Harmonized Inland Navigation Transport through education and information technology

APPLICATION OF SIMPLE MULTI-CRITERIA DECISION MAKING METHODS FOR COMPARISON OF ALTERNATIVES OF TRANSPORTATION TASK

WP 3: Harmonization of IWT education and IT deployment
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1 SCOPE OF THE REPORT

The scope of this report is to give an example how multimedia elements can be used in the training and education of personnel in IWT field. In this case the multimedia element is an appropriate e-learning platform, for which a special course dealing with the application of simple multi-criteria decision making methods for comparison of alternatives of a transportation task is drafted.

In this report the course and its program is described, and the way how it can be made available for the public is shown. Last but not least, an example of the application of a simple multi-criteria decision making method is also given.

2 THE COURSE

2.1 The name of the course

Application of simple multi-criteria decision making methods in the field of transportation

2.2 Target group

All decision makers in the field of logistics, IWT

2.3 Goal of the course

The main goal of the subject is to show how simple multi-criteria decision making methods can help the decision-makers in the field of transportation in their daily work.

Decision making was always an important task in history as well, as all the decisions have serious consequences. Making social and economic decisions on higher levels without precise examination can cause considerable damages to all stakeholders

The complexity of the transportation decision problems requires that in many cases different economical, technical, social and environmental aspects must be considered. It is also very common for transportation decision problems that interests of different stakeholders and their contradictory points of view must be analysed. The following groups of stakeholders are usually interested in the rational solutions of the transportation decision problems: customers of the transportation companies, owners and managers of the companies, employees of the companies (including an important group of drivers), authorities responsible for transport operations, local communities. The requirements and interests of those groups must be satisfied, at least to same degree. In such circumstances the application of the MCDA methodology to solve complex decision problems seems to be reasonable.

Multiple criteria decision aid is a dynamically developing field which aims at giving the decision-maker some tools in order to enable him to advance in solving a complex decision problems, where several – often contradictory – points of view must be taken into account. In contrast to the classical techniques of operations research, multicriteria methods do not yield “objectively best” solutions, because it is impossible to generate such solutions which are the best simultaneously, from all points of view.

The transportation decision problem is a complex task or question that refers to transportation companies, processes or systems and requires a solution. The decision problem emerges when the decision maker (DM) searches for the most desirable action (decision, alternative, variant) among many feasible actions (decisions, alternatives, variants). The transportation decision problem results from the DM's observations of the "transportation" reality and the recognition of such a problem or situation that needs to be solved or requires the decision to be made.
Important transportation decision problems are as follows:

- Accepting / rejecting the incoming orders;
- Design and management of the transportation services portfolio;
- Labour force sizing;
- Vehicle assignment (to transportation jobs);
- Vehicle routing;
- Price definition for different transportation services;
- Fleet sizing;
- Fleet replacement;
- Fleet selection, purchasing of new vehicles;
- Assignment of employees (to transportation jobs);
- Transport mode selection;
- Transport infrastructure investments.

The purpose of this course is to present the methodology that helps the DM to solve complex transportation problems. The course involves the recognition of a transportation decision problem and the modelling and solving problems with the application of the MCDA methodology.

2.4 Description of the course

The course program should practically be in line with the main steps of a decision problem solving. Therefore, first these steps are detailed in the following sub-chapter and after that the course program is given.

2.4.1 Steps of decision making

In the following table the steps 1.-4. define the framework of the decision problem for which steps 5.-8. give the solution.

Step	Title	Description
1	Define the decision or planning situation	As a first step the definition of the problem is necessary. Beside this, one has to define who the key actors (decision makers, stakeholders, etc.) are and whether there are any constraints.
2	Define objectives/goals	Definition of the objectives is crucial to finally have a good decision. Different actors can have various goals.
3	Define interests/criteria/indicators	After definition of the objectives interests/criteria can be derived from them. Interests serve as the criteria by which to evaluate each alternative. Relevant interests/criteria can be identified through a facilitated discussion of the stakeholders/interest groups. While selecting the interests/criteria/indicators to be used for the assessment available information must be checked. If applicable sub-groups can be determined in main groups of

		criteria.
4	Define, identify alternatives	What are the possible alternatives? After these steps the matrix of the alternatives and criteria is available.
5	Assignment of weights to interests/criteria/indicators	This is where personal preferences matter. In group decision making, each member assigns his/her own weights to each interest or sub-interest. Weights are used for aggregation of the results of alternatives on each criterion. Consistent determination of weights is a hard but important task.
6	Assess the alternatives against all criterion	A hard step in the decision making. Depending on the criterion either subjective or objective assessment is possible. For objective criteria necessary calculations must be made, in case of subjective criteria a rating is to be done. Calculations, gathering opinions, expert judgments, information from studies, modelling, questionnaires, interviews etc. can be used for the assessment.
7	Aggregate the results	Create one score for each alternative after assessment on all criteria
8	Analyse the results and realize the sensitivity analysis	Analysis of what are major issues of agreement and disagreement, what are the most liked and disliked alternatives and why?
9	MAKE THE DECISION!	

