10.2478/v10144-009-0035-x

Development of impact aggregation procedure for sustainable transport system

Antons Patlins[1], Nadezhda Kunicina[2],
Researcher (Riga, Latvia), senior researcher (Riga, Latvia)
Antons.Patlins@rtu.lv [1]*, Nadezda.Kunicina@rtu.lv[2]

Abstract - **In the investigation, the problems of utility evaluation methodology application for transport development projects evaluation are described. The main steps of development of impact aggregation procedure for sustainable transport system are described in the article. The new 3 stage environmental impact aggregation procedure is suggested.**

Keywords: **MCDM, MCDA, sustainable transport, public transport, electrical transport, UTA method.**

INTRODUCTION

The existing situation in Europe requires an efficient and harmonized evaluation methodology of the projects, which are in scope of transportation system renovation, with the aim to develop sustainable transport system. The main activities are related to public city transport system improvement, based on electrical transport usage as main transit transportation system. The building environmentally sustainable transport network is not inconceivable without considering in evaluation process environmental impacts and its evaluation.

This article presents a procedure for transport project evaluation procedure, including environmentally sustainable approach. This research is a part of environmentally transport indicator aggregation methodology evaluation and development task in COST 356: Towards the definition of a measurable environmentally sustainable transport (EST).

The decision making process now in transport sector is mainly based on single criteria decision making methodology (such as cost – benefit analysis), however single criteria methods couldn't be used for indicator measurements consideration in evaluation process. Considering environmental sustainable impacts the technical solutions and new rolling stock and vehicles are developed, including traffic control procedures and urban restrictions. Multi criteria analysis is efficient in long term decisions, as well as efficient for impacts aggregation.

PROBLEM STATEMENT

In the investigation, the problems of utility evaluation methodology application for transport development projects evaluation are described. The new developed utility based procedure is compared with Cost benefit (Social Cost benefit) approaches and with Multi objective programming approach.

The transport infrastructure development projects deal with large amount of transport system users. Transport system also is influenced by many factors, which are connected with all transport system main subsystems: infrastructure, energy, and vehicle. The main impacts are Emissions NO_x, PM_{10}, CO_2, Land take, Light pollution, non renewable resources use, traffic safety, non – recyclable waste, electromagnetic pollutions, noise, fire risk, visibility, vibration, green house effect and others [1]. The utility based methodology could include impact aggregation as well as expert evaluations. Both these evaluation parts are important, the decision support systems are based on the indicators evaluation aggregation, but the final decisions are taken by decision makers, based on expert's evaluation.

This decision making procedures are analyzed for transport equipment development and application efficiency, as well new technology application problems and transport infrastructure development project evaluation in Latvia conditions.

USAGE OF ENVIRONMENTAL IMPACTS

What are the impacts on environment? What are their characteristics or typical features? The answer to these questions, i.e. the taking into account all environmental impacts [1] and the description of the chain of causalities from the source to each final impact allows us to define what we want to measure with indicators of environmental impacts. At the same time, it allows to define quite precisely the term 'environment'.

Categories of impact of emissions of atmospheric pollutants (in the field of transport system):

-*Greenhouse effect* - more exactly the increase of greenhouse gases;

-*Ozone depletion* - halogen compounds react with stratospheric ozone and lead to the depletion of the ozone layer. Although theoretically under control, this impact has not disappeared and is thus still of great interest;

-*Photochemical pollution* - nitrogen oxides and volatile organic compounds react to form tropospheric ozone outside urban centres, toxic for humankind and nature;

-*Acidification* - nitrogen oxide and sulphur dioxide are transformed into acid compounds that acidify the natural environment up to 1,000 km away from the point of emission;

-*Eutrophication* - nitrogen oxides contribute towards increasing plant biomass whose excessive development leads to anoxia in aquatic environments, then harms fauna and flora;

-*Direct restricted health effects* - effects on human health, which is restricted since it does not include harm to welfare and psychological aspects (integrated in sensitive pollution), and direct since it only considers effects due to exposure to primary pollutants. Health impacts due to secondary pollutants (acidification, photochemical pollution, etc.) are regulated by impact laws of different natures;

-*Direct ecotoxicity* - primary pollutants affecting human health can also affect nature;

-*Sensitive pollution* - perceived by our senses, mainly sight and smell, it is composed of smoke, soiling and odours;

-*Degradation of common man-made heritage* - this is mainly due to the affects of particles and corrosive products. It incorporates the impacts of photochemical pollution and acidification on buildings;

-*Degradation of historic man-made heritage* - this is separated from the previous category as the impact is not chiefly sensitive or economic, but cultural and irreversible insofar as each work is unique and impossible to recreate identically. There is also the factor of loss of know-how in certain cases.

