QUANTITATIVE ANALYSIS OF ENVIRONMENTAL IMPACT OF TRANSPORT PROJECTS*

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Methods of evaluation of environmental indicators preferences and consequently evaluation of new transport projects are presented in this paper. This research is part of European co-operation in the field of scientific and technical research (action COST 356) which main objective is to design harmonised methods to build better environmental indicators system by using existing European indices, and to build methods to be applied to the decision-making process in the transport sector. We suggest a new methodology using the Analytic Hierarchy/Network Process (AHP/ANP methods) and Aspiration Levels Method for decision-making and evaluation of transport projects or strategies and their impacts on sustainable environment. Application of suggested method is illustrated on pilot study. This pilot study also maps a contemporary situation in environmental impact assessments or strategic environmental assessments (EIA/SEA) of transport projects.

environmental indicators; weights; AHP/ANP methods; Aspiration Levels Method

INTRODUCTION

Environmental issues play an important role in the decision-making process of transport policies, plans, programmes and projects. The environmental impacts to be considered increase in complexity and relevance, as do the decisions to be taken. Sustainable mobility calls for a truly multidisciplinary approach to decision-making in order for the complex issues to be efficiently elucidated. The multidisciplinary approach must involve environmental scientists, traffic engineers, economists, policy analysts, land-use planners and public also.

This wide multi-disciplinarity has not yet been jointly achieved within the framework of transport research in Europe. In addition to the multi-disciplinarity of topics within a single field, the multicultural aspect of the European society plays an important role as well, and research and knowledge are not yet evenly spread over all European countries.

Most of the present EIA/SEA do not take into account properly the variety of the environmental impacts, or are using markers, indicators, criteria and more generally tools which do not represent the impacts. A correct representation of the whole range of impacts is necessary to ensure that sustainability takes into account environmental issues to a satisfactory degree. This is especially important for the transport sector where the concerns and the stakes are important. Therefore it is so important to create and to appraise an evaluation procedure of impacts preferences (impacts characterised by criteria or by aggregated indicators) with the use of sophisticated methods.

Till now there is no universally accepted method for aggregation of environmental impacts, not even a common approach. Quantitative aggregation is, of course, desirable if subjective judgement or political considerations are to be ruled out. However, the perceived difficulties of attaining a unbiased set of criteria for weighting an aggregating impacts into indexes has led to many administrations to recommend soft approaches to aggregation rather than those based in mathematical factoring and aggregation.

The main objective of our proposed methodology is to design harmonised methods to be applied to the decision-making in the transport sector in the different European countries, in order to contribute to a systemic approach to environmental and transportation issues. Therefore this methodology is based mainly on multi-criteria decision-making methods used experts assessments.

The Analytic Hierarchy Process (S a a t y , 1980, 1999) was chosen for this purpose with the aim to verify possibilities of AHP method used for transport EIA/SEA and to involve three groups of respondents (public, informed public and transport experts) into decision-making.

The Aspiration Levels Method was used for selection the sustainable transport projects from all proposals.

MATERIAL AND METHODS

SEA and EIA

Most of the present strategic environmental assessments (SEA) or environmental impact assessments (EIA)

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do not take into account properly the variety of the environmental impacts, or are using markers, indices and more generally tools which do not represent the impacts (Manual, 2005). A correct representation of the whole range of impacts is necessary to ensure that sustainability takes into account environmental issues to a satisfactory degree. This is especially important for the transport sector where the concerns and the stakes are important (J o u m a r d , 2005).

In too many cases, SEA currently considers very few environmental impacts, often the CO_2 emissions, sometimes in addition noise and a few other types of impact. The people doing these assessments usually believe that CO_2 emissions or noise represent all the environmental impacts, although in fact other impacts can have contradictory trends. Neglecting other environmental aspects jeopardizes the quality of the SEA and thus not only the value of SEA as a basis for decision-making but also the credibility and sustainability of the decisions taken. When more than one or very few impacts are taken into account today, the way they are aggregated is often as simple as possible, independently of the real-world multi-criteria choice by the stakeholders. Clearly, there is a need for tools to make complex decision situations manageable without loosing too much of the information in the process of the necessary simplification.

This situation calls for the development of more practical methods to efficiently integrate complex environmental issues into the SEA process. Guidelines on such impact aggregation can be based on:

a) ***Most adverse category:*** The principle is that the entire strategy should be assessed according to the most adverse assessment of the resources affected;
b) ***Cumulative adverse effects:*** If there is a cumulative effect across a range of resources, than the strategy, as a whole should be scored in a higher category than the resources in isolation;
c) ***Balancing adverse and beneficial effects:*** The principle here is that, where there is a genuine compensatory effect, adverse impacts on some resources may be balanced by beneficial impacts on others.

Several attempts of multi-criteria methods application in transport were carried out. N a j i d et al. (2005) used the Analytical Hierarchy Process (AHP) method to analyse road infrastructure development. The intention of this analysis was to choose the best road development alternative. But they did not take environmental aspects into account.

