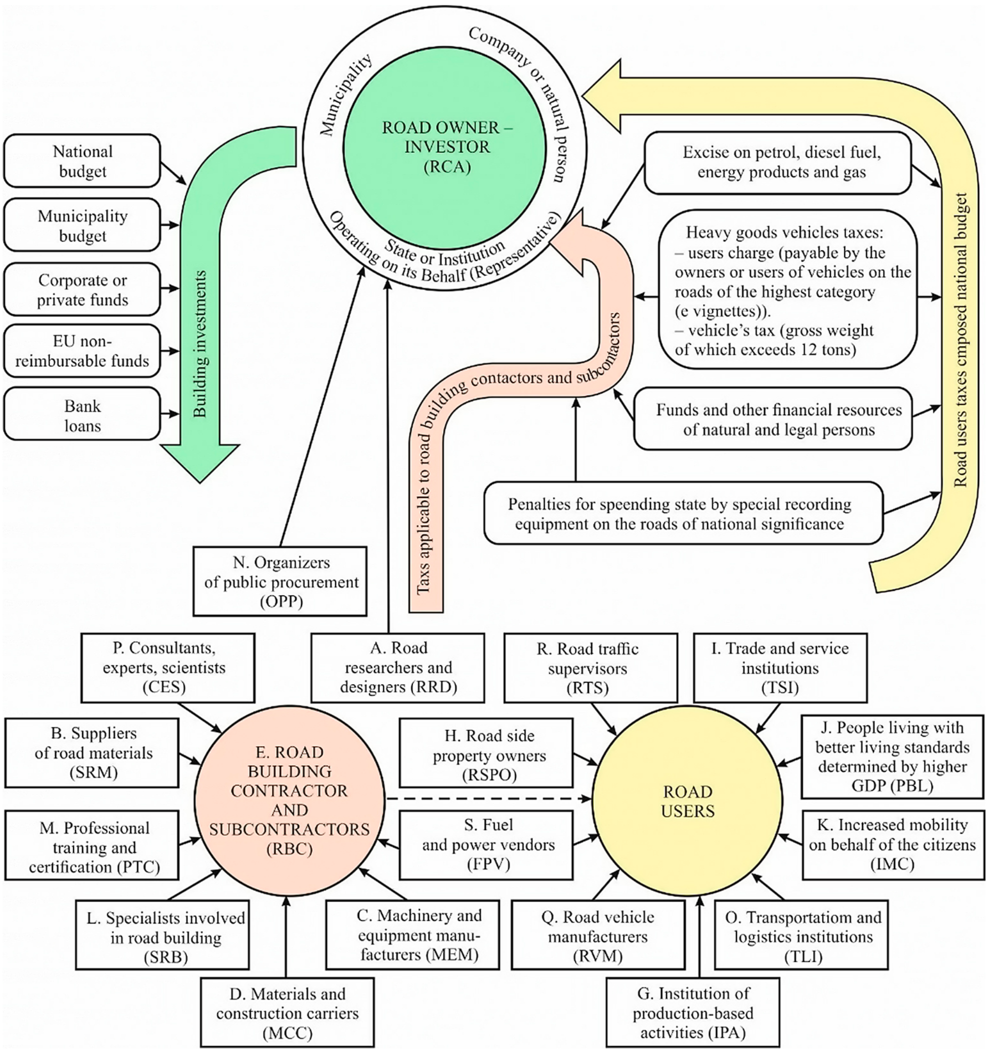

Figure 2. The interaction model for road building participants and users entities with benefits

The construction contractor is the most important entity conducting road construction works and coordinating the work done by subcontractors so that the road is qualitatively built in agreement to the project and on time, using the given funds and following all other requirements of the contract.

The road construction contractor (E) and subcontractors (B, C, D, L, M, P) who win the public procurement tender conducts construction works. The entities doing works pay state-imposed taxes forming a part of construction investment managed by the road engineer. The structure of the taxes paid by the construction contractor and subcontractors is the same as that of road users. The taxes cover a part of excise revenue for sold motor fuel and gas for cars, targeted and other funds created by freight vehicles (FV) registered in the Republic of Lithuania (LR) and road users, large goods and heavy-duty vehicles on the roads, traffic restriction, legal and natural persons, fines for speeding recorded by stationary equipment on the roads of national significance (RNS).

Road users (entities G, H, I, J, K, O, Q, R, S) gain economic benefits from transportation and activities not related to transporting goods and, after paying all taxes, i.e., make profit. In addition to economic benefits, road users receive technical, social and environmental benefits that are also noteworthy and can be explored.

6. The method for calculating the significance of criteria

6.1. The justification of the selected methods

As for the experts assessing the importance of criteria, the rank correlation method (Kendall & Gibbons, 1990) is the simplest, because all criteria are given places (ranks) from 1 to 19 from the most to the least important. The rank is the place occupied by a criterion on the ranking scale. A large number of the assessed criteria prevented the application of the popular Analytic Hierarchy Process (AHP) method best suited when 7 criteria are compared with each other or when the number of criteria varies from 5 to 9 (Saaty & Ozdemir, 2003). Thus, for studying a vast number of criteria, they are divided into a hierarchical structure.

Although the significance of the ranked criteria writes down that one criterion is more important than the other, it does not show the size of the difference. Moreover, the evaluator has a better understanding of the principle illustrating that the most important criterion is given the highest numerical estimate, i.e., weight. Weights are mostly normalized, i.e., the sum of the weights of all entities (criteria) is equal to 1. Criterion significance expressed by their normalized subjective weights is figured out applying different algorithms (methods). None of these techniques has a theoretical advantage over the other methods. All of them allow us to set the same priority of criterion significance, but the differences between the highest and lowest weights may vary drastically, i.e., the methods of different "sensitivity".