Key impacts and indicators for Strategic Environmental Assessment:

Impacts	Indicators
Climate change	Emission of greenhouse gases
Acidification	Emission of SO_2, NO_X
Use of natural resources	Energy consumption, land take
Loss of biodiversity	Loss and damage of habitats and species
Air quality	Emission or concentration of pollution
Water quality	Number of water sources affected, concentration of pollutants
Visual impacts	Scale and key physical characteristics
Severance	Barriers, population size in affected areas
Noise	Noise levels, affected surface, population affected
Historical, archaeological, nature conservation	Recognized sites and areas of importance

PROBLEM MATHEMATICAL FORMULATING

There are following destination are given:

Set of impact $i=(i_1, i_2, \ldots i_n)$;

Set of criteria's weight $G=(g_1, g_2, \ldots g_m)$;

Set of criteria $C=(c_1, c_2, \ldots c_k)$

Set of usability $U=(u_1, u_2, \ldots u_n)$

Set of alternatives $A=(a_1, a_2, \ldots a_m)$

The following destinations are used:

For each A alternative a set of criteria ($C^a= C^a_1, C^a_2 \ldots C^a_e$), which describes alternatives properties exists.

C^a is aggregated criteria, which describe properties of each alternative A.

As evaluation alternatives also industrial system development projects could be evaluated.

Criteria	C_1 (g_1	C_2 g_2	......	C_N g_N)
Alternatives				
A_1	a_{11}	a_{12}	......	a_{1N}
A_2	a_{21}	a_{22}	......	a_{2N}
.	.	.		.
A_M	a_{M1}	a_{M2}	.....	a_{MN}

Fig.1. Structure of a typical decision matrix

The aim of calculation is to build the sequence of alternatives, based on alternative paridvise comparison, with condition (1)

$$\begin{cases} u[g(a_1)] > u[g(a_2)]: a_1 \succ a_2 \text{ (preference)} \\ u[g(a_1)] = u[g(a_2)]: a_1 \sim a_2 \text{ (indifference)} \end{cases} \quad (1)$$

As impact aggregation procedure are proposed to use evaluation principle, based on the assumption, that each of impact are one criteria.

- Taking into account preferences of a Decision Maker (DM), rank all the actions of set A from the best to the worst

Finally the alternatives in set A will become strongly sequenced.

MULTI CRITERIA DECISION ANALYSIS (MCDA)

Evaluation of transport system development alternatives could be done in various commissions of decision making, individually or using decision support tools. Environmental impacts also could be used for transport motion control.

In Table I the main decision making paradigms are described.

Multiple criteria decision making (MCDM) includes two complementary areas:

- mathematics-based multiple objective programming (MOP) and
- decision maker-driven multiple criteria decision analysis (MCDA).

The goal of MCDA – encompasses decision makers' judgments and preferences to derive a preferred decision becoming the policy to be implemented for the problem.

Furthermore, they engineers had to take into account the diverse, not clearly articulated preferences of all involved groups of interest. Typical questions illustrating engineering task in this new context were:

Which type of transport, energy resource, conversion technology to use?

The classical – multiple criteria ranking problem includes:

- Dominance relation is too poor – it leaves many actions non-comparable;

- One can „enrich" the dominance relation, using preference information elicited from the Decision Maker;
- Preference information permits to build a preference model that aggregates the vector evaluations of actions;
- The preference model induces a preference relation in set *A*, which makes the actions more comparable;
- A proper exploitation of the preference relation in *A* leads to a final recommendation in terms of ranking.

- Three families of preference modelling methods:
- Multiple Attribute Utility Theory (MAUT) using a utility function;
- Outranking methods using an outranking relation *S*

a_1 *S* a_2 = "a_1 is at least as good as a_2"

- Decision rule approach using a set of decision rules

e.g. "If *gi*(*a*)³*ri* & *gj*(*a*)³*rj* & ... *gh*(*a*)³*rh*, then *a* ® *Class t* or higher"

"If *Δi*(a_1, a_2)³*si* & *Δj*(a_1, a_2)³*sj* & ... *Δh*(a_1, a_2)³*sh*, then a_1S a_2"

- Decision rule model is the most general of all three [2]

Aggregation paradigms

- Disaggregation-aggregation (or regression) paradigm:

The holistic preference on a subset *AR*⊆*A* is known first, and then a compatible criteria aggregation model (compatible preference model) is inferred from this information to be applied on set *A*.

