MULTI-ATTRIBUTE DECISION-MAKING METHODS FOR ASSESSMENT OF QUALITY IN BRIDGES AND ROAD CONSTRUCTION: STATE-OF-THE-ART SURVEYS

Edmundas Kazimieras Zavadskas[1], Roode Liias[2], Zenonas Turskis[3]

[1, 3] *Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
E-mails: [1] edmundas.zavadskas@adm.vgtu.lt; [3] zenonas.turskis@st.vgtu.lt
[2] *Tallinn University of Technology, Ehitajete tee 5, 19086 Tallinn, Estonia*
E-mail: [2] roode@staff.ttu.ee

Abstract. Multi-attribute analysis is a popular tool in many economical, managerial, constructional etc. problems. This document provides a review of international and national practices in investment decision support tools in bridges and road quality management. Cost benefit analysis and multi-attribute analysis are principal methodologies in supporting decision-making in bridges and road quality management. The complexity of the applications shows significant differences in international practices. There are continuing discussions amongst practitioners and researchers, regarding to which one is more appropriate in supporting decision-making. It is suggested that more than one approach should be regarded as complementary instead of competitive means. Multi-attribute analysis may be particularly helpful in early stages of project development, strategic planning. Cost benefit analysis is used most widely for project prioritization and selecting the final project from a set of alternatives. These methodologies are applicable to the problems with large numbers of scenarios and attributes. The research has concluded that multi-attribute decision-making methods are very useful for bridge and road construction.

Keywords: bridge, road, design, construction, alternative, quality, multi-attribute, assessment, decision-making

1. Introduction

Roads and bridges infrastructure assets are drivers of economic development and social equity. They also have a significant impact on the natural and man-made environment. Transport system forms the backbone of local, regional, national, and international trade, making most economic activities critically dependent upon this resource. The infrastructure objects are complex engineering facilities and their construction and use require much special scientific knowledge.

Transportation plays a vital role in enhancing the productivity and the quality of life in the Baltic States, private sector development, generates business activities, creates jobs, boosts property values and tax earnings, and connects employers and workers. Communities with good public transit systems are economically thriving communities and offer location advantages to businesses and individuals choosing to work or live in them. Many researchers investigated problems of transport and road network.

Leonovich and Kashevskaja (Леонович, Кашевская 2007) analysed the quality management as a three-level system:

- *Strategic* - the management of the road sector as a whole is discussed;
- *Tactical* - the solutions for distributing the road quality management and the planned resources between the contracting organisations are realised;
- *Operative* - the quality is operatively managed in the course of production process.

The researchers showed that the essential attributes of bridges and road quality management monitoring are:

- technical (engineering);
- financial;
- social.

The harmony in the residential environment much depends on the road network density and the number and capacity of bridges. As of late, the research of general plans (Bardauskienė 2007) and transport flows (Jakimavičius, Mačerinskienė 2006) receives an increasing attention.

Ugwu *et al.* (2006a; 2006b) discussed project-level sustainability assessment mathematical models and computational methods. Ugwu *et al.* investigated a segment of the bridge infrastructure. Sustainability in different project phases was described by 55 sustainability attributes. The generation of alternatives that are evaluated along the same

sets of attributes is an essential part of the decision-making processes especially in the domain of infrastructure projects. It is shown that sustainability appraisal at the design stage could generate substantial savings and facilitate better decision-making before the construction stage, where design decisions could be difficult or impossible to retract.

Wang and Elhag (2006) investigated the bridge risk assessment using a fuzzy TOPSIS method, based on alpha level sets and non-linear programming solution procedure.

Kamaitis (2007a; 2007b) investigated the problem of the durability and quality of reinforced concrete structures. In a number of situations reinforced concrete structures must be protected by barrier materials to prevent contact with aggressive agents. One of the ways to protect concrete foundations, bridges, or dams from corrosion is to use protective coatings. The author has demonstrated that proposed deterioration mechanism and limited state functions can be efficiently applied to assess the service life and performance of protective polymer coatings under different liquid exposure conditions.

Simulation of bridges construction is a complicated process. Marzouk *et al.* (2007) presented a model, dedicated to assist contractors in planning the segmental bridge construction using incremental launching technique. Frangopol and Liu (2007) pointed that cost-competent maintenance and management of civil infrastructure requires a balanced consideration of both the structure performance and the total cost accrued over the entire life-cycle.

Miyamoto *et al.* (2006) presented a comprehensive decision-support system. The system is developed for the formation of maintenance strategies with/without annual budget limitations. This system is based on life-cycle cost analysis of an entire bridge inventory, which comprises part of a highway network. The formulation of an optimum bridge maintenance program for an entire stock of bridge structures has been impeded historically by an insufficient information concerning the existing structural conditions.

Witzany and Zigler (2007) investigated modification quality of the bridge body filler during the construction of new road pavements on stone bridges. A reliable design of conservation and prevention of failures of historical stone bridge structures requires theoretical and experimental research including the problems of the historical stone structure in relation to mineralogical and petrographic aspects, the problems of chemical and biochemical degradation processes and the effect of these processes on the properties of building materials and the service life of the historical structure as a whole. According to the authors, it can be concluded that it is a multi-attribute problem.

