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MULTI-CRITERIA DECISION MAKING AND LIFE CYCLE MANAGEMENT MODEL FOR OPTIMAL TRANSPORT SELECTION

Abstract: *Throughout the whole life cycle - from design and production, over maintenance and operation to the end of life, considerable amounts of resources are used by transportation vehicles. Nowadays environmentally conscious companies are paying special attention to environmental burdens where life cycle management presents a valuable assessment tool. Multi-criteria decision making tools aid decision makers in solving selection problems of optimal transport alternative that considers the life cycle environmental burdens as well. This paper proposes the model for optimal transport selection based on multi-criteria decision making where the environmental aspects and costs are considered through the life cycle perspective. Proposed model was verified on a transpotation problem where a company needs small packages to be delivered from point A to point B in urban environments. Environmental, economic, social and technical aspects have been considered in a proposed model for selection of optimal transport. Environmental criteria were expressed through life cycle anassessment of delivery vehicle considering the following processes: production, operation, maintenance and end of life. Economic criteria were presented through the life cycle costing, while the social criteria were defined through the personal subjective judgement. The technical criteria have been expressed through the delivery time, the period of time needed for package delivery. The considered transporting alternatives included: transport by foot, bicycle, scooter, car, bus and tram.*

Keywords: *multi-criteria decision making, life cycle mangement, transport, just-in-time delivery*

1. INTRODUCTION

Considerable amounts of resources are used by transportation vehicles throughout their whole life cycle - from design and production, over maintenance and operation to the end of life stage. When considering transport selection problem, nowadays environmentally conscious companies are paying special attention to environmental burdens where life cycle analysis (LCA) presents valuable assessment tool. Selection of optimal transport alternative for both - employees and goods, that considers the life cycle environmental burdens is a multi-criteria decision making (MCDM) problem.

In order to obtain sustainable evaluation of life cycle management alternatives, methods such as LCA, life cycle costing (LCC), and MCDM can be combined [1]. Perillo et al. [2] developed a tool for systematic sustainability assessment based on LCA, LCC, and analytic hierearchy process (AHP). They verified this tool on a air energy storage system in a small scale stand-alone power plant of a radio base station for mobile telecommunications. LCA and LCC were used for comparative assessment of trade offs between product environment versus economic efficiency in [3]. Same study [3] also investigated in which conditions extended durability of energy-intensive produst is desirable from an environmental and an economic perspective. A quayside crane was assessed by a cradle-to-grave LCA and LCC in [4]. The purpose of Wen’s et al. study [4] was to identify the key processes that effected the environment, as well as, sought out the opportunities for improving the environmental profiles of Quayside Cranes. An economic input–output based hybrid life cycle assessment is performed in conjunction with Multi-Objective Linear Programming to evaluate various delivery truck fleet combinations and to provide a comprehensive analysis of fleet performance in research by Zhao et al. [5].

In this research the model for optimal transport selection based on MCDM is proposed, where the environmental and economic aspects are considered through the life cycle management (LCM) perspective. The aim of the proposed MCDM & LCM model is to assist companies which activities are occasionally connected to just-in-time delivery business, in their environmental impact decrease. An illustrative example has been provided for the verification of the proposed model.

2. METHODS

This section describes the model for optimal transport selection based on MCDM where the environmental and economical aspects are considered through the life cycle perspective. The proposed MCDM & LCM model consists of six steps as shown on Fig. 1 and considers environmental, economic, social and technical criteria for selection of optimal transport. Firs step is to identify the transport alternatives.