Contemporary Situation in Transport (Road) Environmental Assessment

The current situation of EIA/SEA in Czech Republic is possible to characterize on the base of research results and obtained data from the Czech Republic's information system (Informační systémy EIA/SEA ČR, 2009). The research was carried out to determine what and how indicators were used in transport projects assessment. Data were logged from 101 of road projects and 52 car parking projects of EIAs carried out during the last two years in the Czech Republic. As typical example can serve EIA that was carried out near to Prague with the aim to select the best variant of new road around the city Kralupy n/V. (see Fig. 1).

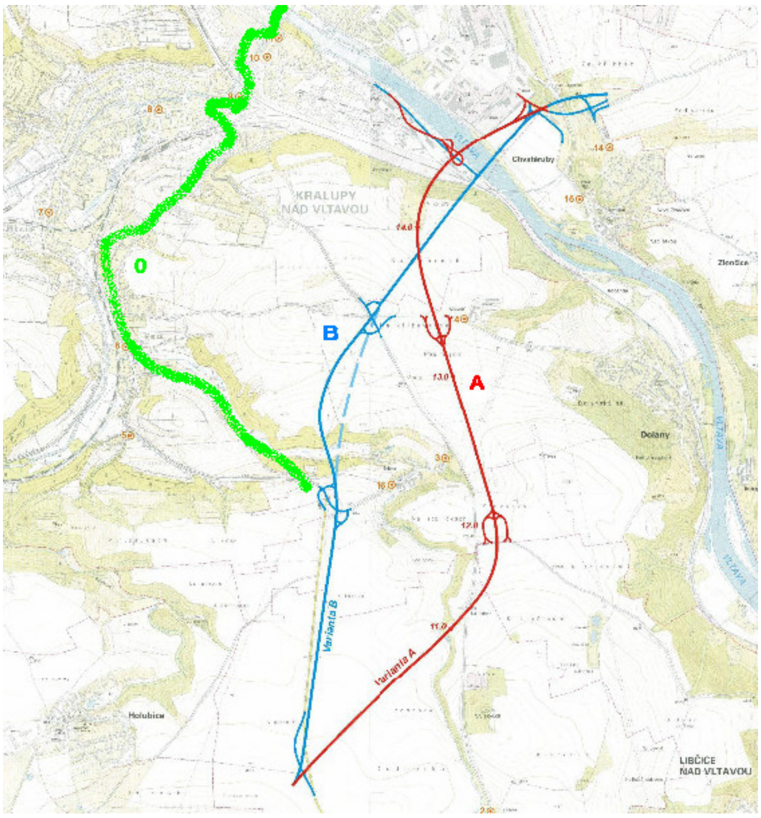

Fig. 1. EIA of road construction (0 – contemporary situation, A, B – proposed variants)

Table 1. Comparison of EIA variants – city Kralupy n/V. 2004 (company VPÚ DECO PRAHA a.s.)

Criterium	Variant 0	Variant A	Variant B
Impacts on residential households	–2	1	2
Impacts on surface water	0	–1	–1
Noise impacts on residential housing in comparison with existing one	0	–1	–1
Impacts linked with waste	–2	1	2
Impacts on flora and fauna	0	–1	–2
Impacts on landscape view	0	–1	–2
Impacts on residents	–2	1	2
Impacts on archaeology findings	0	–1	–1
Impacts of remaining (old) ecological impacts	0	–1	0
Other impacts	0	–1	–1
Total	–6	–4	–2

Impacts assessment of this example includes criteria that are listed in the Table 1. The EIA uses different indicators to determine criteria but their values are modified by a vague interpretation into the criteria value. Finally values of criteria are summoned without any comparison, determination of weights, comparing etc. and as the best variant is taken the one with the maximal value. In this case the variant B was recommended to be constructed.

As it is shown in this example the assessment of the transport impacts has two aspects – the first one is to determine values of criteria (aggregated indicators) and the second one is to compare these criteria (to weight them) to obtained quantified values of criteria. Quantification of these two aspects is based on results obtained in action COST 350 and methods suggested in action COST 356.

COST 350

The former research of transport environmental impacts was carried out in the frame of European co-operation in the field of scientific and technical research, action COST 350 (Calderón et al., 2009) and it was mainly devoted to the availability of input data, the feasibility of the environmental assessment, the validity, reliability and scientific quality of the environmental assessment tools.

Results of COST350 proposed 16 indicators including aims and targets that must be taken into account as far as the environments protection is concerned were elaborated. They include the following: tackling climate change; protecting nature and bio-diversity; environment and health (water protection, soils protection. air quality protection against noise); sustainable use of natural resources and management of wastes.

Results of COST 350 show available methods for the joint consideration often called aggregation of socio-economic and environmental impacts in the transportation sector. Aggregation is here defined as the combination of impact scores into a final/overall assessment score at the project and strategy/plan scale within individual topics. As it is obvious, aggregation is part of the assessment process whereby decision-makers would opt for a preferred transport alternative. It is also evident aggregation is close to the final stages of decision-making and, thence, it can be seen to an aid to those responsible of the final decision; likewise, it can be seen as a tools for democratic public participation in the process of assigning importance scores to all impacts stemming from alternatives under consideration.