Gerbrandt and Berthelot (2007) pointed that over the past decade pressures on the road network have increased, resulting in accelerated road damage and increased demand to upgrade portions of the highway network. The research work involves evaluating the technical and economic feasibility of undertaking alternative road construction techniques. A critical component of this research effort is to evaluate the economic feasibility associated with different road construction techniques. On the basis of performance predictions and designed struc-

tural performance, resource allocation can be optimized more reliably across limited resources and alternative road strengthening systems, providing technically sound solutions that are more attractive economically. With an ability to predict the whole life-cycle performance on the basis of future maintenance treatments, road managers can more reliably assess alternative surfacing and structural preservation strategies. The primary focus of this paper is to demonstrate the economic considerations in evaluating alternative road design and construction methods. The longer-term evaluation approach allows selection of more effective strategic investments in highway infrastructure and considering innovative road structural rehabilitation and management strategies.

Čygas *et al.* (2008) stated that the rapid growth of heavy traffic, the increase in the standard axle load make scientists to look forward for new durable road constructing materials and their mixes. The continuously increasing need for strengthening the road pavement structures induces to use new road reconstruction technologies, to search for new methods in constructing pavement structural layers and investigate pavement structures under real conditions. The authors presented investigation of experimental pavement structures and described the installation process of stress and strain transducers in different layers of experimental pavement structures and initial results of stress and strain measurements.

Butkevičius *et al.* (2007) illustrated that by means of methodology for evaluating the state of flexible road pavement construction it is possible with an adequate precision for practical purposes to measure the remaining resource of pavement construction strength. The presented methodology suggests in every particular case the necessary measures to stop early and speedy deterioration of road pavement.

Petkevičius and Sivilevičius (2008) determined that a poor quality of asphalt concrete is the main cause (65%) of early fatigue cracking of asphalt concrete pavement of roads in Lithuania and neighbouring countries. The poor quality is mainly predetermined by production errors of hot mix asphalt and designed suboptimal mass ratio of constituents. The dynamics of rapid cracking of asphalt concrete paving of Lithuanian roads is shown, emphasising the inadequacy of hot mix asphalt structure and properties to increased traffic volume and axial workloads. A quality assurance method has been developed based on mathematical statistical methods.

Ekrias *et al.* (2008) focused his investigation on lighting dimensioning and lighting quality of traffic lighting. It is important to consider the combined effect of fixed road and street lighting and automobile lighting, when analyzing and optimizing the visual environment in night-time driving. Simulation offered efficient ways for developing automobile lighting.

Žilionienė and Laurinavičius (2007) pointed that with respect to traffic safety Lithuania is a country of increased risk. To improve winter maintenance of the highway the change in the number of accidents was analysed.

Ziari and Khabiri (2007) studied the performance of asphalt concrete, where some of the fractional fine aggre-

gate is replaced with crushed steel slag material. The investigation has demonstrated that the recycling and use of waste steel slag in asphalt concrete is feasible.

Kapliński and Janusz (2006) proposed the multi-attribute modelling of construction processes. Authors used the following elements of the procedure as multi-and partial regression, correlation analysis, sensitivity analysis. Besides the classic verification activities, the method of artificial neural networks has been applied. Authors used the above-listed tools to model the processes of assembly of structural corrugated steel plate structures. They are used for constructing small bridges, culverts as well as pedestrian and vehicle underpasses.

Vaidogas (2007) considered the problem of risk-based design of protective highway structures. The proposed procedure serves for a comparison of alternative designs of the protective structure. It is shown that the multi-attribute selection can be carried out as a simulation-based presentation of the epistemic uncertainties.

Žilionienė *et al.* (2007) stated that gravel pavement prevails in Lithuanian state roads of regional significance. Dustiness of gravel roads reduces visibility and hinders traffic safety. Gravel becomes finer because of pavement wear. Researchers presented investigation into dust reduction on gravel roads through the use of bitumen emulsions, calcium chloride, and calcium lignosulfonate.

2. Applying the multi-attribute quality assessment methods

The complex nature of decision-making requires practitioners to select investment options based on a wider variety of policy considerations in addition to cost benefit analysis and pure technical considerations. Road transport services are related to several society's economic and social functions. It can be outlined that the common considerations in decision-making process as regional economic and social policies, unemployment, poverty, stay in budget, provide desired level of service, satisfy travel demand, car ownership, technology innovation, environment etc.

The goals of bridges and road quality management can be generalized as to:

- promote national and regional economic growth;
- improve access to service;
- improve bridges and road safety;
- improve movement of people and freight;
- responsibly manage environment;
- integrate with other transportation modes.

It is identified that there is an increasing demand for establishing a holistic investment decision-making framework for bridges and road quality management, which brings all social, environmental, economic, and political factors to bear in a logical and systematic way.

Cost benefit analysis approach is useful tool for investment decision-making from an economic perspective. Cautions should also be given to the methods of determining the value of social and local interests. Interactive approach has the advantage in helping decision-makers to elaborate their preferences. However, computation may result in losing interests of decision-makers during the solution process of a large-scale problem. Current practices tend to use cardinal or ordinal scales in measure in non-monetized attributes. Distorted valuations can occur, where variables measured in physical units are converted to scales. It is suggested to assign different weights to individual score. Due to overlapped goals, the problem of double counting also appears in some of multi-attribute analysis. The situation can be improved by carefully selecting and defining investment goals and attributes. As the actual result is not known, the attributes taking into consideration all possible results are needed. An alternative in multi-attribute evaluation is usually described by quantitative and qualitative attributes. These attributes have different units of measurement. In addition, the selected evaluation attributes should also be based on the measurement culture of the decision-maker.