In several steps there are various methods facilitating the job, however, for selection of the proper method no exact rules exist. The most appropriate method can be chosen after the identification of the concrete decision problem.
For this reason in the course program several simple methods are introduced and practiced.

2.4.2 Course Program

The following table gives an insight to the program details. The course is planned to be divided to 9 lectures (L) and 3 practices (P).

Lesson	Title	Content
L1	Introduction to MCDA	• general introduction to transportation-related decision making problems • need for assessment of various alternatives in transportation-related issues • what MCDA is good for, and what it is not • general description of the decision making process

L2	The first steps	• definition of the problem itself
		• definition of the objectives
		• definition of criteria/indicators
		  o requirements for the criteria
		  o selection of good criteria
		• hierarchy of criteria

		• identification of possible alternatives
L3	Evaluation of the alternatives	• evaluation of possible alternatives against all criterion • objective and subjective assessment • uncertainties
L4	Weighing	• need for weighing • description of weighing methods o simple estimation o Churchman-Ackoff o Guilford o trade-off o SMART
P1	Practicing...	... the basics
L5	Elementary decision making methods	• Pros and cons analysis • Maximin and maximax methods • Conjunctive and disjunctive methods • Lexicographic method
L6	Aggregation methods	• SAW (Simple Additive Weighting Method) • MAUT/MAVT (Multi Attribute Utility/Value Theory) • AHP (Analytic Hierarchy Process) • SMART (Simple Multi Attribute Ranking Technic) and SMARTER • TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) • WinGDSS (Windows based Group Decision Support System)
P2	Practicing...	... the simple aggregation methods
L7	Outranking methods	• ELECTRE (Elimination and Choice Expressing the Reality) • KIPA (Kindler, Papp) • PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations)
L8	Results	• Group decision making • Sensitivity analysis
L9	Decision making aids (softwares)	introduction of several commercial software
P3	CASE STUDY	introduction of SAW application in the decision making process for transport mode selection for a given task
Home work		The students must define a certain decision situation related to transport and their profession and must elaborate the

		whole decision aiding process by determining the problem, the criteria, weights, etc. By using the example given in the case study they must elaborate their own Excel-based calculator and have to carry out the assessment of various alternatives.

3 THE E-LEARNING MODULE FOR THE COURSE

The course is provided as an e-learning course to involve multimedia elements into the education. Moreover, on such a platform other multimedia elements (like videos, animations, etc.) can be introduced to improve the quality of the course.
The basis of the course outlined in the previous chapter was elaborated and uploaded to a dedicated site in the http://adn.vrht.bme.hu . As the course is not worked out fully within this task of the project (this was not the objective), only the general information about the lessons is given on different modules, illustrated by some simple figures. For future application the whole subject must be elaborated.
In addition to this, a sample Excel file is also uploaded. This demonstrates the usage of SAW method and provides an insight for the calculations and comparison made in the Case Study (Practice 3 of the course).

4 EXAMPLE OF APPLICATION OF MCDA – CASE STUDY

4.1 The problem

An analysis indicates that, although a greater proportion (70%) of the logistics service providers include the sustainability concept in their strategic objectives, only barely 40% of them carry out any kind of calculation or estimation for example for the social effects, and even fewer communicate this to the clients. Moreover, just 10% of the clients are ready to pay any additional costs of an environmentally friendly transportation, and hence in practice only the market conditions – so mainly the costs and tariffs – dictate the forwarders' decision-making process.
For awareness-raising and evaluation of different transport means already available and used in logistics, an evaluation method that involves the environmental aspects of a transportation system is necessary. The values of the various indicators reflecting the two different aspects are changing in different scales, and have different units. For the determination of the "goodness" of any alternative according to the economical-environmental aspects, i.e. the ranking of the alternatives, these values of very different kinds are to be summarized, taking their weights also in consideration. This is typically a multi-criteria problem, therefore it calls for appropriate solution. This example shows how to perform such an assessment.