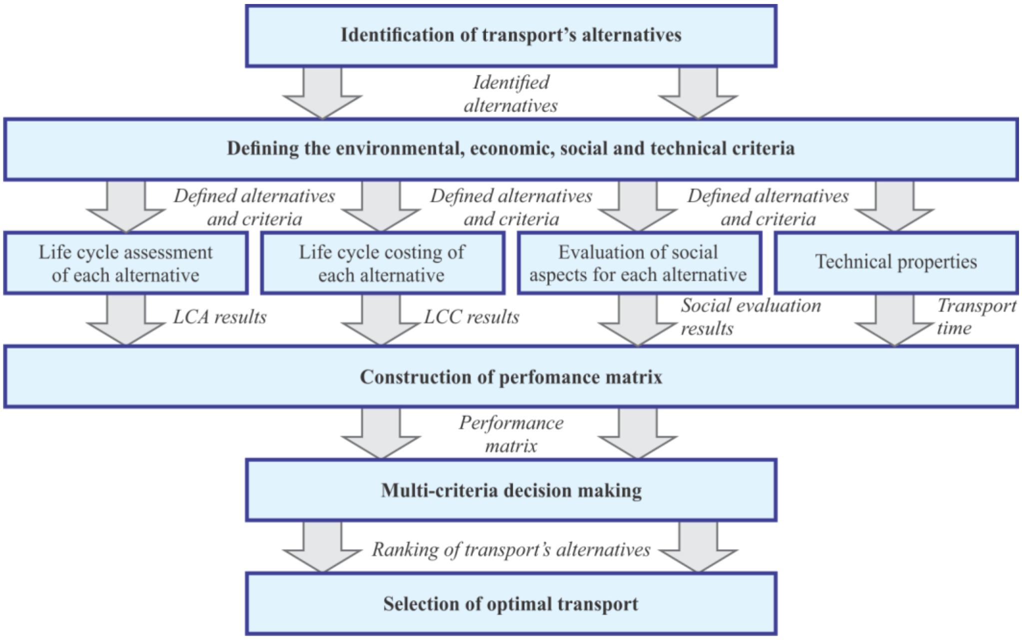

Figure 1 *- MCDM & LCM Model for optimal transport selection*

Environmental criteria are expressed through the LCA of delivery vehicle considering the following processes: production, operation, maintenance and end of life. Construction, maintenance and disposal of road are also included in the system bounderies. The functional unit is defined as the transport of one person with small package from one point to another and return in urban environment.

Economy criteria is defined with LCC of transportation alternatives. LCC of the company vehicle alternatives can be calculated with the following equation:

$$C = TD\left(\frac{VC\left(1-(1-RD)^{n}\right)+n\cdot M}{TTD}+FC\cdot FP\right) \quad (1)$$

Where are:

C - Transporting cost [€],

VC – vehicle cost [€],

n – Number of years in vehicle's life cycle period [-],

RD - the rate of depreciation of vehicle value per year [-], $0 \leq RD \leq 1$,

M – Annual maintenance cost [€],

TTD – total traveling distance of vehicle per life cycle [km],

TD – transport distance per FU [km],

FC – vehicle fuel consumption [l/100km],

FP – fuel price [€].

It has to be noted that equation 1 does not consider the use of vehicle for other purposes.

Social criteria is based on decision maker's subjective assessment of the following sub-criteria: weather condition, comfort, additional walking (Fig. 2). A well known MCDM method analytic hierarchy process (AHP) [6] is proposed for evaluation of alternatives. Technical criteria is presented through the total traveling time from point A to B and return.

Defined criteria and alternatives enable construction of a performance matrix that present a input data for MCDM evaluation of each alternative. For MCDM step of the model for optimal transport selection TOPSIS method is proposed. The TOPSIS method [7] is based on a principle that the optimal alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. The output from MCDM is the ranking of alternatives that can help decision makers in selecting the optimal alternative.

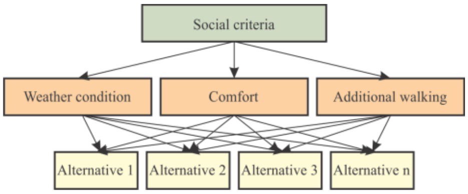

***Figure 2** - General hierarchy for evaluation of transport alternatives by social criteria*

3. TRANSPORT SELECTION PROBLEM

The transportation problem evaluated here is of a company that needs small packages to be delivered from point A to point B in urban environments. According to the previously defined MCDM & LCM model, first the transport alternatives are defined as well. The considered alternatives include: transport by foot, bicycle, scooter, car, and public transportation (bus and tram). The transport distance depends on a transporting alternative: 4.9 km for transportation by foot and bicycle, 5.7 km for transportation by car and scooter, and 6 km for transportation by public transport (bus and tramp).