The use of unreasonable monetization methods in some cases has discredited cost benefit analysis in the eyes of decision-makers and the public. Some social externalities, such as employment and regional economic impacts, are generally omitted in current practices. It may be appropriate to consider these externalities in qualitative forms in a multi-attribute analysis. In the real world, decisions in bridges and road quality management are recognised as multi-attribute problems. Therefore, after the popularity of cost benefit analysis and related engineering economic evaluation techniques, there was an increasing popularity of *multi-attribute analysis*, which is capable of dealing with the multiple dimensions of evaluation problems. These techniques aim to solve conflicting social, environmental, political and economic issues in modern decision-making.

Multi-attribute analysis techniques are flexible ways in optimising decisions under complex environment. They are able to consider quantitative as well as qualitative factors in the decision-making process. Theoretically, the decision problem can be better formulated with respect to reality. However, as each multi-attribute analysis technique has different properties suited for different type of problems, there is no simple answer which method to use for a particular problem. Weighting and scoring systems are critical in most multi-attribute analysis. However, the processes of assessing weights and scores were criticized as highly arbitrary and subjective. Furthermore, the use of arbitrary weights in multi-attribute analysis and lack of a standard methodology increases the scope for misuse and deliberation.

The use of multi-attribute analysis to support public and private sector policy decisions has steadily grown since the 1970s. Various multi-attribute analysis techniques were adopted around the world. The result is that different multi-attribute analysis analysts are unlikely to reach consistent conclusions about a polical measure. Multi-attribute analysis generally use weights and scores (Hwang, Yoon 1981; Завадскас 1991) to reflect decision makers' preferences. Despite the very considerable mathematical and statistical efforts that have been given to weighting and scoring systems, the underlying analytical framework remains highly arbitrary and subjective.

Cost benefit analysis relies on the concept of net present value to permit comparisons of costs and benefits that accгке at different points in time. The treatment of time in multi-attribute analysis seems to have been given scant attention in the literature.

A decision is intrinsically related to a plurality of points of view, which can roughly be defined as attributes. Contrary to this very natural observation, for many years the only way to state a decision problem was considered to be the definition of a single attribute, which amalgamates the multidimensional aspects of the decision situation into a single scale of measure. Even today the textbooks of Operations Research suggest dealing with a decision problem as follows: first, to define an objective function, i.e., a single point of view like a comprehensive profit index (or a comprehensive cost index) representing the preferability (or dis-preferability) of the considered actions and then to maximize (minimize) this objective. Multi-attribute decision-making methods intuition is closely related to the way humans have always been making decisions. Consequently, despite the diversity of multi-attribute decision-making methods approaches, methods and techniques, the basic ingredients of multi-attribute decision-making methods are very simple: a finite or infinite set of actions (alternatives, solutions, courses of action...), at least two attributes, and, obviously, at least one decision-maker. Given these basic elements, multi-attribute decision-making methods are an activity which helps making decisions mainly in terms of choosing, ranking or sorting the actions.

The idea of multi-attribute decision-making methods is so natural and attractive that several thousands of articles and books have been devoted to the subject, with many scientific journals regularly publishing articles about multi-attribute decision-making methods. The main ideas are well established there.

3. Multi-attribute decision-making (MADM) problems in construction

The appropriateness of MADM depends upon the suitability of other economic evaluation frameworks. Four main economic evaluation frameworks are available:

- cost-benefit analysis;
- cost-effectiveness analysis;
- cost-utility analysis;
- multi-attribute analysis.

The process for choosing which of cost-benefit analysis, cost-effectiveness analysis, cost-utility analysis, and MADM to apply depends largely on the valuation of benefits.

A generic multi-attribute analysis model generally can be described by the following components:

- a set of objectives or attributes;
- a set of feasible alternatives;
- a number of decision constraints;
- a preference structure or weights;
- a set of performance evaluations of alternatives for individual objectives or attribute.

Multi-attribute decision-making methods have different characteristics. There are different ways to classify them. Multi-attribute methods can be classified by the type of initial information (deterministic, stochastic, fuzzy set theory methods) or by the number of decision-makers (one or group). One of possible approaches is based on the type of information received from decision maker (Ustinovičius *et al.* 2007). It includes:

1. Methods, based on quantitative measurements. This group consists of common methods of the multi-attribute utility theory (Завадскас 1991) and some new methods (Hwang, Yoon 1981; Zavadskas *et al.* 2006). The principles of this value system are based on the essential of the multi-attribute utility theory. This approach tries to assign a utility value to each action. Utility is a real number representing the preferability of the considered action. Despite its simplicity, the approach presents some technical problems. The first are related to the axiomatic basis and to the construction of marginal utility functions (i.e. the utility functions relative to each single criterion), both in case of decision under certainty and uncertainty. This approach is widely used by management consultants and usually provides reasonable results but lacks on the estimation of the weights of the attributes and on the evaluation of the jobs on the attributes. Actually, the factors' weights are estimated through a survey analysis or are directly expressed by an expert or a management consultant. It is obvious that in this case the determination of the components of the value system operates like a "black box" for the organisation. Also, the individual circumstances of the enterprise or organisation are not taken into account to the extent that is required.