4.1.1 Definition of the objectives

The objective of the work is to determine the combined economic-environmental performance of road, rail and inland waterway transportation for a specific transportation task. The data of this specific task:

- transportation of 300 TEU from Port of Constanza to Csepel Freeport, Budapest,
- there is no intermediate transhipment,
- empty running of vehicles is not considered.

4.1.2 Definition of criteria/indicators

Indicators are as varied as the types of systems they monitor. However, there are certain characteristics that effective indicators have in common:

- Effective indicators are relevant; they show you something about the system that you need to know.
- Effective indicators are easy to understand, even by people who are not experts.
- Effective indicators are reliable; you can trust the information that the indicator is providing.
- Lastly, effective indicators are based on accessible data; the information is available or can be gathered/calculated.

Obviously, in this specific task, two main groups of indicators were identified: economical and environmental. For the sake of simplicity only one economical indicator was determined, this is the total cost of transporting the certain amount of cargo on a route most appropriate for the transport mode.
For the environmental assessment more criteria were identified, which are divided to two sublevels. Here the main categories are the natural resource use, the energy efficiency, the technology used, and the emissions. Some of these can be further divided. Concerning the usage of natural resources it is also important from the environmental point of view that how much renewable energy is used. Therefore beside the total amount of used energy the ratio of renewable resources was also introduced. Energy efficiency is a good indicator of the transport modes, it shows how much cargo can be transported for 1 kilometer by using the same amount of energy. The emissions to air are also subdivided according to the polluters, hence CO_2, NO_x, PM and SO_x emissions are introduced on the 3. level. These indicators can be determined and calculated by using the widely available literature resources. The indicators and their hierarchy are shown in the next tables and figure.

Table 1.– List of economic indicators

Category	Name	Dimension	Notation
Costs	Total cost (with infrastructure costs, with loading-unloading costs)	EUR	GK1

Table 2.– List of environmental indicators

Category	Name	Dimension	Notation
Natural resource use	Total energy use during transportation	MJ	KEF1
	Rate of use of renewable resources	%	KEF3
Energy efficiency	Energy efficiency of transportation	tkm/MJ	KE1
Emissions to air	Total CO_2 emissions	t	KLK1 EXT
	Total NO_x emissions	kg	KLK2 EXT
	Total PM emissions	kg	KLK3 EXT
	Total SO_2 emissions	kg	KLK4 EXT