6.2. Average rank transformation into weight (ARTIW) methods

Expert evaluation methods allow to calculate the normalized subjective weights of criteria considering the averages of criterion ranks. The average of the ranks (j = 1, 2, ..., n) of each criterion the number of which is i = 1, 2, ..., m is worked out by experts n and calculated as follows:

$$\bar{R}_i = \frac{\sum_{j=1}^{n} R_{ij}}{n}, \tag{1}$$

where R_{ij} is the rank assigned to the *i-th* criterion by the *j-th* expert.

From the average of the ranks $\bar{R}_i$, the normalized weight ω_i of each criterion is calculated. Since ω_i has the linear functional relationship with $\bar{R}_i$, the latter expert evaluation method is called the ARTIW-L (Average Rank Transformation into Weight – Linear) method (Sivilevičius, 2011):

$$\omega_i^{\text{ARTIW-L}} = \frac{m - \bar{R}_i + 1}{\sum_{i=1}^{m} \bar{R}_i}, \tag{2}$$

where $\bar{R}_i$ is the arithmetic mean of the ranks of the *i-th* criterion; m is the number of the criteria describing the research object.

The normalized weights of criteria are calculated using the other technique called the Average Rank Transformation into Weight – Nonlinear (ARTIW-N) method (Maskeliūnaitė & Sivilevičius, 2021):

$$\omega_i^{\text{ARTIW-N}} = \frac{\min_i \bar{R}_i}{\bar{R}_i \sum_{i=1}^{m} \frac{\min_i \bar{R}_i}{\bar{R}_i}}, \tag{3}$$

where $\min_i \bar{R}_i$ is the significance of the most important criterion having the lowest arithmetic mean of the ranks; $\bar{R}_i$ is the average of the ranks of the *i-th* criterion; m – the number of the criteria describing the research object. The normalized weights of the criteria calculated using both methods of transforming ranks into weights differ slightly, but the priorities of criterion significance remain the same (Sivilevičius & Martišius, 2023).

6.3. The consistency of expert opinions

In order for the opinions of the expert group on the significance of the criteria expressed as the averages of the normalized weights to be taken as the result of solving the problem, opinion consistency is necessary. Only when the evaluations of all experts are similar (insignificantly different), the weight of the criterion is a reliable solution to the problem.

Concordance coefficient W calculated from the below formula shows the consistency of the opinions of the expert team:

$$W = \frac{12 \cdot \sum_{i=1}^{m} \left[\sum_{j=1}^{n} R_{ij} - \frac{n(m+1)}{2} \right]^2}{n^2 m \left(m^2 - 1\right)}. \tag{4}$$

The calculated value of concordance coefficient W is compared with its minimum threshold value $W_{\min}$ subject to the number of the degrees of freedom $\nu = m - 1$, the selected level of significance α, the statistical critical value of Pearson's chi-square $\chi_{v,a}$, the number of criteria m and the number of experts n (Sivilevičius, 2011):

$$W_{\min} = \frac{\chi_{v,a}^2}{n(m-1)}. \tag{5}$$

In practice, significance level $\alpha = 0.05$ is usually chosen. Critical value $\chi_{v,a}^2$ is taken from a table of mathematical statistics (Montgomery et al., 2007).

The consistency of the opinions of the expert group is checked calculating the empirical value of chi-square χ^2:

$$\chi^2 = \frac{12 \cdot \sum_{i=1}^{m} \left[\sum_{j=1}^{n} R_{ij} - \frac{n(m+1)}{2} \right]^2}{nm(m+1)}. \tag{6}$$

Having set up that $W > W_{\min}$ and $\chi^2 > \chi_{v,a}^2$, it is possible to calculate the number of times the results obtained from research data (expert opinions) are greater than the critical values. In that case, the consistency coefficient of expert opinions is calculated (Sivilevičius & Martišius, 2023):

$$k_c = \frac{W}{W_{\min}} = \frac{\chi^2}{\chi^2_{v,a}}. \tag{7}$$

When expert opinions are not contradictory (consistent), then $k_c > 1$, and when the opinions differ significantly, $k_c < 1$. The actual consistency coefficient of expert opinions k_c is compared with the maximum possible value of the coefficient $k_{c\max} = W_{\max}/W_{\min}$. The maximum value $k_{c\max}$ is obtained dividing 1 by $W_{\min}$ subject to the number of criteria m, which shows the same ranks given by all experts to each criterion, i.e. the experts have absolutely the same opinion.

6.4. The average weights of the criteria established by three categories of experts

The normalized weights $\omega_i^{\text{ARTIW-L}}$ and $\omega_i^{\text{ARTIW-N}}$ of the criteria calculated applying ARTIW-L ir ARTIW-N methods considering the averages of the ranks assigned to criteria by the experts differ slightly. The above mentioned methods do not have a theoretical advantage over each other, and therefore the calculated averages of criterion weights are more exact than the weights calculated employing one of the methods. The average of criterion weights ω_i^{ARTIW} is calculated by the formula:

$$\omega_i^{\text{ARTIW}} = \frac{\omega_i^{\text{ARTIW-L}} + \omega_i^{\text{ARTIW-N}}}{2}. \tag{8}$$

When the opinion of two or more categories of experts is used in the study, the total average of the weights given to criteria by all categories of experts $\bar{\omega}_i^{\text{ARTIW}}$ is calculated by the formula:

$$\bar{\omega}_i^{\text{ARTIW}} = \frac{\sum_{e=1}^{r}\left(\frac{\omega_i^{\text{ARTIW-L}} + \omega_i^{\text{ARTIW-N}}}{2}\right)_e}{r}, \tag{9}$$

where $\omega_i^{\text{ARTIW-L}}$ and $\omega_i^{\text{ARTIW-N}}$ are the weights of the *i-th* criterion calculated using ARTIW-L and ARTIW-N methods respectively; r is the number of expert categories involved in the study ($e = 1, 2, ..., r$).

As for this study, the significance of criteria (benefit entities) was assessed by three categories of experts, including road engineers, transport engineers and traffic participants, and hence $r = 3$.