- Traditional aggregation paradigm:

The criteria aggregation model (preference model) is first constructed and then applied on set *A* to get information about holistic preference.

The problem is to compare, rank and evaluate a set of actions, or projects, with respect to N different criteria (C) which measure the favorable consequences of the projects. The measurements of these consequences are given by the vector g(a)=(g_1(a); g_2(a); . . . ; g_N(a)) for any project a belonging to A. The existence of an additive utility function is assumed:

$$U[g(a)] = \sum_{i=1}^{N} u_i[g_i(a)] \tag{2}$$

with

$$u_i(g_i) \geq 0,$$

which satisfies the classic axioms of decision theory, namely the axioms of comparability, reflexivity, transitivity of choices, continuity and strict dominance. The additivity implies in particular that the partial utility of a criterion $u_i(g_i(a))$ depends only on the level of that particular criterion. This function provides an aggregation of the criteria in a common index to compare, rank and assess the projects.

In the formula mentioned above, the utility function assumed by decision makers is simply additive. But what would happen if the decision makers' subjective preferences were affected by some interdependence between criteria? In order to examine this problem, a set of estimations of UTA additive utilities was computed on the basis of stated preferences between projects resulting from utility functions characterized by some interdependence between outcomes. Thus, we assumed that the decision makers' utility for project A was:

$$u(A) = \sum_{i=1}^{z} u_i(g_i(A)) + b \cdot \prod_{i=1}^{z} g_i(A) \tag{3}$$

where g_i(A) is the outcome of A on the i[th] impact, $u_i(g_i(A))$ is the partial utility of the outcome of A on the i[th] impact and (b,c,d…..) - are the coefficients of the interdependence terms.

UTA METHOD

In the research the expediency of the use of an UTA-method is considered with decision-making in the system of equipment choosing efficiency evaluation.

The UTA method [7] has several interesting features: it makes possible the estimation of a nonlinear additive function, which is obtained by the use of a linear program which provides a convenient piecewise linear approximation of the function, and the only information required from the decision maker is global stated preferences between the projects.

- The marginal value functions (breakpoint variables) are estimated by solving the LP problem

$$\text{Min} \rightarrow E^{UTA} = \sum_{x^k \in A^R} \left(\sigma^+(x^k) + \sigma^-(x^k)\right)$$

subject to

$$\left.\begin{array}{l} U'(x^k) \geq U'(x^{k+1}) + \varepsilon \Leftrightarrow x^k \succ x^{k+1} \\ U'(x^k) = U'(x^{k+1}) \Leftrightarrow x^k \sim x^{k+1} \end{array}\right\} k=1,\dots,n-1$$

$$u_i(x_i^{j+1}) - u_i(x_i^j) \geq 0 \quad j = 0,\dots,\gamma_i;\ \forall i \in I$$

$$\sum_{i=1}^{m} u_i(\beta_i) = 1$$

$$u_i(\alpha_i) = 0 \quad \forall i \in I$$

$$u_i(x_i^j) \geq 0,\ \sigma^+(x^k) \geq 0,\ \sigma^-(x^k) \geq 0,\ \forall x^k \in A^R,\ \forall i \text{ and } j$$

C (3)

where ε is a small positive constant.

- If EUTA*=0, then the polyhedron of feasible solutions for ui(xi) is not empty and at least one utility function U[g(x)] compatible with the complete preorder on AR exists there;
- If EUTA*>0, then there is no utility function U[g(x)] compatible with the complete preorder on AR;

In order to apply that method, the field of variation of each criterion [g_i*; $g*_i$], defined by its least favorable value of that criterion (g_i*) and its best value ($g*_i$), is divided into a_i equal intervals [g_i^j; g_i^{j+1}]. The variables to be estimated by the program are the partial utilities at these bounds, say u_i (g_i^j). The utility at intermediate values of the criteria are given by linear interpolation.

For each pair of projects (a, b) belonging to A`, the decision-maker, taking into account the set of criteria, must express his/her overall preferences or indifferences.