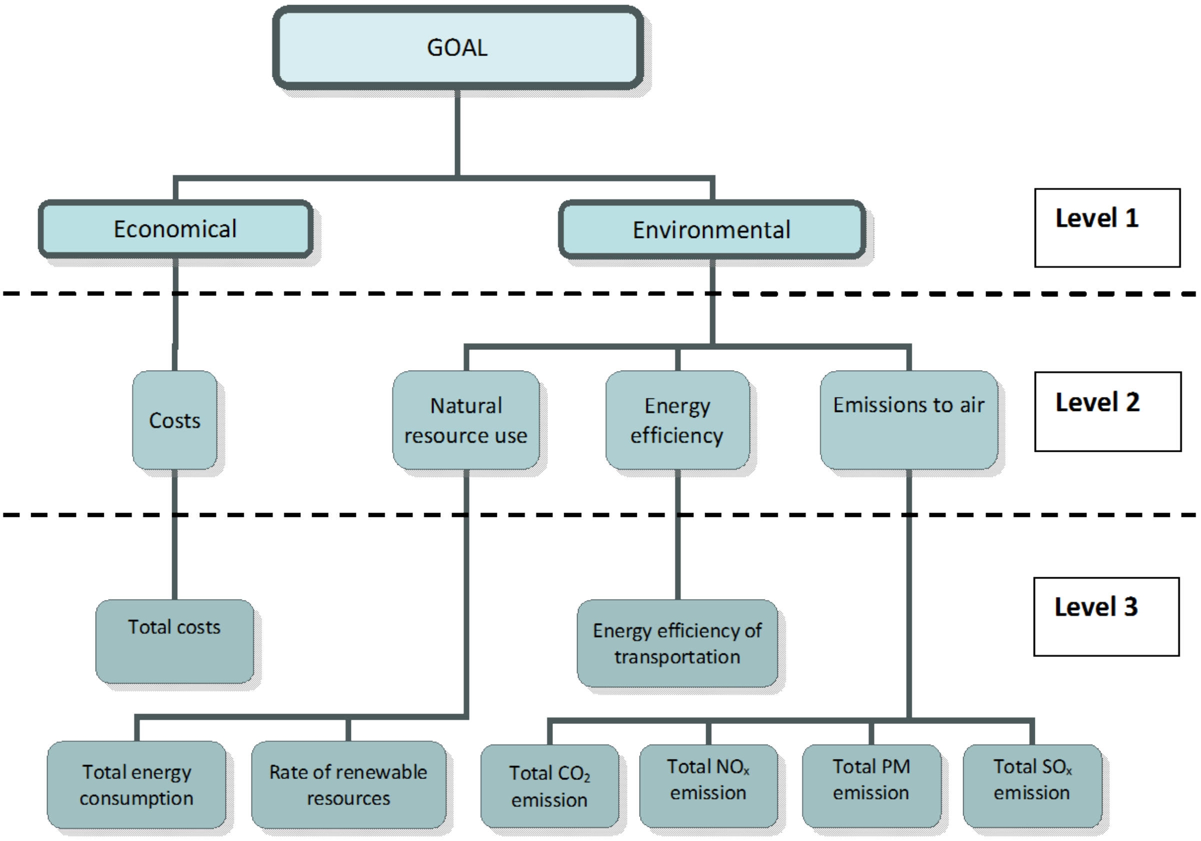

Figure 1. Hierarchy of criteria

4.1.3 Identification of possible alternatives

Although it would be possible to define other alternatives with other types of vehicles, routes, assembly, etc. in this example only the following 4 was elaborated:

- A1 – road haulage with modern, EURO 3 class trucks, 2 TEU/truck, route on Figure 2.;
- A2 – transport on the Danube by a new self-propelled ship plus a barge in convoy, capacity 2x150 TEU;
- A3 – transport on the Danube by old push-boat with two pushed barges, capacity is the same: 2x150 TEU;
- A4 – rail transport, electric traction, border crossing at Lökösháza, 3 TEU/railcar and 25 railcar/assembly.

When determining the route of an alternative the shortest way with highest quality was selected. With regards to inland navigation transport the only route is the Danube. In this case, upstream sailing was obviously taken into consideration. It must also be noted that the Danube provides a much longer route than for the two other modes (which are very similar to each other concerning the length).

Figure 2. Routes

4.1.4 Evaluation of possible alternatives against all criterion

At this part of the work all alternatives must be evaluated against each criterion. Different methods, calculations or approaches can be practical for each. In the following a short overview is given how the evaluation can be done for the specified criteria. All the necessary input data and the calculations are not presented here.

The costs are not calculated, rather quoted freight rates received from Hungarian intermodal service providers were used. The total value for the road and rail is 1000 EUR/40' container. Fee for the inland waterway transport is 900 EUR for a same container.

The total energy consumption of such a transport task is determined by numerous general factors, like vehicle/vessel type, age, load, power, average speed, number, etc. Beside this some mode-specific factors also influence the energy use, nautical conditions (up- or downstream, regulated- or non-regulated river stretches), resistance, nature of the terrain, etc. can be mentioned here. The more of these factors are taken into account, the more precise the result, however, the more difficult the task is, since the input parameters necessary for the calculations may not be easily available. Specific literature must be consulted. Energy for the different transport modes may have different dimensions, therefore conversion of all value to (for example) MJ is necessary.

Use of renewable energy is not common in road and inland waterway transportation, but electric traction is widely used throughout Europe. However, the source of electric energy used by trains is a question, it may come from atomic, fossil or renewable (water, wind) energy. Statistic data for the energy mix is available in several literatures.

It is important to note that for a fair comparison in all cases the primer energy consumption is determined. In road and IWT transport it means the amount of fuel burnt in the engines, for electric traction rail transport the amount of energy used in the power plant to produce the necessary electric power is applied (in reality the total amount needed for traction is divided by the efficiency of the electric motor of tractor, the efficiency of the network used for transporting the electric power and the power-plant efficiency).

The rate of the renewable energy can be easily derived knowing the total amount and the renewable part.

By knowing the total transported amount (300 TEU), the total length of the route and the total amount of energy the energy efficiency can also be derived.
The emissions are determined by using the emission factors for the 4 types of emissions. These multiplied by the total energy consumption gives the total emissions.
The calculated values are presented in Table 3.