6.5. The inverse hierarchy for assessment main criteria importance (IHAMCI) method

When the research object consists of numerous criteria, they are divided into the hierarchical multi-level structure. The classic hierarchy is most often applied. The inverse hierarchy allows the hierarchically unstructured criteria to be divided into separate groups called the main criteria and to calculate the normalized weights of each of them thus comparing the weights conforming to significance (Maskeliūnaitė & Sivilevičius, 2021).

The paper has ranked 19 entities receiving benefits from roads and divided them into 3 groups, i.e. the main criteria considering the nature of the interaction of the entities representing these groups with the road. The first main criterion consists of three entities (A, F, N), the second includes seven entities (B, C, D, E, L, M, P) and the third one involves nine entities (G, H, I, J, K, O, Q, R, S).

The normalized weight $\tilde{\omega}_c$ of the main *c-th* criterion (c = 1, 2, ..., k) made of m_c criteria (i = 1, 2, ..., m_c) is calculated using the Inverse Hierarchy for Assessment Main Criteria Importance (IHAMCI) method:

$$\tilde{\omega}_c = \frac{\dfrac{\sum_{i=1}^{m_c} \bar{\omega}_i}{m_c}}{\sum_{c=1}^{k} \left(\dfrac{\sum_{i=1}^{m_c} \bar{\omega}_i}{m_c} \right)}, \tag{10}$$

where $\bar{\omega}_i$ is the global normalized weight of the *i-th* sub-criterion determined using ARTIW or other methods; k is the number of benefit entities of the main criteria that make up the research object (c = 1, 2, ..., k); m_c is the number of the sub-criteria forming the *c-th* main criterion (i = 1, 2, ..., m_c).

The normalized weights of individual sub-criteria and the main criteria allow us to find their significance and priority in comparison with each other. As a result, the study was conducted with reference to the above introduced methods.

7. Experts

The conducted research applied to the three categories of expert opinions. All 132 experts agreed to fill in the questionnaire and fell into 3 categories considering the nature of their relation to road transport, qualifications and knowledge. The number of road engineers (RE) and transport engineers (TE), i.e. the number of experts in the field was similar (35 and 36 respectively). The number of traffic participants (TP) was almost 2 times higher (61) (Table 1), because it was expected that the consistency of their opinions would be not that high due to lower qualifications, which requires increasing the number of evaluators.

The scientific discussion of determining of necessary minimum number of experts is still ongoing.

A sufficient number of the experts able to obtain reliable results can be checked calculating standard deviations from expert opinions expressed as ranks. Having set the required accuracy (acceptable margin of error) Δ_i and significance level α figuring out the critical value

Table 1. Experts who assessed the significance of benefits received by roads related entities

Abbreviation	Expert category	Number of experts in the category	
		Total	Doctors of Science
RE	Road engineers	35	11
TE	Transport engineers	36	30
TP	Traffic participants	61	7

of t-student's criterion, it is possible to calculate the smallest number of experts $n_{\min}$ in line to the sample size formula. Scientific literature suggests confirming this number embodying other principles, for example, it is said that the number of experts must be greater than that of criteria. Actually, the common statement proposes that the number of data $n \geq 30$ required for research is barely justified due to the fact that in one case such number of studies is sufficient enough if dispersion is small whereas in the other – it is insufficient.

The expert was given the prepared questionnaire on criterion description (Chapter 3) following the discussion on the purpose of the study and having received verbal consent to fill the questionnaire in.

8. Results and discussion

In order for the averages of significance (ranks or weights) determined to criteria for the sample size calculated by the expert team in each category of experts n to be taken as a reliable result of solving the problem, the consistency of the opinions expressed by the respondents was examined. The values of concordance coefficient W, Pearson's chi-square (χ^2) test and consistency coefficient k_c are provided in Table 2.

Table 2. The results of consistency in the significance of the benefits received by road-related entities considering opinions expressed by different categories of experts

Expert category	Statistics for rank consistency					Conclusion on the consistency of expert opinions
	W	$W_{\min}$	χ^2	$\chi^2_{v,a}$	k_c	
Road engineers (RE)	0.211	0.055	133.1	34.8	3.82	consistent opinions
Transport engineers (TE)	0.305	0.054	197.5	34.8	5.68	consistent opinions
Traffic participants (TP)	0.113	0.032	123.6	34.8	3.55	consistent opinions

The strict level of significance $\alpha = 0.01$ was accepted in the study, and therefore the critical value of the Pearson distribution was equal to $\chi^2_{18;\ 0.01} = 34.8$. The obtained data show that the values of W and χ^2 calculated pursuant to formulas (4)–(7) are from 3.55 to 5.68 times higher than the critical values of $W_{\min}$ and $\chi^2_{v,a}$. The opinions of all categories of experts are consistent, but the degree of consistency varies. The opinions of transport engineers are the most consistent (k_c = 5.68), while road users are in the worst position (k_c = 3.55). The higher qualifications owned by experts, the more consistent are the opinions of the expert team.

The averages of the ranks of all road-related and thus benefit-receiving entities (criteria) $\bar{R}_i$, weights $\omega_i^{\text{ARTIW-L}}$ and $\omega_i^{\text{ARTIW-N}}$ are calculated employing ARTIW-L and ARTIW-N methods applying formulas (1), (2) and (3). Calculation data (Table 3) reflect that the evaluations of the experts standing for different categories vary. The largest differences between the most and less important ranks (Figure 3a) of criteria and the normalized weights (Figure 3b) were calculated from the survey questionnaires completed by transport engineers, i.e., the experts having the highest qualification and the highest degree of consistency in opinions (Figure 3).