The results of these comparisons are introduced under the form of this constraint:

$$\sum_{i=1}^{N}\{u_i(g_i(a_1))-u_i(g_i(a_2))\}+\sigma(a_1)-\sigma(a_2)\geq\delta$$

$$\Leftrightarrow a_1Pa_2$$

in the event of strict preferences, and

$$\sum_{i=1}^{N}\{u_i(g_i(a_1))-u_i(g_i(a_2))\}+\sigma(a_1)-\sigma(a_2)=0$$

$$\Leftrightarrow a_1Ia_2$$

in the event of a strict preference. The constant δ on the right-hand side of the inequality (2) must be strictly positive. Its value can influence very well the solution of the program, so that it must not be given too high an initial value.

The hypothesis that the partial utilities increase with the value of the criteria imposes a series of additional constraints:

$$u_i(g_i^{j+1})-u_i(g_i^{j})\geq s_i \tag{4}$$

$j=1,2,\ldots,\alpha_i$, $i=1,2,\ldots,N$

where s_i must be (strictly) positive. As for δ, it is better to give it a small initial value.

Finally there are normalization and non-negativity conditions:

$$\sum_{i=1}^{N}\{u_i(g_i^{*})=1 \text{ and } u_i(g_{i*})=0 \tag{5}$$

$\forall i$, $\sigma(a)\geq 0$ $\forall a\in A'$, $u_i(g_i^j)\geq 0$ $\forall i$, $\forall j$.

To improve the accuracy of the estimation, more detailed specifications could also be adopted if additional information can be given by the decision maker, such as utilities` differences between projects. However, the questionnaire addressed to the decision maker becomes then longer and more difficult.

When there is not a single solution, a function which is the average of the extreme optimal functions obtained from a sensitivity analysis applied on the last bounds of each criterion should simply be used. The sensitivity analysis is made adding this new restriction to the model:

$$\sum_{a\in A'}\sigma(a)\leq F^{*}+\theta \tag{6}$$

where θ is a small positive number.

In the basic model, it was noted that the values given to δ and s were close to some extent arbitrary.

Obviously, their level influences the results as well as the predictive quality of the model, like it will be illustrated by simulations later. For that reason, and following the suggestion by Srinivasan and Shocker (1973), it is worthwhile to look for optimal values of δ and/or s. First, it is possible to aim at accentuating the difference between utilities by maximizing δ, the minimum difference between the utility of two different actions. This model, named UTAMP1 in order to point out that, on the basis of UTA, it maximizes δ to better identify the relations of preference between projects. The objective of this second-step program is then to maximize δ, subject to constraints. For the case where F*=0, this post-optimality analysis is included. In effect, choosing the solution(s) which maximize(s) δ among all the optimal solutions, the optimal set can only be reduced. A side effect is also to limit the convexity or concavity of the utility function.

For the procedure named UTAMP2, the constraints of the previous method, UTAMP1 remain unchanged but all the s_i become equal to $s\geq 0$. The maximization of (δ + s) also reduces the set of optimal solutions.

When F*= 0, these two post-optimality procedures are justified by the dual relationship between the objective function of the UTA primal program and the objective function:

$$F^{*}=\sum_{a}\sigma^{*}(a)=\delta\sum_{j}y_{j^{*}}+s\sum_{k}x^{*}{}_{k}+z^{*}=0 \tag{7}$$

of its dual. Indeed, at the optimum, where the y_j's are the dual variables corresponding to the strict preference constraints, the x_k's are the dual variables of conditions, and z corresponds to the normalization condition.

Given that δ and s are strictly positive, all the dual variables must equal zero. Thus, in this case, marginal variations of δ and s cannot have the effect of increasing F* . However, in cases, where F* > 0, some of the dual variables will be positive and variation of δ and/or s could increase F* , which would result in a ranking of lesser quality. Actually, when there are positive errors, at least one preference constraint will be saturated and at least one dual variable y_j will be positive. Hence, the variation of δ will automatically affect the level of F*.

For the case where F > 0 the difference between the minimum and maximum error of the first estimation is minimized. This can be done by Minimizing the Maximum individual Error z, $z\geq\sigma(a)$ for all a in A`, in a linear model based on UTA and which we named UTAMIME.

MCDA APPLICATION PROCEDURE

The analysis distinguishes between the two broad multi criteria methodologies, namely the multi objective programming (MOP) models (where alternatives are implicitly defined by a set of constraints) and the models dealing with discrete alternative options (where, in general, alternatives are explicitly known a-priori).

The former are the natural evolution of the mono criterion optimization techniques, traditionally used for ensuring the supply of the required quantity of energy at the right time, generally using a monetary indicator as the objective function.