Ideally, an unbiased decision ought to be based upon an objective index reflecting the "value" of the alternative under consideration. However, the difficulties of reaching the undisputed index have led to the purpose acceptation that may not be necessarily producing a single overall environmental index (e.g. compounded with a socio-economic ones), but more simply bringing together all individual impacts across the plan area to be presented to decision-makers and stake-holders at large. Due to all these shortcomings, no formalised method for impact aggregation is available in COST 350.

Analytical Hierarchical Process Method

The Analytical Hierarchical Process (AHP) (Saaty, 1980, 1999) is based on mathematics and psychology and serves as a mathematical solution method for individual or group decision-making with multiple criteria. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. It is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.

Multiple Criteria Evaluation of Transport Environmental Impacts

The transport environmental impacts should be considered in complexity and relevance by utilisation of adopting and modifying methods for cumulative environmental effect assessment. All these indicators should be aggregated to obtain tool for decision-making processes. These problems represent a large group of specific multiple criteria problems. Therefore multiple criteria decision-making methods will be used for solving of these problems.

Especially we choose the Analytical Hierarchical Process and the Aspiration Levels Method (B r o ž o v á et al., 2007, 2008).

Impact Evaluation of New Concept of Transport Strategy or Project

First suggested tool serves for initial evaluation of new concept of transport project or strategy. It is tool for automatic evaluation of its environmental impact indicators according to the selected features or characteristic of transport project or strategy. This tool should be based on large database of indicators values of former research or already realized transport projects.

In the first step of application of its evaluation tool (see Fig. 2) the global characterisation has to be set, global code (Code of transport project or strategy context – CTC) is assigned to transport context. Transport context is derived from transport mode and it should take into account sources and transport means used for the evaluated transport project or strategy. The decision making term must be also determined. The term of decision making is proposed as short term (operational), middle duration term and long term (spatial planning). It is evident that the longer is decision-making term the more environmental impacts must be balanced with beneficial social effects and other factors (e.g. cost benefit analysis, SWOT analysis etc.).

In the second step the more quantitative specific features are set. Decision-maker obtains expected value of environmental impact indicators.

Transport project in the example (see Fig. 2) has the following characteristics:

Transport mode – road
Prevailing propellants – combustion engines
Infrastructure – municipal roads
Used materials for transport means – renewable 50%
Used energy for propeller– renewable 25%
Used land – landtake

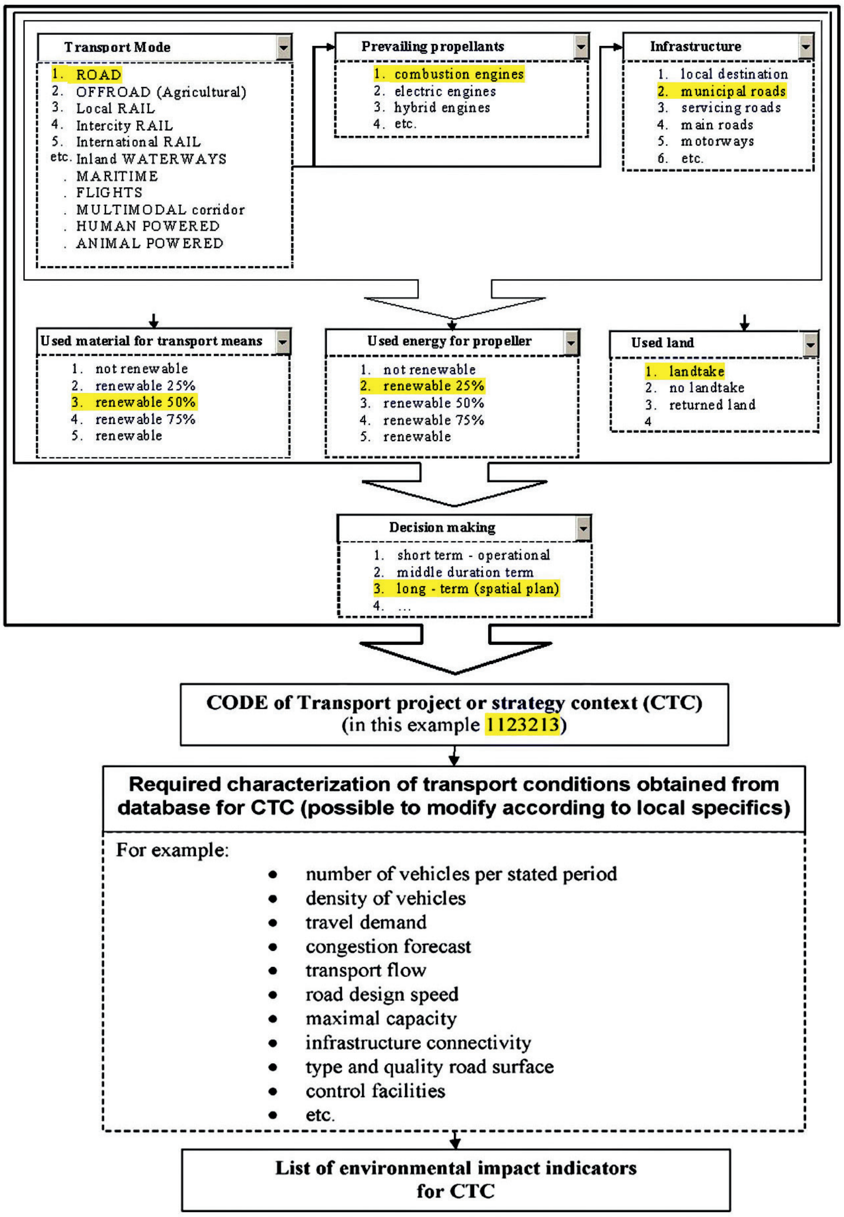

Fig. 2. Schema of transport project or strategy context determination (example)

Decision making – long term (spatial plan).