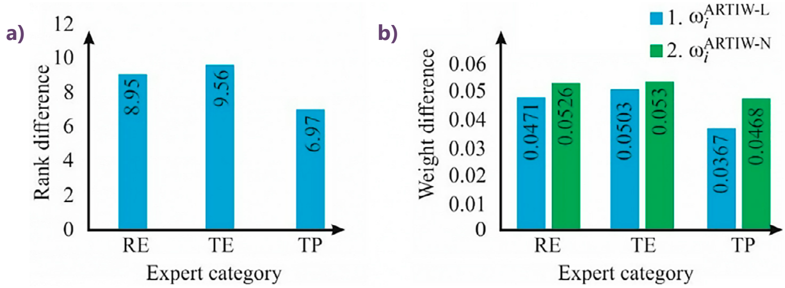

Figure 3. Differences in the significance of the entities gaining the highest and lowest road-related benefits found by the experts of various categories: a – ranks; b – weights

The weights of the benefits received by 19 road-related entities (criteria) set by the categories of experts, including road engineers (RE) (Figure 4a), transport engineers (TE) (Figure 4b) and traffic participants (TP) (Figure 4c), are calculated applying ARTIW-L and ARTIW-N methods and presented from the highest to the lowest values in Figure 4. The sequence of decreasing criterion weights varies. However, the observed trend suggests that the experts of all categories specify the same entities having the most substantial and the most insignificant benefits.

The average weights ω_i^{ARTIW} calculated using ARTIW-L and ARTIW-N methods in line to formula (8) are presented in Table 4 and are more reliable than weights $\omega_i^{\text{ARTIW-L}}$ or $\omega_i^{\text{ARTIW-N}}$ calculated applying one of the above introduced methods.

The averages of criterion ranks $\overline{\overline{R}}_i$ evaluated by three categories of experts (RB, TE, TP) and the global averages of weights $\bar{\omega}_i^{\text{ARTIW}}$ made it possible to determine the overall priority of criteria $\overline{P}$ (Table 4). In agreement to the results of the conducted research, the experts suppose that the residents increasing mobility (K), those improving live conditions (J), owner in road construction (F), the construction contractor and subcontractors (E) and the institutions of manufacturing (G) gain most benefit from road construction. As many as 3 road user entities fall into this top five.

The similarity of expert opinions in these categories was evaluated calculating differences in criterion priorities $\Delta P_{\text{RE–TE}}$, $\Delta P_{\text{RE–TP}}$ ir $\Delta P_{\text{TE–TP}}$ (Table 5). The sums of the modules of criterion priorities compared in pairs $\sum_{e=1}^{r} \left|\Delta P_e\right|$ range from 2 to 14. The opinions of the experts of individual categories are the closest (the sum of the modules of priorities is equal to 2) when assessing the benefits of road researchers and designers (A), increased mobility on behalf of citizens (K), the organizers of public procurement (N), consultants, experts, scientists (P) and road vehicle manufacturers (Q). The average opinions of the experts of individual categories differ the most (the sum of the modules of priorities is equal to 14 and 10) when assessing the benefits of trade and service institutions (I), suppliers of road materials (B) and the road building contractor and subcontractors (E).

The benefits of the construction contractor and subcontractors are evaluated almost equally by road engineers and transport engineers (priorities $P_{\text{RE}} = 4$ ir $P_{\text{TE}} = 3$). However, traffic participants assigned a lower priority to the benefit of criterion E, $P_{\text{TP}} = 8$ (Table 4).

Table 3. The significance of the benefits received by road-related entities throughout the complete life cycle of the road determined by different categories of experts applying different methods

Entities (criterion)	Road engineers, n_{RE} = 35				Transport engineers n_{TF} = 36				Traffic participants n_{TP} = 61			
	Rank average $\bar{R}_i$	Weight of the ARTIW-L method $\omega_i^{ARTIW\text{-}L}$	Weight of the ARTIW-N method $\omega_i^{ARTIW\text{-}N}$	Priority	Rank average $\bar{R}_i$	Weight of the ARTIW-L method $\omega_i^{ARTIW\text{-}L}$	Weight of the ARTIW-N method $\omega_i^{ARTIW\text{-}N}$	Priority	Rank average $\bar{R}_i$	Weight of the ARTIW-L method $\omega_i^{ARTIW\text{-}L}$	Weight of the ARTIW-N method $\omega_i^{ARTIW\text{-}N}$	Priority
A (RRD)	10.40	0.0505	0.0473	11	9.94	0.0529	0.0483	12	10.38	0.0506	0.0488	11
B (SRM)	9.03	0.0577	0.0545	9	7.11	0.0678	0.0576	4	8.95	0.0582	0.0566	7
C (MEM)	10.86	0.0481	0.0453	12	9.47	0.0554	0.0507	10	9.84	0.0535	0.0515	10
D (MCC)	12.63	0.0388	0.0389	15–16	9.81	0.0537	0.0490	11	11.54	0.0445	0.0439	13
E (RBC)	7.54	0.0656	0.0652	4	6.42	0.0715	0.0749	3	9.03	0.0577	0.0561	8
F (ORC)	7.17	0.0675	0.0686	3	6.36	0.0718	0.0756	2	8.87	0.0586	0.0571	6
G (IPA)	7.83	0.0641	0.0628	5	7.36	0.0665	0.0653	6	8.00	0.0632	0.0633	2
H (RSPO)	10.09	0.0522	0.0488	10	8.86	0.0586	0.0542	8	10.54	0.0498	0.0481	12
I (TSI)	8.26	0.0618	0.0595	6	10.58	0.0496	0.0452	13	9.29	0.0563	0.0546	9
J (PBLS)	5.71	0.0752	0.0861	1	7.22	0.0673	0.0666	5	8.02	0.0631	0.0632	3
K (IMC)	6.40	0.0716	0.0768	2	5.69	0.0753	0.0845	1	5.88	0.0743	0.0862	1
L (SRB)	8.91	0.0583	0.0552	8	9.85	0.0566	0.0520	9	8.56	0.0602	0.0592	5
M (PTC)	11.20	0.0463	0.0439	13	12.89	0.0374	0.0373	15	11.87	0.0428	0.0427	17
N (OPP)	14.66	0.0281	0.0335	19	15.25	0.0250	0.0315	19	12.69	0.0385	0.0399	18
O (TLI)	8.40	0.0611	0.0586	7	8.33	0.0614	0.0577	7	8.43	0.0609	0.0601	4
P (CES)	11.63	0.0441	0.0423	14	11.89	0.0427	0.0404	14	11.75	0.0434	0.0431	15
Q (RVM)	13.29	0.0353	0.0370	17	14.31	0.0300	0.0336	16	11,80	0.0431	0.0429	16
R (RTS)	12.63	0.0388	0.0389	15–16	14.61	0.0284	0.0326	17	12.85	0.0376	0.0394	19
S (FPV)	13.27	0.0349	0.0369	18	14.64	0.0282	0.0328	18	11.70	0.0437	0.0434	14
Total	190	1.0000	1.0000	190	190	1.0000	1.0000	190	190	1.0000	1.0000	190

The modulus of the sum of differences in priorities of all 19 criteria is equal to 34, which shows that the evaluations of road engineers and transport engineers are much closer than those of road engineers and traffic participants (the modulus of the sum of differences is 44) as well as those of transport engineers and traffic participants (the modulus of the sum of differences is 46) (Table 5).