2. Methods, based on initial quantitative assessment, results of which later take quantitative form. Peldschus and Zavadskas (Peldschus, Zavadskas 2005; Zavadskas, Turskis 2008) developed the algorithm for fuzzy matrix games. This concept was developed in order to take into consideration both internal and external influential variables. Fuzzy matrix games provide numerous new possibilities of handling practical engineering, economic, investment planning, and other problems. The resolution of fuzzy matrix games constitutes a new quality of decisions representing a high-degree complexity.

3. Methods, based on qualitative measurements but using a few attributes to compare the alternatives (comparison preference method). This group consists of preference comparison methods (Roy 1991; Завадскас 1991; Turskis 2008).

4. Methods, based on qualitative data not using a transformation to qualitative variables. This group comprises verbal decision analysis (Saaty 1980). Verbal Decision Analysis was proposed as a framework for the unstructured problems. This requires that the methods should: 1) use language for problem description that is natural to the decision-maker; 2) implement psychologically valid measurement of attributes and psychologically valid preference elicitation procedures; 3) incorporate means for consistency check of the decision-maker's information; 4) be "transparent" to the decision-maker and provide explanations of the result. Verbal Decision Analysis is orient-

ed on construction of a set of methods for different types of decision tasks within the stated framework.

Methods within all these 4 groups are not widely applied to deal with bridges and road design and construction. At present the analytic hierarchy method (AHP) (Saaty 1980) is used in most cases for different levels when assessing decisions in bridge and road construction.

Saaty (1980) presents a methodology to build utility functions, the AHP (Analytic Hierarchy Process) and its more recent extension, the ANP (Analytic Network Process). AHP is a theory of measurement that uses pairwise comparisons along with expert judgments to deal with the measurement of qualitative or intangible attributes. The ANP is a general theory of relative measurement used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interact with respect to control attributes. The ANP captures the outcome of dependence and feedback within and between clusters of elements. Therefore AHP with its dependence assumptions on clusters and elements is a special case of the ANP.

Su *et al.* (2006) applied AHP method to rank major transport projects to determine implementation priorities and budget allocations. The authors used rankings derived from the Analytic Hierarchy Process and direct subjective rankings to set funding priorities. Authors used a Monte Carlo simulation analysis to help in determining the rank orders.

Wang *et al.* (2006) argued that TOPSIS (technique for order performance by similarity to ideal solution) is a practical and useful technique in dealing with multi-attribute decision making problems, and has been widely employed in the construction management and other fields.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) proposed in (Hwang, Yoon 1981) 1981 is based on the idea that the most preferred alternative should be the shortest distance from the ideal solution and the longest distance from the negative ideal solution. This method is applied for many problems solution in construction (Завадскас 1991).

The TOPSIS method is successfully used in dealing with issues related to sustainable revitalisation of derelict property (Zavadskas, Antuchevičienė 2006) and reliability of bridges (Wang, Elhag 2006) etc.

The COPRAS method developed by the authors was used for real estate (Kaklauskas *et al.* 2007), and to assess sustainability of the city of Vilnius (Viteikienė, Zavadskas 2007), to make sustainable revitalisation of derelict property (Zavadskas, Antuchevičienė 2007), to select rational technological construction processes (Kaklauskas *et al.* 2006; Zavadskas *et al.* 2008). Zavadskas *et al.* (2007) developed and implemented the methodology for multi-attribute assessment of multi-alternative decisions in road construction. COPRAS methodology is applied in this research.

The VIKOR method was used to deal with issues related to sustainable revitalisation of derelict property (Zavadskas, Antuchevičienė 2007). The methods of the game theory were used to select a rational variant for road reconstruction, to model refurbishment of construction objects (Antuchevičienė *et al.* 2006), and to assess compact-

ness of a sustainable city (Turskis *et al.* 2006). Fuzzy sets methods were used to deal with the task related to construction of a water supply pipeline (Peldschus, Zavadskas 2005), and to deal with the aforementioned tasks (Zavadskas, Antuchevičienė 2006).

The ELECTRE ((ELimination Et Choix Traduisant la REalité) (ELimination and Choice Expressing the REality)) method (Roy 1991) for choosing the best action(s) from a given set of actions was devised in 1965, and was later referred to as ELECTRE I (electre one).

It must be noted that only a few of the mentioned multi-attribute decision-making applications are related to dealing with road and bridge construction tasks. Use of multi-attribute decision-making methods in other fields of construction is justified.

4. Life cycle quality and strategy

Economic, financial, organisational, social, technical and other attributes can be used to assess quality of the bridges and roads. Evaluation of bridges and road design and construction has been recognized as a particularly complex task due to its ambiguity and difficult formalisation. There have been no generalized sets of rules for the evaluation process. According to the reviewed researches, it can be concluded that they are used in different stages of bridges and road design and construction. An assessment of quality in most cases is performed according to the one efficiency attribute.

Frangopol and Liu (2007) pointed that cost-competent maintenance and management of civil infrastructure requires a balanced consideration of both the structure performance and the total cost accrued over the entire life-cycle. Most existing maintenance and management systems are developed on the basis of life-cycle cost minimization only. The single maintenance and management solution thus obtained, however, does not necessarily result in satisfactory long-term structure performance. Authors review the recent development of life-cycle maintenance and management planning for deteriorating civil infrastructure with emphasis on bridges using optimization techniques and considering simultaneously multiple and often competing attributes in terms of condition, safety and life-cycle cost. Such multiple-attribute approach leads to a large pool of alternative maintenance and management solutions that helps active decision-making by choosing a compromise solution of preferably balancing structure performance and life-cycle cost.