According to the characteristic code CTC decision maker receives a list of environmental impact indicators.

Preferences Evaluation of Environmental Impact Factors

The second tool is evaluation of environmental indicators preferences using the Analytical Hierarchical Process (AHP). The experts' reports will be obtained by the way of electronic inquiry and they are assumed different for various transport contexts (see above CTC).

The model can have three or four levels complete hierarchy (see Fig. 3) according to the further specification of indicators.

1. The goal is evaluation of the environmental impact indicator preferences.
2. The judgement of asked experts. We suppose experts who will be asked in form of electronic inquiry.
3. 15 environmental indicators are selected as preliminary results project COST350. These indicators are not quite equal to final results of COST 350 but they includes maximum of information needed for purposes of this study, this study begun before the end of COST350.
4. Three types of indicators differing according to the quantity of information can be used.

Preferences of all indicators are calculated as a synthesis of preferences on different levels of hierarchy.

Selection of the Group of Sustainable Transport Strategies or Projects

The third tool serves for selection of the sustainable transport strategies or projects and refusing of non-acceptable ones. This tool is based on Aspiration Levels Method (ALM). ALM (Hwang, Yoon, 1981) is a very simple but an useful decision tool that takes advantage of the concepts of satisfying as well as other concepts of multiple criteria decision making. This tool assumes instead of searching for best transport strategies or projects, refusing alternative that has been found no satisfying a given aspiration level.

The specification of proper aspiration levels for all indicators of environmental impacts is important for this tool. This approach enables to differentiate various transport strategies or projects according to their environmental impacts.

The aspiration levels specification has to respect preferences of different indicators set in previous tool. These aspiration levels can be articulated specifically for different tenders but more systematic way is their global setting for instance in form of general regulation valid for specific region and time period.

Selection of the Best Transport Strategy or Project

The fourth tool serves for selection of the best solution of transport project using preferences of indicators. It is again based on AHP method.

This AHP model has three levels complete hierarchy (see Fig. 4).

1. The goal is the selection of the best variant of transport strategy or project.
2. List of all relevant indicators.
3. There is the group of transport strategies or projects.

As a result of calculation of this model the best transport strategy or project is selected.

RESULTS

The aim of the following pilot study was to obtain experience with possibilities of data collecting and data processing and simultaneously with the assessing of indicators weights for a hypothetical transport project. The comparison of transport project variants was not carried