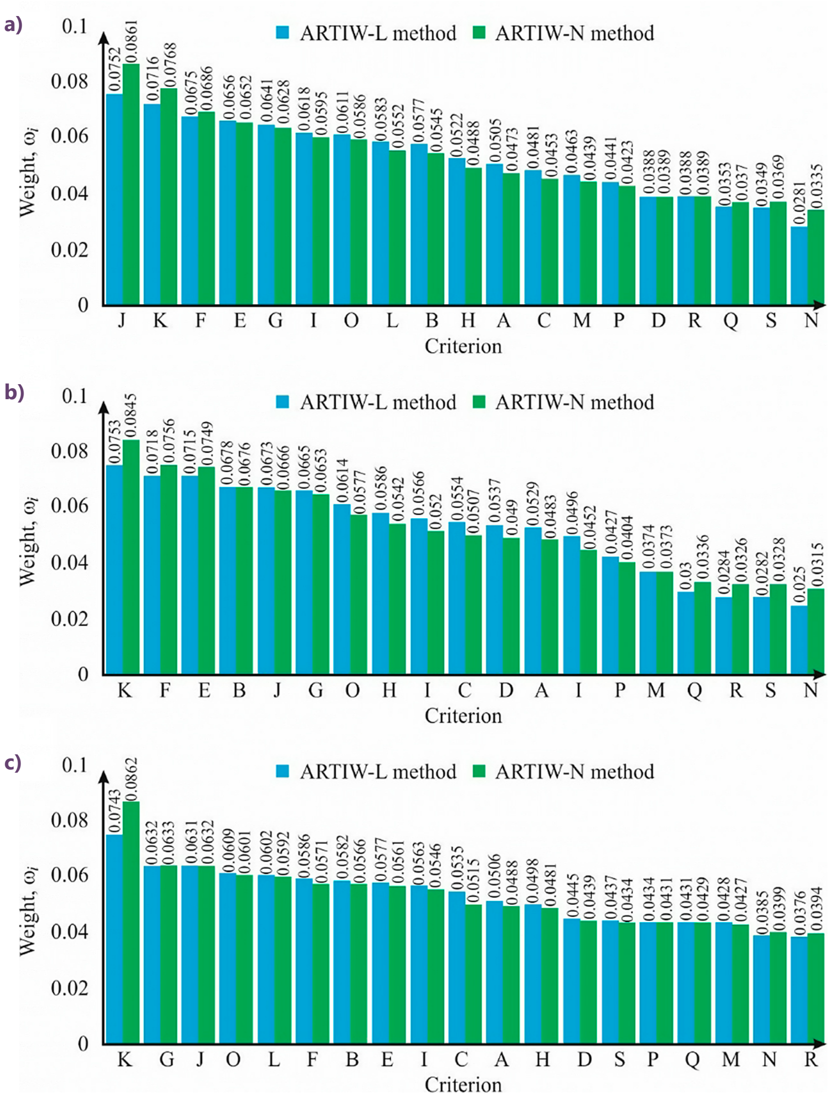

Figure 4. Criterion weights given by the experts of different categories: a – road engineers; b – transport engineers; c – traffic participants

The significance of benefit entities (main criteria) classified conforming to the nature of interaction with the road (Figure 2) was calculated applying the IHAMCI method (Table 6). The normalized weights of the main criteria $\tilde{\omega}_c$ were calculated in line to formula (10). Calculation results show that road users benefit the most from road construction ($\tilde{\omega}_{RB}$ = 0.3485). The road construction contractor and subcontractors benefit less ($\tilde{\omega}_{BC}$ = 0.3325) and the road owner (investor) ($\tilde{\omega}_{RU}$ = 0.3190) benefit the least.

Table 4. Arithmetic averages and priorities of the global weights given to the criteria by experts of individual categories and experts of all categories