Table 3. – Results for the values of alternatives

Name	Notation	A 1	A 2	A 3	A 4	Dim.
Total cost	GK1	157500	135000	135000	150000	EUR
Fossil energy use during transportation	KEF1	1698606	1792609	2293591	1863669	MJ
Rate of use of renewable resources	KEF3	0	0	0	2,7	%
Energy efficiency of transportation	KE1	2,388	3,046	2,381	2,201	tkm/MJ
Total CO_2 emissions	KLK1 EXT	166,85	146,86	187,07	249,35	t CO2
Total NO_x emissions	KLK2 EXT	2514,88	180,06	2777,93	640,51	kg NOx
Total PM emissions	KLK3 EXT	58,62	19,23	141,32	77,73	kg PM
Total SO_2 emissions	KLK4 EXT	380,51	119,57	318,12	1379,11	kg SO2

4.1.5 Weighing

The base-weights for the economic and environmental should firstly be determined. These are the weights that preferably determined by a group of expert, in this example they are taken to equal. The weights for the economical, environmental indicators were defined separately by using the SMART method. The weights are summarised in Table 4.

Table 4. – Weights of indicators

Name	Notation	Weights
Total cost	GK1	0,500
	Σ Economical	**0,500**
Fossil energy use during transportation	KEF1	0,133
Rate of use of renewable resources	KEF3	0,050
Energy efficiency of transportation	KE1	0,050
Total CO_2, emissions	KLK1 EXT	0,067
Total NO_x emissions	KLK2 EXT	0,067
Total PM emissions	KLK3 EXT	0,067
Total SO_2 emissions	KLK4 EXT	0,067
	Σ Environmental	**0,500**

4.1.6 Aggregation method selected

- *Aggregation with SAW*

For the sake of simplicity, in the example the application of the Simple Additive Weighing (SAW) method is shown. In SAW the values of the various alternatives should be normalized. In the model the normalization goes in the following way:

if the greater value is the better:

$$a'_{ij} = \frac{a_{ij} - a_{ij}^{\min}}{a_{ij}^{\max} - a_{ij}^{\min}} \qquad j = 1,\ldots,n$$

if the smaller value is the better:

$$a'_{ij} = \frac{a_{ij}^{\max} - a_{ij}}{a_{ij}^{\max} - a_{ij}^{\min}} \qquad j = 1,\ldots,n$$

With this method all the values will be between 0 and 1 in the way that the betters' are closer to 1.

Using the base equation of the SAW (which is a weighted sum), the Performance Index can be written as:

$$PI_j = 100 \cdot \sum_{i=1}^{m} w'_i \cdot a'_{ij} \qquad j = 1,\ldots,n$$

where:

PI_j is the Performance Index of the A(j), w_i' is the corrected, normalized weight for criterion C*i*, a'_{ij} is the normalized value of A(j) on criterion C*i*.

4.2 Results

By the above mentioned method, the values of each alternative by every criterion (shown in Table 3.) can be transferred to a normalised weighted form. These values are shown in the next table.

Table 5. – Aggregated results of alternatives

Name	Notation	A 1	A 2	A 3	A 4	Dim.
Total cost	GK1	0,000	0,500	0,500	0,167	EUR
Fossil energy use during transportation	KEF1	0,133	0,112	0,000	0,096	MJ
Rate of use of renewable resources	KEF3	0,050	0,050	0,050	0,000	%
Energy efficiency of transportation	KE1	0,011	0,050	0,011	0,000	tkm/MJ
Total CO_2 emissions	KLK1 EXT	0,054	0,067	0,041	0,000	t CO2
Total NO_x emissions	KLK2 EXT	0,007	0,067	0,000	0,055	kg NOx
Total PM emissions	KLK3 EXT	0,045	0,067	0,000	0,035	kg PM
Total SO_2 emissions	KLK4 EXT	0,053	0,067	0,056	0,000	kg SO2

The final performance of an alternative which gives the result of the multi-criteria decision making can be obtained by determining of the Performance Index determined in the previous sub-chapter. The PI values are shown in Table 6 and in Figure 3. Ranking is visible.

Table 6. – Performance Indexes of alternatives

Results (SAW)				
	A 1	A 2	A 3	A 4
PI	**35,3**	**97,9**	**65,7**	**35,3**
PI_eco	0,0	50,0	50,0	16,7
PI_env	35,3	47,9	15,7	18,6

Figure 3. - The performance Index of the 4 alternatives

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