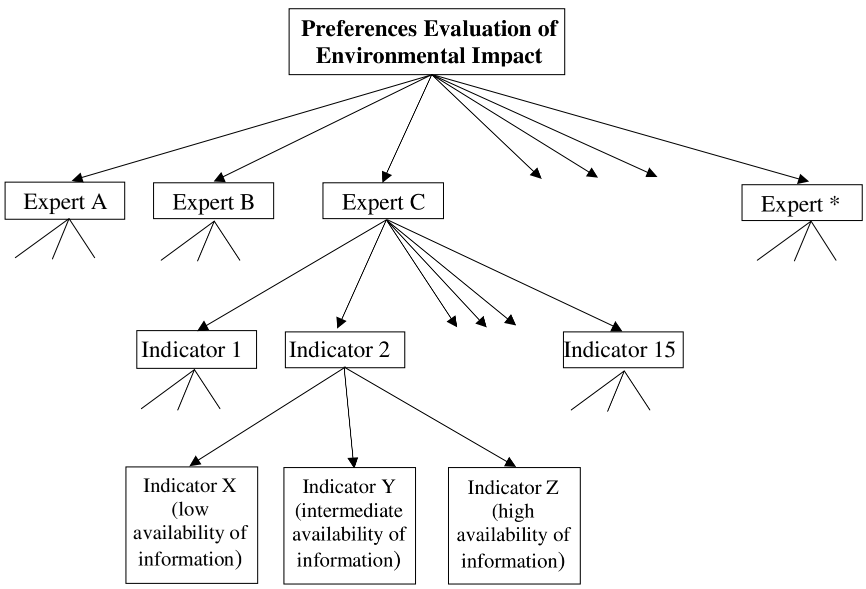

Fig. 3. Hierarchy of environmental impact indicators

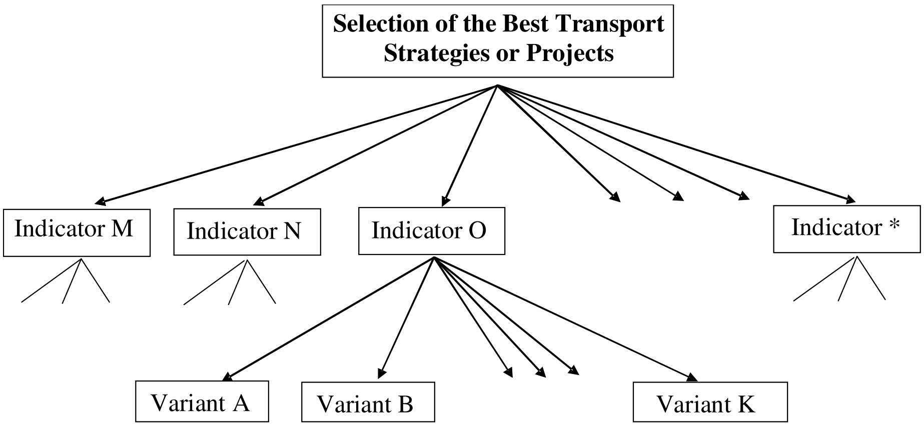

Fig. 4. Hierarchy in AHP for selection of the best transport strategy or project

out in the study. The reason of that is the aggregated indicator values are topic of following research and they should be determined as final results of COST 356 action. But it is evident that the real values of aggregated indicators can not be utilized without the preliminary assessment of their weights.

MS Excel was used to obtained data from different groups of respondents by the form of electronic questionnaire (file). The structure of electronic questionnaire was prepared in a way that enables an easy work for respondent. The MS Excel file consisted of three sheets (one of them invisible) and macro code. The first sheet contents a description of model situation (Fig. 5) and brief explanation of 15 indicators meaning (Noise and vibration, local air quality, regional air quality, quality and use of water, protected areas, waste, loss of biodiversity, light pollution, technological hazards, landscape, cultural and built heritage, land use /landtake/, non-renewable resource use, ozone depletion, climate change, safety of transport users and residents). Explanation serves as a support for public that is not informed about importance (sense) of impacts characterised by indicators.

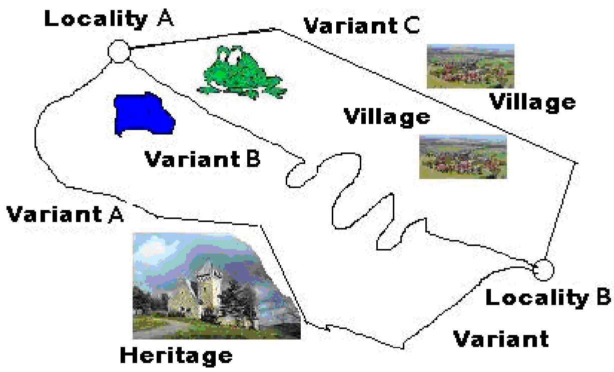

Fig. 5. Description of model situation

The second sheet contents tools (Fig. 6) that can help with pairwise comparison to respondent. Scroll bars and check boxes were used here. Next, expected transport context was described here. Respondent was asked to compare values of these 105 pairs of criteria by use of scroll bar and after it to mark a check box. The condition of questionnaire's completing was that every check box had to be marked. This condition was checked after the use of button