Entity (criterion)	Road engineers			Transport engineers			Traffic participants			Average of the three expert categories		
	Rank average $\bar{R}_i$	Weighted average of ARTIW-L and ARTIW-N methods $\omega_{i,K}^{ARTIW}$	Priority P_{EC}	Rank average $\bar{R}_i$	Weighted average of ARTIW-L and ARTIW-N methods $\omega_{i,K}^{ARTIW}$	Priority P_{TE}	Rank average $\bar{R}_i$	Weighted average of ARTIW-L and ARTIW-N methods $\omega_{i,K}^{ARTIW}$	Priority P_{TP}	Rank average $\bar{R}_i$	Weighted average of ARTIW-L and ARTIW-N methods $\omega_{i,K}^{ARTIW}$	Overage priority $\bar{P}$
A(RRD)	10.40	0.0489	11	9.94	0.0506	12	10.38	0.0497	11	10.24	0.0497	12
B(SRM)	9.03	0.0561	9	7.11	0.0677	4	8.95	0.0574	7	8.36	0.0604	6
C(MEM)	10.86	0.0467	12	9.47	0.0530	10	9.84	0.0525	10	10.06	0.0507	11
D(MCC)	12.63	0.0389	15	9.81	0.0514	11	11.54	0.0442	13	11.33	0.0448	13
E(RBC)	7.54	0.0654	4	6.42	0.0732	3	9.03	0.0569	8	7.66	0.0652	4
F(ORC)	7.17	0.0681	3	6.36	0.0737	2	8.87	0.0578	6	7.47	0.0665	3
G(IPA)	7.83	0.0634	5	7.36	0.0659	6	8.00	0.0633	2	7.73	0.0642	5
H(RSPO)	10.09	0.0505	10	8.86	0.0564	8	10.54	0.0489	12	9.83	0.0519	10
I(TSI)	8.26	0.0606	6	10.58	0.0474	13	9.29	0.0555	9	9.38	0.0545	9
J(PBLS)	5.71	0.0807	1	7.22	0.0670	5	8.02	0.0632	3	6.98	0.0703	2
K(IMC)	6.40	0.0742	2	5.69	0.0799	1	5.88	0.0803	1	5.99	0.0782	1
L(SRB)	8.91	0.0567	8	9.25	0.0543	9	8.56	0.0597	5	8.91	0.0569	8
M(PTC)	11.20	0.0451	13	12.89	0.0373	15	11.87	0.0427	17	11.99	0.0417	15
N(OPP)	14.66	0.0308	19	15.25	0.0283	19	12.69	0.0392	18	14.20	0.0328	19
O(TLI)	8.40	0.0599	7	8.33	0.0596	7	8.43	0.0605	4	8.39	0.0600	7
P(CES)	11.63	0.0432	14	11.89	0.0416	14	11.75	0.0432	15	11.76	0.0427	14
Q(RVM)	13.29	0.0361	17	14.31	0.0318	16	11,80	0.0430	16	13.13	0.0370	16
R(RTS)	12.63	0.0388	16	14.61	0.0305	17	12.85	0.0385	19	13.36	0.0359	18
S(FPV)	13.27	0.0359	18	14.64	0.0304	18	11.70	0.0435	14	13.20	0.0366	17
Total	190.00	1.0000	190	190.00	1.0000	190	190.00	1.0000	190	190.00	1.0000	190

Table 5. Modules of differences in criterion priorities calculated by the pairwise comparison of evaluations of the experts of different categories

Benefit entity (criterion)	Difference in priorities ΔP_e			Module of the sum of differences in priorities $\sum_{e=1}^{r} \lvert \Delta P_e \rvert$
	ΔP_{RE-TE}	ΔP_{RE-TP}	ΔP_{TE-TP}	
A. Road researchers and designers	–1	0	1	2
B. Suppliers of road materials	5	2	–3	10
C. Machinery and equipment manufacturers	2	2	0	4
D. Material and construction carriers	4	2	–2	8
E. Road building contractor and subcontractors	1	–4	–5	10
F. Owner in road construction	1	–3	–4	8
G. Institution of production-based activities	–1	3	4	8
H. Roadside property owners	2	–2	–4	8
I. Trade and service institutions	–7	–3	4	14

End of Table 5

Benefit entity (criterion)	Difference in priorities ΔP_e			Module of the sum of differences in priorities $\sum_{e=1}^{r}\left\|\Delta P_e\right\|$
	$\Delta P_{\text{RE–TE}}$	$\Delta P_{\text{RE–TP}}$	$\Delta P_{\text{TE–TP}}$	
J. People having a better living standard figured out by higher GDP	–4	–2	2	8
K. Increased mobility on behalf of the citizens	1	1	0	2
L. Specialists involved in road building	–1	3	4	8
M. Professional training and certification	–2	–4	–2	8
N. Organizers of public procurement	0	1	1	2
O. Transportation and logistics institutions	0	3	3	6
P. Consultants, experts, scientists	0	–1	–1	2
Q. Road vehicle manufacturers	1	1	0	2
R. Road traffic supervisors	–1	–3	–2	6
S. Fuel and power vendors	0	4	4	8
Module of the sum of differences in priorities	34	44	46	124

Table 6. The significance of benefits for road-related entity groups (main criteria) calculated applying the IHAMCI method

Benefit entity (criterion)	The average global weight $\overline{\omega}_i$	Overall priority $\overline{P}$	Description of the main criterion and size m_c	Benefit entity (criterion)	The average global weight of sub-criteria $\overline{\omega}_i$	The sum of the average global weight in the main criterion $\sum_{i=1}^{m_c}\overline{\omega}_i\cdot\omega_c$	Normalized local weight $\omega_i=\frac{\overline{\omega}_i}{\omega_c}$	Average weight of the sub-criteria for the main criterion $\overline{\omega}_c=\frac{\omega_c}{m_c}$	The weight of main criteria $\tilde{\omega}_c=\frac{\overline{\omega}_c}{\sum_{c=1}^{k}\overline{\omega}_c}$
A (RRD)	0.0497	12	Road owner (investor) m_{RE} = 3	A	0.0497	0.1490	0.3336	$\frac{0.1490}{3}=$ 0.0497	$\frac{0.0497}{0.1558}=$ 0.3190
B (SRM)	0.0604	6		F	0.0665		0.4463		
C (MEM)	0.0507	11		N	0.0328		0.2201		
D (MCC)	0.0448	13	Road construction contractor and sub-contractors m_{BC} = 7	B	0.0604	0.3624	0.1667	$\frac{0.3624}{7}=$ 0.0518	$\frac{0.0518}{0.1558}=$ 0.3325
E (RBC)	0.0652	4		C	0.0507		0.1399		
F (ORC)	0.0665	3		D	0.0448		0.1236		
G (IPA)	0.0642	5		E	0.0652		0.1799		
H (RSPO)	0.0519	10		L	0.0569		0.1570		
I (TSI)	0.0545	9		M	0.0417		0.1151		
J (PBLS)	0.0703	2		P	0.0427		0.1178		