Decision-makers needs evaluation of possible decisions according to many attributes related to the strategic technical life cycle management of bridges and roads. The critical point is that the selected attributes should have a direct effect on performance. It should be noted that the decision-makers must adjust the attributes depending on the demand of each project. The evaluation of all possible actions is not always sufficient. Each action may lead to several, sometimes conflicting results.

The definitions of *"quality"* include an object's nature or character (how good or bad it is), and it can also mean

that something is of a high standard. The main aspects of *"life cycle quality"* can be defined as follows (Fig. 1):

- performance of the bridge (road),
- ecology,
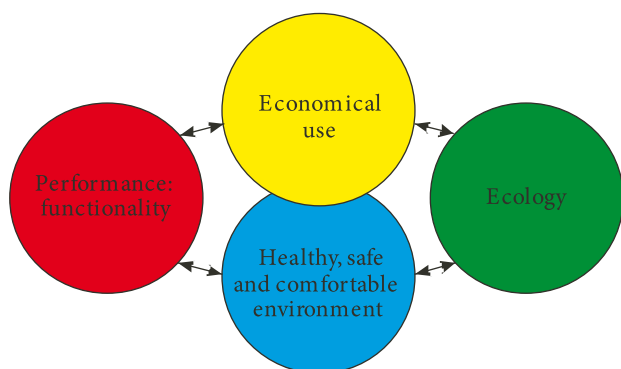- safety,
- health,
- comfort,
- economy.

Fig. 1. Main aspects of the detailed road life cycle – quality design

They may be grouped for analytical purposes as follows:

- functional efficiency, the adaptation of the road to the activities for which it is to be used;
- durability, the physical qualities of the road, which determine, how long the road can continue to render useful services;
- attractiveness, the aesthetic qualities of the road.

In optimization of bridges and road alternatives and maintenance strategy defining, the ideas of Zavadskas (Завадскас 1991) can be applied. If the analysis phase is done rigorously enough, the strategy module may proceed quite quickly, since most of the decisions have already been made in the analysis phase and they can be used as input in strategy development. Road management includes construction, road administration, road maintenance functions and the demolition of roads. In Figs 2 and 3 are shown the concepts.

Efficiency of created new technology or application of already known one depends on the applied methods of a multi-attribute assessment of decision variants and control facilities of this estimation. Quality of applied decisions directly depends on these decisions.

Managerial process by quality is phasic and includes five stages of a multi-attribute assessment (MAA):

- MAA_I. Designing and preparation of construction processes (supply with information);
- MAA_{II}. Factory manufacturing of construction production;
- MAA_{III}. Complete set, transportation, warehousing;
- MAA_{IV}. Processes on a construction site;
- MAA_V. Operation of construction production.

The generic scheme of construction managerial process is shown in Fig. 3.

Requirements to performance result quality of technological process and to performance ways development of process in certain construction conditions are formed at stage MAA_I.

Stage MAA_I generally includes processes of research works, research and development works, drawing up of the contract design, design examination, preparation of construction processes. Some of the listed processes cannot enter into stage MAA_I.

It depends on the social order for the project development. RW and SDW, together with some other stages can not be included there, when using well-known technologies and constructive decision stages. The social order in this case is an input of stage MAA_I. An output of stage MAA_I is the project of developed object and the organizational-technological documentation.

The basic purposes of functioning of stage MAA_I is the following:

- choice of rational decisions on a design stage (optimization approach);
- definition of accepted decisions conformity to some in advance established requirements;
- checking at a stage of examination (normative approach).

Purpose of stage MAA_{II} is creation of necessary conditions for production at construction industry factories. Thus observance of technology requirements which are
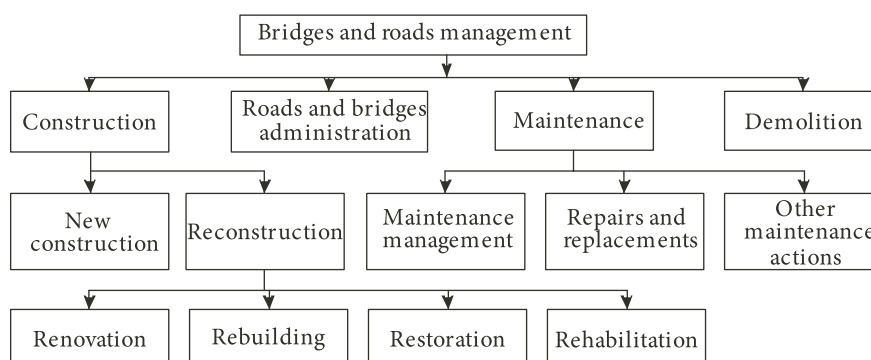