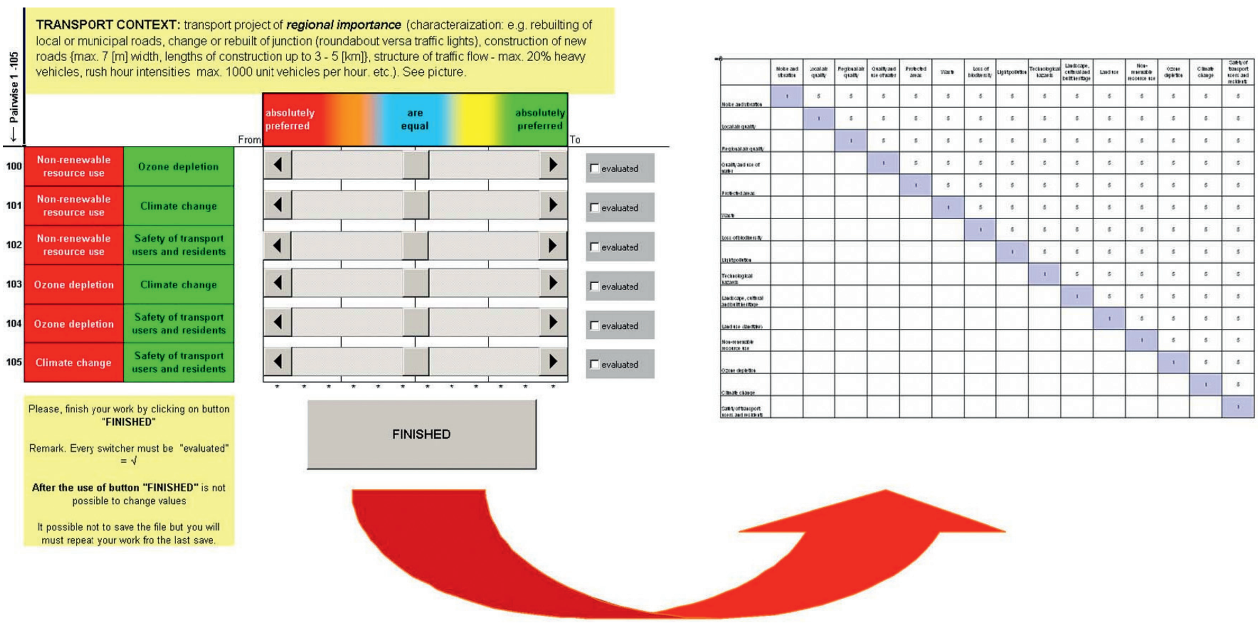

Fig. 6. Electronic questionnaire and responding hidden sheet

"FINISHED". In case that every check box was marked the sheet was protected against changes and respondent was asked for saving the file. Values of scroll bars were linked with the table located on invisible (hidden) sheet (Fig. 3). Values from this table were used for calculation indicators preferences using AHP.

The advantage of this generally accepted model is that respondents are not influenced by their specific or individual interests (NIMBY).

Evaluation method for environmental impact indicator preferences or importance uses AHP method. A hierarchical structure of criteria and experts' (respondents) preference estimation of elements on different levels can be used for calculation of quantitative weights of all primary indicators.

Two variants of model were specified and used.

The first model variant can be called **"One-step comparison"**. This model has four levels complete hierarchy (Fig. 7).

1. The goal is the indicators preference setting.
2. It consists of three groups of respondents. First one is group of experts, the second is group of students of course "Decision Models", and the third is a group of students of course "Logistic Systems",
3. It represents the judgement of asked experts and students.
4. There are 15 indicators that are selected as a preliminary results of COST350.

The second model variant can be called **"Two-step comparison"**. This model has five levels complete hierarchy (Fig. 8).

1. The goal is the indicators preference setting.
2. It consists of three groups of respondents. First one is group of experts, the second is group of students of subject "Decision Models", and the third is a group of students of subject "Logistic Systems",
3. It represents the judgement of asked experts and students.
4. Four groups of indicators represents the proximity of environmental impact factors.
5. There are 15 indicators that are selected as a preliminary result of COST350.

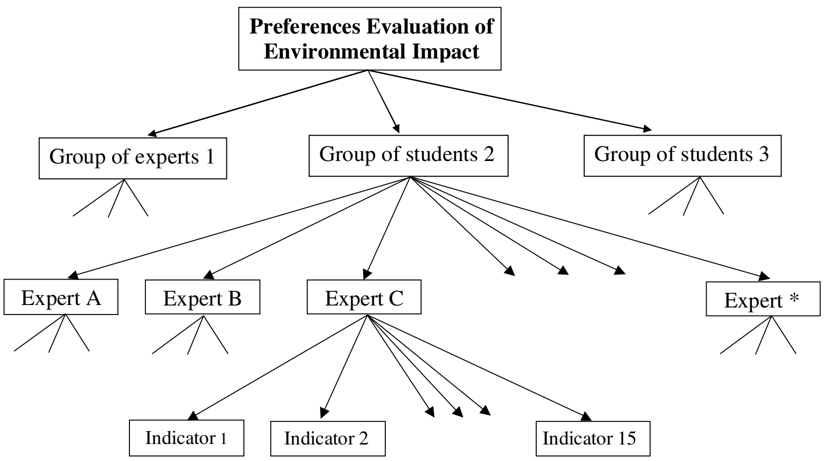

Fig. 7. One-step comparison hierarchy

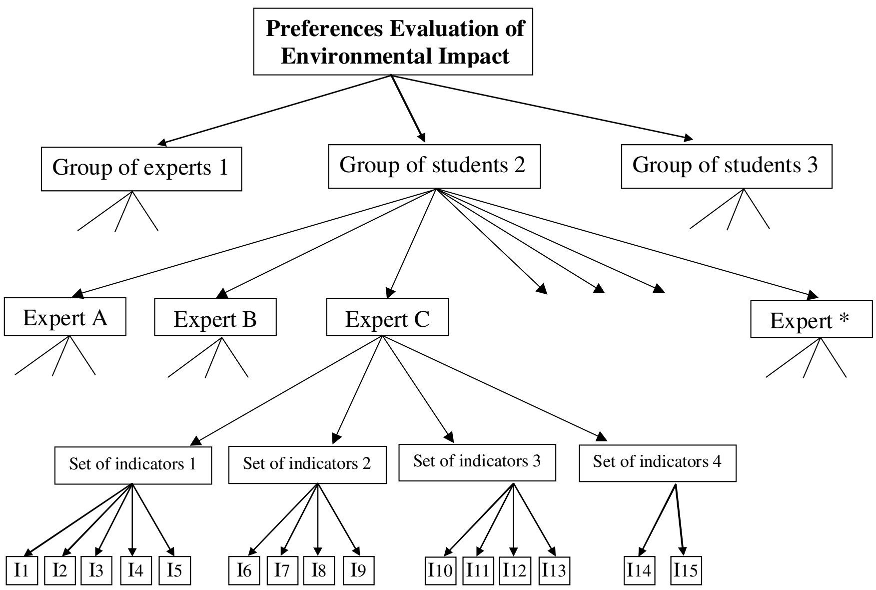

Fig. 8. Two-step comparison hierarchy

DISCUSSION

Three groups of respondent consist of 22 transport experts (people employed in transport sector), 59 students of "Logistic Systems" (so called "informed public") and 24 students of "Decision Models" (so called "public") were inquired. It is necessary to remark that this sample represents educated people without any links to specified conditions (NIMBY was excluded).