End of Table 6

Benefit entity (criterion)	The average global weight $\bar{\omega}_i$	Overall priority $\bar{P}$	Description of the main criterion and size m_c	Benefit entity (criterion)	The average global weight of sub-criteria $\bar{\omega}_i$	The sum of the average global weight in the main criterion $\sum_{i=1}^{m_c} \bar{\omega}_i \cdot \omega_c$	Normalized local weight $\omega_i = \frac{\bar{\omega}_i}{\omega_c}$	Average weight of the sub-criteria for the main criterion $\bar{\omega}_c = \frac{\omega_c}{m_c}$	The weight of main criteria $\tilde{\omega}_c = \frac{\bar{\omega}_c}{\sum_{c=1}^{k} \bar{\omega}_c}$
K (IMC)	0.0782	1		G	0.0642		0.1314		
L (SRB)	0.0569	8		H	0.0519		0.1062		
M (PTC)	0.0417	15		I	0.0545		0.1115		
N (OPP)	0.0328	19		J	0.0703		0.1439		
O (TLI)	0.0600	7	Road users $m_{RU} = 9$	K	0.0782	0.4886	0.1601	$\frac{0.4886}{9} = 0.0543$	$\frac{0.0543}{0.1558} = 0.3485$
P (CES)	0.0427	14		O	0.0600		0.1228		
Q (RVM)	0.0370	16		Q	0.0370		0.0757		
R (RTS)	0.0359	18		R	0.0359		0.0735		
S (FPV)	0.0366	17		S	0.0366		0.0749		
Total	1.0000	190	–	–	1.0000	1.0000	3.0000	0.1558	1.0000

This study based on the opinions of the experts standing for different categories shows the greatest benefits of road transport infrastructure development for road users. The benefits of road engineers are lower, and therefore funding given from the state budget each year is mostly needed for road users and must be increased considering the degree of wear and tear on the road and the necessary development of the road network.

9. Conclusions

The extent of benefits to road construction process participants and users varies throughout the complete life cycle of the road and is often discussed by politicians, lobbyists and other decision makers for the purpose of distribute funding for road transport infrastructure. Expert-based research methods were applied for figuring out the size of benefits, which made it possible to compare 19 beneficiaries with each other thus assigning them ranks. Differences in the qualification of individual experts and their territory made it necessary to divide all experts involved in the study into three categories: road engineers, transport engineers and road users. The opinions of the experts in each category were consistent. The highest values of concordance coefficient W were set for transport engineers (0.305), medium values – for road engineers (0.211) and the lowest values – for road users (0.113). Higher qualifications owned by the experts are shown by a large number of PhDs and figure out greater consistency in opinions.

To increase the reliability of research results, the significance of the benefits of a few road-related entities was found applying the averages of the normalized weights of two expert-based research methods (ARTIW-L and ARTIW-N). The experts suppose that the major benefits are gained by increased mobility on behalf of citizens (normalized weight 0.0782), people having a better living standard decided by higher GDP (0.0703), clients in road construction (0.0665), the road building contractor and subcontractors (0.0652) and the institutions of production-based activities (0.0642). The organizers of public procurement (0.0328), road traffic supervisors (0.0359), fuel and power vendors (0.0366), road vehicle manufacturers (0.0370) and professional training and certification (0.0417) have the least benefits.

The significance of the benefits calculated applying the IHAMCI method for the classified entities shows that nine road users benefit the most, because the normalized weight making 0.3485 for this main criterion is the highest. The main criterion made by the construction contractor and subcontractors from seven entities was evaluated as a moderate benefit (0.3325). Three entities that make up the main criterion of the road owner (investor), investor have the least benefit (0.3190). The obtained data allow to reasonably claim that money from the state budget is required for road users transporting passengers and cargo and thus improving national military mobility and for those driving personal vehicles rather than for road workers building and maintaining roads.

References

Anastasopoulos, P. C., Haddock, J. E., & Peeta, S. (2014). Cost overrun in public-private partnerships: Toward sustainable highway maintenance and rehabilitation. *Journal of Construction Engineering and Management*, *140*(6). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000854

Asres, E., Ghebrab, T., & Ekwaro-Osire, S. (2022). Framework for design of sustainable flexible pavement. *Infrastructures*, *7*(1), Article 6. https://doi.org/10.3390/infrastructures7010006

Begum, S., Fisher, R. S., Ferranti, E. J. S., & Quinn, A. D. (2022). Evaluation of climate change resilience of urban road network strategies. *Infrastructures*, *7*(11), Article 146. https://doi.org/10.3390/infrastructures7110146

Bertolini, L., D'Amico, F., Napolitano, A., Bianchini Ciampoli, L., Gagliardi, V., & Diezmos Manalo, J. R. (2023). A BIM-based approach for pavement monitoring integrating data from non-destructive testing methods (NDTs). *Infrastructures*, *8*(5), Article 81. https://doi.org/10.3390/infrastructures8050081

Choi, S., Kim, D. Y., Han, S. H., & Kwak, Y. H. (2014). Conceptual cost-prediction model for public road planning via rough set theory and case-based reasoning. *Journal of Construction Engineering and Management*, *140*(1). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000743

Cirilovic, J., Vajdic, N., Mladenovic, G., & Queiroz, C. (2014). Developing cost estimation models for road rehabilitation and reconstruction: Case study of projects in Europe and Central Asia. *Journal of Construction Engineering and Management*, *140*(3). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000817

Dumbliauskas, V., Grigonis, V., & Barauskas, A. (2018). The impact of cost-benefit analysis on decision making concerning the development of the urban transport system: Case of Kaunas City. *Transport*, *33*(4), 1045–1051. https://doi.org/10.3846/transport.2018.6158

European Commission, Directorate – General for Mobility and Transport. (2011). *White paper on transport – Roadmap to a single European transport area – Towards a competitive and resource efficient transport system*. Publications Office of the European Union. https://data.europa.eu/doi/10.2832/30955

Farhan, J., & Fwa, T. F. (2009). Pavement maintenance prioritization using Analytic hierarchy process. *Transportation Research Record*, *2093*(1), 12–24. https://doi.org/10.3141/2093-02

Jaśkowski, P., Czarnigowska, A., Tokarski, Z., & Sobotka, A. (2015). Simulation for selecting road works equipment. *The Baltic Journal of Road and Bridge Engineering*, *10*(3), 216–223. https://doi.org/10.3846/bjrbe.2015.27

Kendall, M. G., & Gibbons, J. D. (1990). *Rank correlation methods* (5th ed.). Oxford University Press.