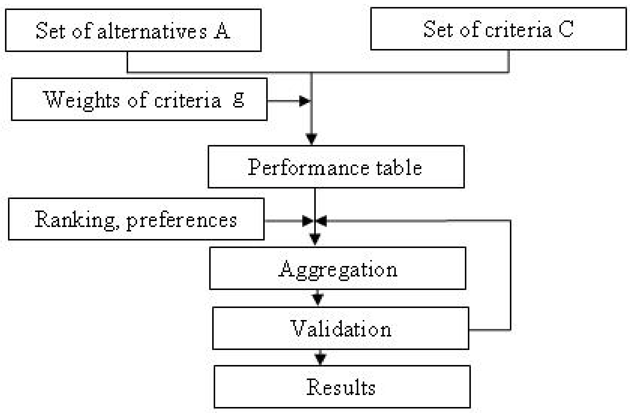

Fig. 2. The structure of expert system rule interpreter

In case, when there are set of projects A and set of impacts I the utility of all alternatives are calculated as mentioned before

$$u(A) = \sum_{i=1}^{z} u_i(g_i(A)) + b \cdot \prod_{i=1}^{z} g_i(A) \qquad (8).$$

The application of decision making method a 3 stage procedure is proposed, using environmentally impacts aggregation function.

Stage 1: the weight assignment for each impact

Stage 2: the impact aggregation, in one utility criteria

Stage 3: the evaluation alternatives, using UTA method, as utility criteria in ranking process the aggregated utility.

EXAMPLE

As an example the railway transport interlocking system improvement is considered. Interoperability is a key topic in the Strategic Railway Research Agenda (SRRA), with a whole chapter of the technical annex devoted to it. The SRRA suggests a common development of technologies at European level. New technologies require new product acceptance methods, which are developed together by all European countries under a common platform. This is a right way of obtaining the benefits of the latest technologies while assuring cross acceptance of the new products. The development of new technologies using EU level platforms facilitates future cross acceptance. The idea is that a new, Europe-wide spread and accepted common technology substitutes all local variations of older technologies.

The gauge and all interlocking system difference between Europe and Russia/ Baltic states now is important time and money loss disadvantage in comparison transportation by rail and by road traffic. The problem decision is very complex, and this is a European level decision, to develop the common Railway system. This is mainly economic based decision, but also the impact aggregation for development situation description and analysis.

Under the current situation in Latvia there are few different interlocking systems, but all these systems are based on railway interval regulatory principle – relay based automatic. Full modernization of railway techniques is long enough process connected with the big capital investments. For this reason the European commission supports project realization on safety of movement of a railway transportation and traffic control by railway transportation. This project is known under name ERTMS/ETCS. The project provides gradual modernization of an infrastructure of railway transportation in Europe. At the first stage the minimum capital investments which are connected with installation of receivers-transmitters «eurobalise», and also with installation of road electronic blocks LEU are necessary. The system of digital communication of railways GSM-R is a second stage of modernization of an infrastructure of the European railways.

A communication system on the Latvian railway also, morally obsolete. System GSM-R commissioning will allow to realize the second part of the project and to provide reliability and traffic safety of trains according to standards ERTMS/ETCS. It means use of a radio channel for data exchange between the roadside and onboard equipment. It will give the chance to refuse the roadside traffic lights which use becomes impossible at speed of movement reaching 300 km/h and above. At the big speeds of movement the machinist cannot simply consider a signal of a roadside traffic light and have time to react in due time and adequately to it.

The first level ERTMS is the control system meaning maintenance of reliability and traffic safety of trains, supervising a brake way. As a matter of fact is a dot alarm system of locomotives with an information transfer in concrete points of a way and supervision for long a brake way to the following point. Numbering of levels is made according to the increasing in the degree of complexity of system:

1st level – standard ALS the system which contains the basic functions necessary for maintenance of reliability and traffic safety of trains, and also provides alarm system presence on locomotives;

2nd level – system of maintenance of full safety and train dispatching. The system uses a radio channel for data exchange with roadside devices;

3rd level – the improved variant 2 levels which completely is based on radio channel use, thus the necessity of use of signals of the majority of roadside devices (traffic lights, counters of axes, etc.) disappears; in the case of need, the use of road block-posts for restriction of movement of trains is provided.

Commissioning of new interlocking system is very expensive and difficult process, partly therefore process of renovation of equipment and devices is providently divided into levels and stages, so the decision making procedure for interlocking service choosing problem for each station is actual.

As alternatives the railway stations renovation alternatives are evaluated.

The area of application of decision analysis methodology is very wide.