Processing of obtained data performs the consistency checking and omitting of non-consistency responses. Global synthetic preferences were carried out according to the decision hierarchy. Above described models with following evaluation of weights were used:

- One-step comparison model
  Equal preferences of group of respondents – (1/3);
  Equal preferences of respondents within group – (1/n);
  Preferences values of indicators are set using Saaty's pairwise comparison method.
- Two-steps comparison model without weights
  Equal preferences of group of respondents – (1/3);
  Equal preferences of respondents within group – (1/n);
  Equal preferences of group of indicators – (1/4);
  Preferences values of indicators are set using Saaty's pairwise comparison method with grouping of indicators.
- Two-steps comparison model with weights
  Equal preferences of group of respondents – (1/3);
  Equal preferences of respondents within group – (1/n);
  Preferences of group of indicators are set according to the number of indicators in these four groups – (5/15, 4/15, 4/15, 2/15). Table 2describes these groups of indicators.

The final results are presented in Fig. 9 and Fig. 10. The Fig. 9 presents order (rank) of indicators. These values represent average rank of all respondents (excluding respondents with low consistency). It is possible to say that some indicators have a very high correspondence between every model – especially land use, light pollution, landscape and heritage, non-renewable resources – but every criterion of these correspondences has higher values of rank i.e. its importance is lesser (lesser weight). Lesser rank correspondence between one-step and two-steps models can be seen in local air quality, regional air quality, noise and vibration. These differences are reduced in comparison of weighted and non-weighted two-steps comparison models, where the weight is higher (Fig. 10).

Table 2. Four groups (subgroups) of indicators

Group I	Group II
Local air quality	Noise and vibration
Regional air quality	Waste
Quality and use of water	Light pollution
Ozone depletion	Non-renewable resource use
Climate change	
Group III	**Group IV**
Protected areas	Technological hazards
Loss of biodiversity	Safety of transport users and residents
Landscape, cultural and built heritage	
Land use	

Important difference can be seen in indicators Climate change and Safety of transport users. It can be explained by regional transport context, and by extremely different views of respondents, because public do not include safety as indicator for environmental impact.

CONCLUSIONS

Indicators of the environmental impacts of different transport subsystems (as ITS or telematic, agriculture transport etc.) are contradictory in reality and interests of various decision-making subjects can be even in a conflict. Similar problem is also quantification of available information and their combination. The results of previous action COST 350 propose a list of 16 main different indicators that could be used as the key indices for transport impact assessment. According to the new action COST 356 the transport environmental impacts should be considered in complexity and relevance by utilisation of adopting and modifying methods for cumulative environmental effect assessment. All these new indicators should be aggregated to obtain tool for decision-making processes.

We suggest multiple attributes approach containing four basic tools with different aims:

- The first tool serves for environmental impact indicators evaluation of new context of transport project or strategy. It is tool for their automatic evaluation based on the selected features or characteristic.
- The second tool consists of the Analytical Hierarchical Process (or Analytical Network Process) using application of AHP/ANP hierarchical structure of indicators and their experts' preference estimation. The aim of this tool is the evaluation of indicator preferences.
- The third tool is based on setting of the worst values of environmental indicators and selection of accepted transport projects according to their environmental impacts. The aim of this approach is to select group of the sustainable projects.
- The fourth tool is again application of Analytical Hierarchical Process (or Analytical Network Process). The aim is to find the best transport project from sustainable tendered projects from previous step.

In the further work we also suggest a discussion about the using of Analytical Network Process Method (S a a t y , 2001, 2003) and DEMATEL method (L i o u , 2007) because the dependencies between different factors and its different indicators are very complex.

The experience with the use of AHP method and Saaty's pairwise comparison for determination of aggregated indicator preferences proved the following conclusions:

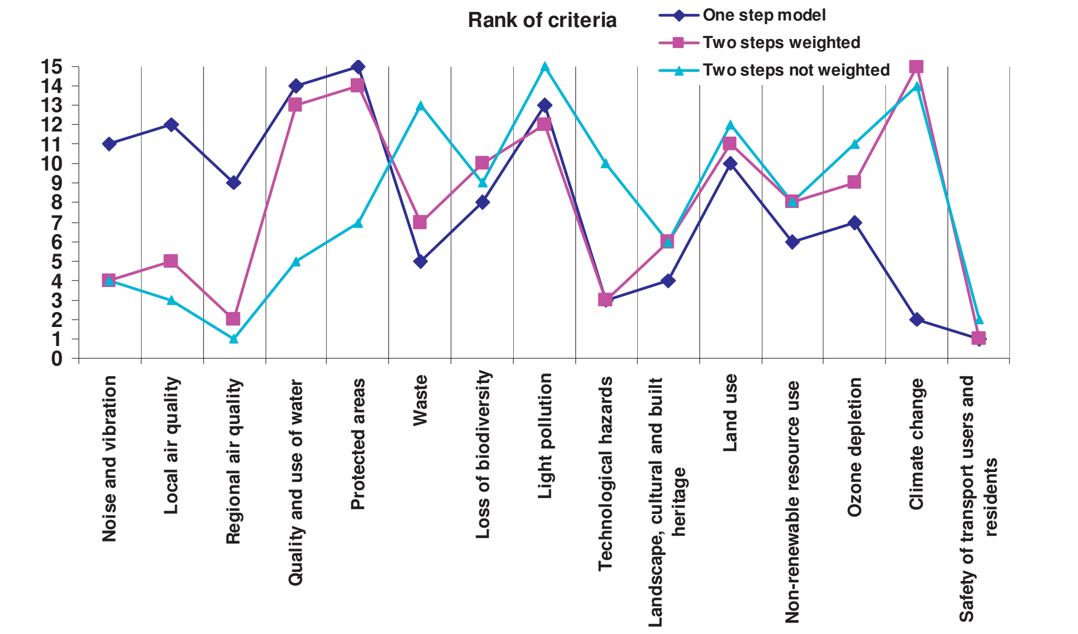

Fig. 9. Rank (order) of indicators

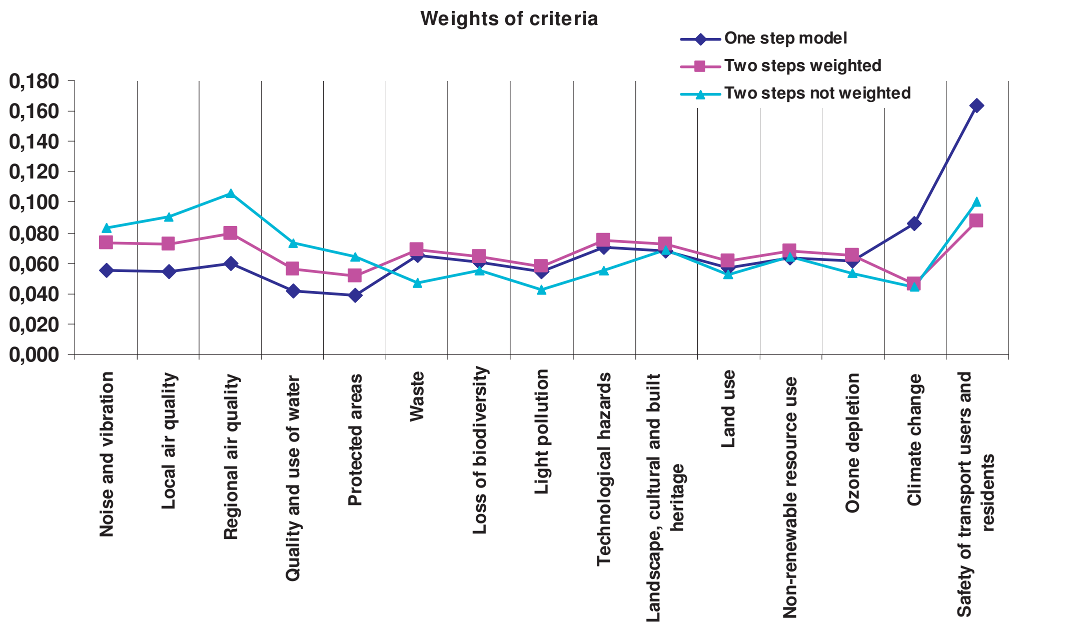

Fig. 10. Weights of indicators

- It possible to recommend electronic questionnaires from the point of view of easy data processing (in practice, pairwise comparison value could be obtained from internet database with adequate interface and non/restricted access instead of used MS Office product);
- In case of higher number of indicators, the number of pairwise comparisons has increasing tendency. It is possible to recommend to group the criteria and herewith to reduce number of pairwise comparisons.
- Results of indicators preference determination prove possibilities to use criteria weights and AHP method for EIA/SEA instead of contemporary ways of assessment.
- The case study proves necessity to determine quantified aggregated indicators for enhancing EIA/SEA processes.

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Kvantitativní analýza environmentálních dopadů dopravních projektů.

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V tomto článku je navržena metoda pro ohodnocení preferencí environmentálních indikátorů vhodná k ohodnocení dopravních projektů. Tento výzkum je částí evropského projektu COST 356, jehož hlavním cílem je navrhnout soubor metod pro konstrukci nového systému environmentálních indikátorů, který by byl využit pro rozhodování v dopravním sektoru v rámci Evropské unie.

Navrhujeme novou metodologii pro ohodnocení preferencí environmentálních indikátorů vhodnou k ohodnocení dopravních projektů s využitím analytického hierarchického/síťového procesu (AHP/ANP) a metody aspiračních úrovní pro hodnocení a rozhodování o dopravních projektech a strategiích.

Uvedená pilotní studie ukazuje možnosti praktické realizace a využitelnost navržených postupů při posuzování vlivů dopravních projektů na životní prostředí (EIA/ SEA).

environmentální indikátory; váhy; metoda AHP/ANP; metoda aspiračních úrovní

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