Mačiulytė-Šniukienė, A., Butkus, M., & Szarucki, M. (2022). Infrastructure in the framework of production functions: Evidence of EU member states at the regional level. *Technological and Economic Development of Economy*, *28*(6), 1897–1914. https://doi.org/10.3846/tede.2022.18090

Magazzino, C. & Mele, M. (2021). On the relationship between transportation infrastructure and economic development in China. *Research in Transportation Economics*, *88*, Article 100947. https://doi.org/10.1016/j.retrec.2020.100947

Makarova, I., Yakupova, G., Buyvol, P., Abashev, A., & Mukhametdinov, E. (2022). Risk management methodology for transport infrastructure security. *Infrastructures*, *7*(6), Article 81. https://doi.org/10.3390/infrastructures7060081

Marzouk, M. & Fouad, M. (2014). Simulation-based model for optimizing highways resurfacing operations. *The Baltic Journal of Road and Bridge Engineering*, *9*(1), 58–65. https://doi.org/10.3846/bjrbe.2014.08

Maskeliūnaitė, L., & Sivilevičius, H. (2021). Identifying the importance of criteria for passenger choice of sustainable travel by train using ARTIW and IHAMCI methods. *Applied Sciences*, *11*(23), Article 11503. https://doi.org/10.3390/app112311503

Meduri, S. S., & Annamalai, T. R. (2013). Unit costs of public and PPP road projects: Evidence from India. *Journal of Construction Engineering and Management*, *139*(1), 35–43. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000546

Meneses, S. & Ferreira, A. (2013). Pavement maintenance programming considering two objectives: Maintenance costs and user costs. *International Journal of Pavement Engineering*, *14*(2), 206–221. https://doi.org/10.1080/10298436.2012.727994

Montgomery, D. C., Runger, G. C., & Hubele, N. F. (2007). *Engineering statistics* (4th ed.). Jon Wiley & Sons.

Mostafa, M. A., & El-Gohary, N. M. (2014). Stakeholder-sensitive social welfare-oriented benefit analysis for sustainable infrastructure project development. *Journal of Construction Engineering and Management*, *140*(9). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000788

Niu, W., Xu, Z., Liu, B., & Liu, C. (2023). Internationalization of the construction industry in the global value chain. *Technological and Economic Development of Economy*, *29*(4), 1336–1352. https://doi.org/10.3846/tede.2023.19426

Palei, T. (2015). Assessing the impact of infrastructure on economic growth and global competitiveness. *Procedia Economics and Finance*, *23*, 168–175. https://doi.org/10.1016/S2212-5671(15)00322-6

Pellecuer, L., Assaf, G. J., & St-Jacques, M. (2014). Life cycle environmental benefits of pavement surface maintenance. *Canadian Journal of Civil Engineering*, *41*(8), 695–702. https://doi.org/10.1139/cjce-2013-0508

Petkevičius, K., Maskeliūnaitė, L., & Sivilevičius, H. (2019). Determining travel conditions on motorways for automobile transport based on the case study for Lithuanian highways. *Transport*, *34*(1), 89–102. https://doi.org/10.3846/transport.2019.7842

Raffaniello, A., Bauer, M., Safiuddin, M., & El-Hakim, M. (2022). Traffic and climate impacts on rutting and thermal cracking in flexible and composite pavements. *Infrastructures*, *7*(8), Article 100. https://doi.org/10.3390/infrastructures7080100

Saaty, T. L., & Ozdemir, M. S. (2003). Why the magic number seven plus or minus two. *Mathematical and Computer Modelling*, *38*, 233–244. https://doi.org/10.1016/S0895-7177(03)90083-5

Sedighian-Fard, M., Solatifar, N., & Sivilevičius, H. (2023). Calibration of regression-based models for prediction of temperature profile of asphalt layers using LTPP data. *Journal of Civil Engineering and Management*, *29*(4), 329–341. https://doi.org/10.3846/jcem.2023.18611

Siverio Lima, M. S., Buttgereit, A., Queiroz, C., Haritonovs, V., & Gschösser, F. (2022). Optimizing financial allocation for maintenance and rehabilitation of Munster's Road network using the World Bank's Ronet model. *Infrastructures*, *7*(3), Article 32. https://doi.org/10.3390/infrastructures7030032

Sivilevičius, H. (2011). 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. https://doi.org/10.3846/bjrbe.2011.07

Sivilevičius, H., & Martišius, M. (2023). The significance of the factors increasing the asphalt Pavement recycling rate in the country, determined using multiple-criteria decision-making methods. *Applied Sciences*, *13*(22), Article 12226. https://doi.org/10.3390/app132212226

Solatifar, N., Abbasghorbani, M., Kavussi, A., & Sivilevičius, H. (2018). Prediction of depth temperature of asphalt layers in hot climate area. *Journal of Civil Engineering and Management*, *24*(7), 516–525. https://doi.org/10.3846/jcem.2018.6162

Sun, C., Mackley, A., & Edara, P. (2014). Programmatic examination of Missouri incentive/disincentive contracts for mitigating work zone traffic impacts. *Journal of Construction Engineering and Management*, *140*(1). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000796

Urazán-Bonells, C. F., Caicedo-Londoño, M. A., & Rondón-Quintana, H. A. (2022). Correlation analysis between roadway networks and economic ranking-case study: Municipalities and departments of Colombia. *Infrastructures*, *7*(9), Article 118. https://doi.org/10.3390/infrastructures7090118

Vaitkus, A., Čygas, D., Motiejūnas, A., Pakalnis, A., & Miškinis, D. (2016). Improvement of road pavement maintenance models and technologies. *The Baltic Journal of Road and Bridge Engineering*, *11*(3), 242–249. https://doi.org/10.3846/bjrbe.2016.28