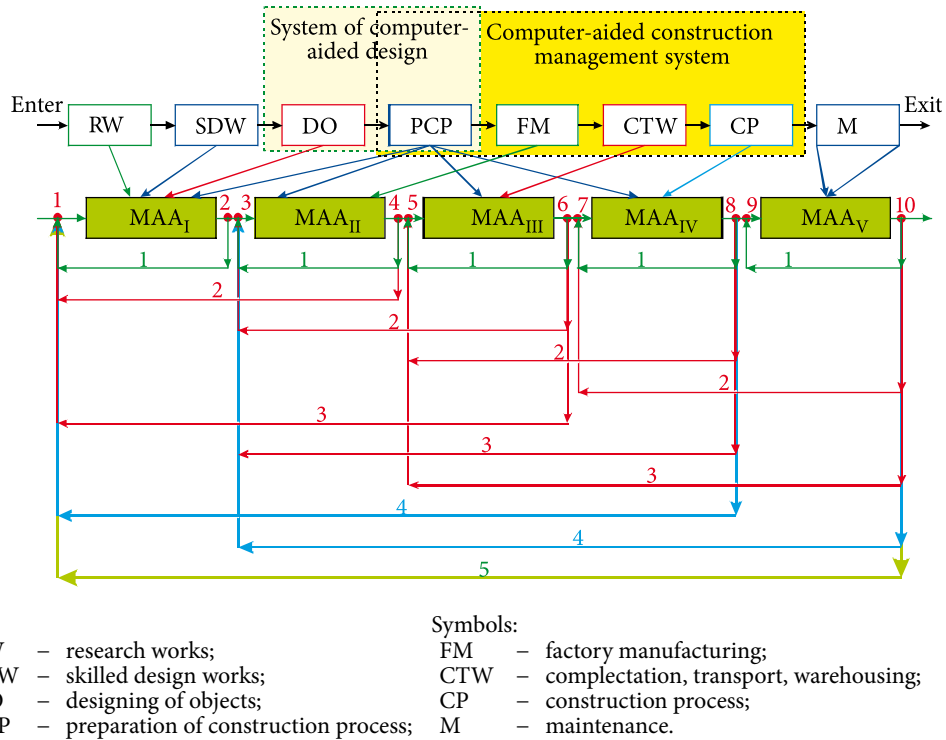**Fig. 2.** Concepts of bridges and roads management and repairing

Symbols:

RW	– research works;	FM	– factory manufacturing;
SDW	– skilled design works;	CTW	– complectation, transport, warehousing;
DO	– designing of objects;	CP	– construction process;
PCP	– preparation of construction process;	M	– maintenance.

Fig. 3. Decision-making assessment stages - local stages of MAA

stipulated in the project is obligatory. Hence, inputs of stage MAA_{II} are results of stage MAA_I, concerning technologies of the construction industry factories.

Operated variables of stage MAA_{II} become DO, RW and CP. Output of stage MAA_{II} are the finished goods (semi-finished details, materials, construction details, construction parts), corresponding requirements of the project and suitable for application.

Stage MAA_{III} is directed on a technological complete set and transportation of necessary resources means of work (including their warehousing) on construction objects. As an input of stage MAA_{III} serves the information acting from stages MAA_{II} and MAA_I about properties of made production and about its necessary quantity for performance of stage MAA_{IV} (on the basis of results of stage MAA_I). An output of stage MAA_{III} is maintenance of stage MAA_{IV} with all necessary resources.

Stage MAA_{IV} is intended for realization of the technological decisions stipulated by stage MAA_I on a construction site. As an input of stage MAA_{IV} serve the information on requirements to a stage (on the basis of results

of stage MAA_I) and the received necessary resources (at stage MAA_{III}). An output of stage MAA_{IV} is the finished building production which is meeting the requirements, designed at stage MAA_I.

Stage MAA_V is realized at a stage of construction production operation. This process is directed to research and realization of rational technology modes at operation of separate constructive elements and constructions as a whole. Realization of rational modes in this case is understood as periodicity repairmen of separate constructive elements, terms current and major overhauls, the prediscretion of opportunities (necessity) of reconstruction. Inputs of a stage are the parameters of efficiency reached as a result of MMA_{IV} stage realization. Output of stage MMA_V becomes construction production which quality changes in time for the size stipulated by stage MMA_I.

It is necessary to note, that managerial process of technology is iterative. The model of this process on which contours of technological management (Table 1) are allocated is presented in Fig. 3. Thus stage MMA_I is included in 5 contours, and stage MMA_V – in one. The general

Table 1. Management contours

MAA Phasic Stages	Number of MAA phased stages included to the MAA management contours				
	1	2	3	4	5
MAAI	I–2–1	I–II–4–1	I–II–III–6–1	I–II–III–IV–8–1	I–II–III–IV–V–10–1
MAAII	II–4–3	II–III–6–3	II–III–IV–8–3	II–III–IV–V–8–3	–
MAAIII	III–6–5	III–IV–8–5	III–IV–5–10–5	–	–
MAAIV	IV–8–7	IV–V–10–7	–	–	–
MAAV	V–10–9	–	–	–	–

number of contours equals 15. In Fig. 4 cybernetic scheme of MMA is presented.

5. Conclusions

Cost benefit analysis approach is a useful tool for investment decision-making from a financial perspective.

While the decision involves conflicting goals, the multi-attribute analysis approach is more powerful.

Due to the complex natural of decision-making in Bridges and Road quality management, there is not a single method that can satisfy all decision-making problems. The choice of evaluation technique depends on the feature of the problem at hand, on the aims of the analysis, and on the underlying information base.

Generally, the application of multi-attribute analysis in road sector is promising, however, the applications are in preliminary stage.

Some multi-attribute analysis techniques, such as TOPSIS, Analytic Hierarchy Process, and Goal Programming are found in practice. Others just present various impacts to decision-makers to characterise the projects.

Some social and environmental externalities cannot be readily and credibly quantified or monetised, such as service quality and reliability, landscape etc. These externalities should be incorporated in a multi-attribute analysis.