The example of using 3 stages procedure for alternative choice is given.

Usability evaluation fragment is given in Table I.

TABLE I
USABILITY EVALUATION FRAGMENT

	1.alter native	1a.alte rnativ e	2.alter native	2a.alte rnativ e	3.alter native	3a.alte rnativ e
Air quality	6	4	5	3	1	2
Visual impacts	1	2	1	6	4	5
Severance	2	6	1	3	4	5
Noise	2	1	6	3	6	4
U(a)	**20**	**27**	**29**	**42**	**43**	**44**

Normalization is completed by criteria with definition (Table II):

TABLE II
USABILITY EVALUATION FRAGMENT

Impact/Criteria	Weight g
Air quality	1
Visual impacts	4
Severance	2
Noise	3

$$U[g(a)] = \sum_{i=1}^{N} u_i[g_i(a)]$$

$U(a_1)=6x1+1x4+2x2+2x3=20$

	A	B	C	D
1				
2		**Price**	**Time**	**Usability**
3	Alternative 2	3	10	1
4	Alternative 2a	4	20	2
5	Alternative 1	2	20	0
6	Alternative 1a	6	40	0
7	Alternative 3a	30	30	3
8	Alternative 3	3	20	2

Fig. 3. Renovation alternatives ranking

Many projects are similar by evaluation, that's for the interval scale will be used, so the usability evaluation is divided into groups 0, 1, 2, 3. Ranking of 6 alternatives of renovation are shown in Fig. 4.

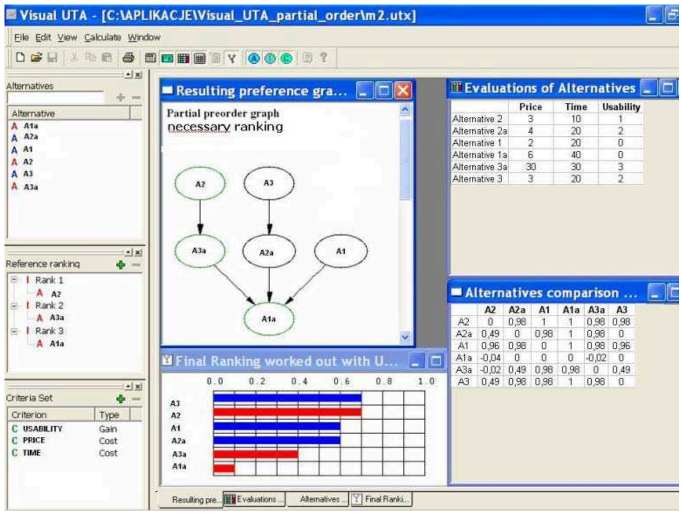

Fig. 4. Visual UTA-example screenshot

CONCLUSIONS

The main steps of development of impact aggregation procedure for sustainable transport system are described in the article. The new 3 stage environmental impact aggregation procedure is suggested. This decision making procedure is usable not only for transport projects evaluation, but also for other industrial system development projects.

The structure of this algorithm includes utility of project and of each system impact, so it is possible to evaluate projects, and also manage technological process.

This research results could be used as environmentally transport indicator aggregation methodology evaluation and development task in COST 356: Towards the definition of a measurable environmentally sustainable transport (EST).

REFERENCES

[1] COST 356 - Towards the definition of a measurable environmentally sustainable transport. cost356.inrets.fr/
[2] S. Greco, B. Matarazzo, R. Słowiński,: Axiomatic characterization of a general utility function and its particular cases in terms of conjoint measurement and rough-set decision rules. European J. of Operational Research, 158 (2004) no. 2, 271-292
[3] Čaiko, N. Kuņicina, A Patļins., A. Pelņiķis, L. Ribickis Development of decision-making procedure of choice of the equipment for railway crossing at stations // Transport means 2008, Transport Means 2008, Lietuva, Kaunass, 23.-24. oktobris, 2008. - 151-154. lpp.
[4] S. Russel, P. Norvig, Artificial intelligence a modern approach second edition Prentice Hall.2002 1058p.
[5] G. Weiss, Multiagent systems: a modern approach to distributed artificial intelligence. – Cambridge (Mass.) :London : MIT Press – 2000. – 619p.
[6] M. Mezitis "Microprocessor centralization systems reaction time reduction", Vilnius: VGTU 2005.
[7] R. Słowiński, S. Greco MCDS With set of utility functions or a set of decision rules compatible with holistic preference information MCDM Conference, Chania, Greece, 2006.