In early stages of project development, multi-attribute analysis may be particularly helpful.

There is a need to reach a degree of commonality on considering social and environmental externalities by aggregating the best practices.

The conventional cost benefit analysis approach and multi-attribute analysis approach should be regarded as complementary rather than competitive analytical tools.

However, the cost benefit analysis approach is used most widely for project prioritisation and selecting preferred project from amongst a given set of alternatives.

Due to lack of information or undeveloped techniques, models for some key social and environmental externalities are not available.

There is not a generally accepted framework in the choice of modelling methods and externalities.

The processes of assessing weights and scores are highly arbitrary and subjective.

The lack of a framework for choosing externalities in multi-attribute analysis could lead to double counting.

References

Antuchevičienė, J.; Turskis, Z.; Zavadskas, E. K. 2006. Modelling renewal of construction objects applying methods of the game theory, *Technological and Economic Development of Economy* 12(4): 263–268.

Bardauskienė, D. 2007. The expert's estimates application in the preparation of city general plan, *Technological and Economic Development of Economy* 13(3): 223–236.

Butkevičius, S.; Petkevičius, K.; Kamaitis, I. Z. 2007. Evaluation of flexible road pavement construction state using objective strength criteria, *The Baltic Journal of Road and Bridge Engineering* 2(2): 61–66.

Čygas, D.; Laurinavičius, A.; Vaitkus, A.; Perveneckas, Z.; Motiejūnas, A. 2008. Research of asphalt pavement structures on Lithuanian roads (I), *The Baltic Journal of Road and Bridge Engineering* 3(2): 77–83.

Ekrias, A.; Eloholma, M.; Halonen, L.; Song, X.-J.; Zhang, X.; Wen, Y. 2008. Road lighting and headlights: luminance measurements and automobile lighting simulations, *Building and Environment* 43(4): 530–536.

Frangopol, D.; Liu, M. 2007. Maintenance and management of civil infrastructure based on condition, safety, optimization, and life-cycle cost, *Structure & Infrastructure Engineering* 3(1): 29–41(13).

Gerbrandt, R.; Berthelot, C. 2007. Life-cycle economic evaluation of alternative road construction methods on low-volume roads, *Transportation Research Record* 1989: 61–71.
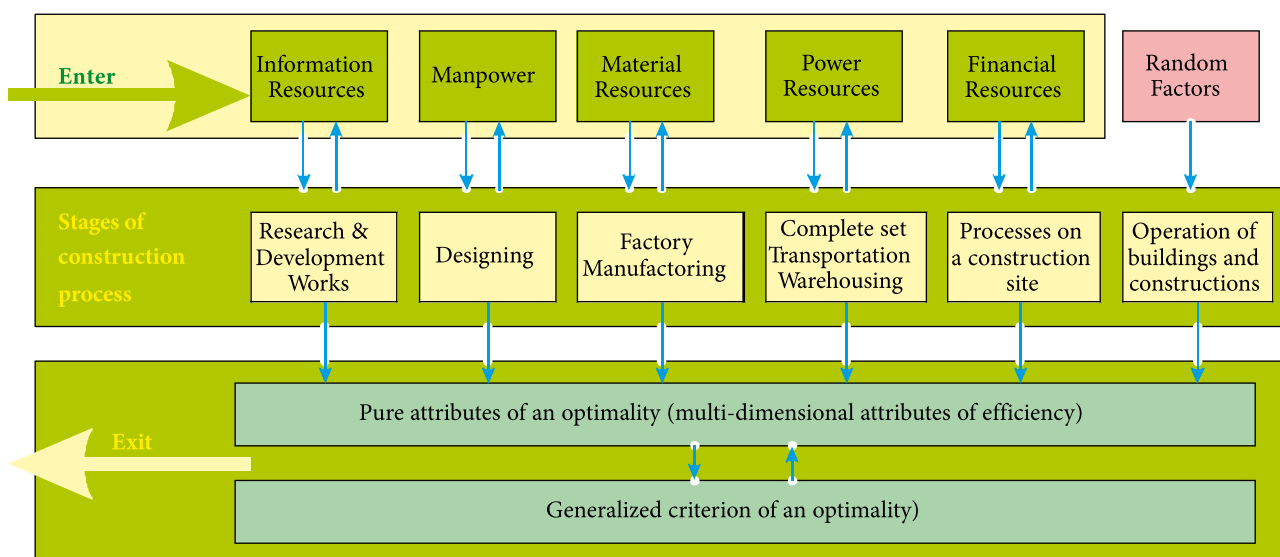

Fig. 4. Cybernetic system of MAA

Hwang, C. L.; Yoon, K. 1981. *Multiple attribute decision making: methods and applications; a state-of-the-art survey.* 1st edition. Berlin: Springer. 259 p. ISBN 3540105581

Jakimavičius, M.; Mačerinskienė, A. 2006. A GIS-based modelling of vehicles rational routes, *Journal of Civil Engineering and Management* 12(4): 303–309.

Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S.; Ginevičius, R.; Komka, A.; Malinauskas, P. 2006. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: a Lithuanian case, *Energy and Buildings* 38(5): 454–462.

Kaklauskas, A.; Zavadskas, E. K.; Banaitis, A.; Šatkauskas, G. 2007. Defining the utility and market value of real estate a multiple criteria approach, *International Journal of Strategic Property Management* 11(2): 107–120.

Kamaitis, Z. 2007a. Structural design of polymer protective coatings for reinforced concrete structures. Part 1: theoretical consideration, *Journal of Civil Engineering and Management* 13(1): 11–17.

Kamaitis, Z. 2007b. Structural design of polymer protective coatings for reinforced concrete structures. Part II: experimental verification, *Journal of Civil Engineering and Management* 13(1): 19–26.

Kapliński, O.; Janusz, L. 2006. Three phases of multifactor modelling of construction processes, *Journal of Civil Engineering and Management* 12(2): 127–134.

Marzouk, M.; Zein El-Dein, H.; El-Said, M. 2007. Application of computer simulation to construction of incremental launching bridges, *Journal of Civil Engineering and Management* 13(1): 27–36.

Miyamoto, A.; Konno, M.; Nakamura, H.; Bruhwiler, E. 2006. Maintenance plan optimization system for existing concrete bridge groups, *Structure and Infrastructure Engineering* 2(2): 91–115.

Peldschus, F.; Zavadskas, E. K. 2005. Fuzzy matrix games multi-criteria model for decision-making in engineering, *Informatica* 16(1): 107–120.

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.

Roy, B. 1991. The outranking approach and the foundations of ELECTRE methods, *Theory and Decision* 31: 49–73.

Saaty, T. L. 1980. *The analytic hierarchy process: planning, priority setting, resource allocation*, McGraw-Hill, Tx. 287 p. ISBN 0070543712.

Su, Ch.-W.; Cheng, M.-Y.; Lin, F.-B. 2006. Simulation-enhanced approach for ranking major transport projects, *Journal of Civil Engineering and Management* 12(4): 285–291.

Turskis, Z.; 2008. Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique, *Technological and Economic Development of Economy* 14(2): 224–239.

Turskis, Z.; Zavadskas, E. K; Zagorskas, J. 2006. Sustainable city compactness evaluation on the basis of GIS and Bayes rule, *International Journal of Strategic Property Management* 10(3): 185–207.

Ugwu, O. O.; Kumaraswamy, M. M.; Wong, A.; Ng, S. T. 2006a. Sustainability appraisal in infrastructure projects (SUSAIP). Part 1: development of indicators and computational methods, *Automation in Construction* 15(2): 239–51.

Ugwu, O. O.; Kumaraswamy, M. M.; Wong, A.; Ng, S. T. 2006b. Sustainability appraisal in infrastructure projects (SUSAIP). Part 2: a case study in bridge design, *Automation in Construction* 15(2): 229–238.

Ustinovičius, L.; Zavadskas, E. K.; Podvezko, V. 2007. Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction, *Control and Cybernetics* 36(1): 251–268.

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

Viteikienė, M.; Zavadskas, E. K. 2007. Evaluating the sustainability of Vilnius city residential areas, *Journal of Civil Engineering and Management* 13(2): 149–155.

Wang, Y. M; Elhag, T. M. S. 2006. Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment, *Expert Systems with Applications* 31(2): 309–319.

Witzany, J.; Zigler, R. 2007. The analysis of non-stress effects on historical stone bridge structures (monitoring, theoretical analysis, maintenance), *Journal of Civil Engineering and Management* 13(2): 157–167.

Zavadskas, E. K.; Antuchevičienė, J. 2006. Development of an indicator model and ranking of sustainable revitalization alternatives of derelict property: a Lithuanian case study, *Sustainable Development* 14: 287–299.

Zavadskas, E. K.; Antuchevičienė, J. 2007. Multiple criteria evaluation of rural building's regeneration alternatives, *Building and Environment* 42(1): 436–451.

Zavadskas, E. K.; Turskis, Z. 2008. A new logarithmic normalization method in Games theory, *Informatica* 19(2): 303–314.

Zavadskas, E. K.; Zakarevičius, A.; Antuchevičienė, J. 2006. Evaluation of ranking accuracy in multi-criteria decisions, *Informatica* 17(4): 601–618.

Zavadskas, E. K., Kaklauskas, A.; Peldschus, F.; Turskis, Z. 2007. Multi-attribute assessment of road design solutions by using the COPRAS method, *The Baltic Journal of Road and Bridge Engineering* 2(4): 195–203.

Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamošaitienė, J. 2008. Selection of the effective dwelling house walls by applying attributes values determined at intervals, *Journal of Civil Engineering and Management* 14(2): 85–93.

Ziari, H.; Khabiri, M. M. 2007. Interface condition influence on prediction of flexible pavement life, *Journal of Civil Engineering and Management* 13(1): 71–76.

Žilionienė, D.; Čygas, D.; Juzėnas, A. A.; Jurgaitis, A. 2007. Improvement of functional designation of low-volume roads by dust abatement in Lithuania, *Transportation Research Record* 1989: 293–298.

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

Завадскас, Э. К. 1991. *Системотехническая оценка технологических решений строительного производства* [Zavadskas, E. K. Systems of estimation of technological solutions in building construction]. Ленинград: Стройиздат. 256 с. ISBN 5274011691.

Леонович, И.; Кашевская, Е. 2007. Выбор критериев мониторинга процессов на оперативном уровне управления качеством автомобильных дорог [Leonovich, I.; Kashevskaja, E. Selection of criteria for process monitoring at the operative level of road quality management], *Technological and Economic Development of Economy* 13(2): 144–152.