After defining the alternatives, the environmental, economic, social and technical criteria are defined have to be defined as well. For the environmental criteria LCA was performed with CML [8] as the life cycle impact assessment method, while the SimaPro software [9] was used for LCA calculation. The results from global warming potential impact category, one of the most important impact category in LCA, were used as environmental criteria in MCDM. All the inventory data for the transport alternatives were taken from ecoinvent database. For the transportation by foot alternative, only the impact of building the sidewalk is considered.

The calculation of LCC of transporting alternative is performed by the previously defined equation (1). The input parameters for LCC are provided in table 1 for each alternative. For the public transportation (bus and tramp alternatives) this is the ticket price, while for the transportation by foot no expenses were taken into account.

Decision maker's subjective assessment is used to define social criteria. For this purpose decision maker used AHP to evaluate alternatives by the weather condition, comfort, and additional walking (Fig. 3).

Technical criteria, the total traveling time is the forth considerd criteria. For the public transportation alternatives, bus and tramp, the traveling time considers time needed for waiting and walking from the station to the final destination. Furthermore, in other transportation alternatives that include use of vehicles, traveling time incudes time needed for walking from the location of the parking to the final destination.

In MCDM, in criteria weighting, three scenarios have been assembled with different weighting perspectives in order to provide more comprehensive evaluation:

A. All criteria are of same importance,
B. Social and technical criteria are considered to be more important,
C. Technical and environmental criteria are considered to be more important.

Weighting of criteria and obtaining the three weighting scenarios was perfomed with AHP also. When all the criteria and alternatives have been defined, the data for each alternative has been collected and calculated, the perfomance matrix is assembled (table 2). The performance matrix is the input for the MCDM.

Table 1. *- Life cycle cost parameters*

	VC	n	RD	M	TTD	TD	FC	FP
Parameter Unit	[€]	[-]	[-]	[€]	[km]	[km]	[l/100km]	[€/km]
By foot	-	-	-	-	-	-	-	-
Bicycle	300	5	0.2	10	12000	4.9	0	0
Scooter	1800	5	0.2	120	12000	5.7	3	1.5
Car	10000	5	0.2	180	12000	5.7	6	1.5
Bus	-	-	-	-	-	-	-	-
Tramp	-	-	-	-	-	-	-	-

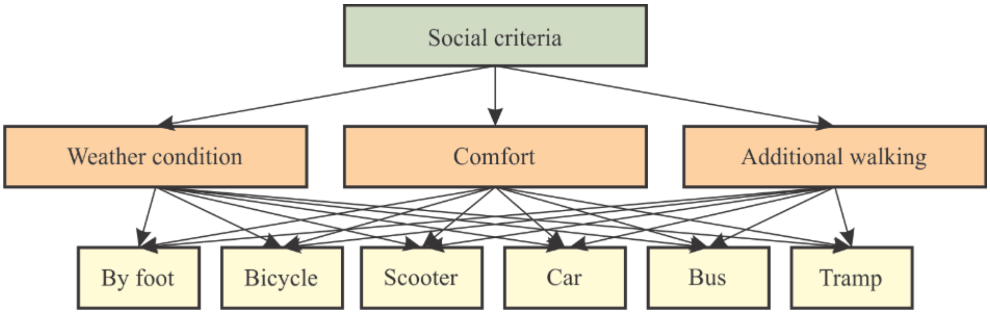

Figure 3 *- Evaluation of transport alternatives by social criteria*

Table 2 *- Performance matrix*

Criteria		Environmental	Economy	Social	Techincal
Criteria unit		[kg CO_2 eq]	[€]	[-]	[minute]
Weighting scenario	A	0.2500	0.2500	0.2500	0.2500
	B	0.0645	0.1431	0.5048	0.2876
	C	0.3051	0.0783	0.0783	0.5383
Criteria type		Min	Min	Max	Min
Transport alternatives	By foot	0.0028	0.0000	0.1000	60
	Bicycle	0.0581	0.1028	0.1060	20
	Scooter	0.6290	1.1216	0.1360	13
	Car	1.6007	4.1340	0.4120	13
	Bus	0.6151	1.2000	0.1230	35
	Tramp	0.2382	1.2000	0.1230	38

3. RESULTS AND DISSCUSSION

Fig. 3 shows the model output, MCDM evaluation for each alternative. The MCDM results from the previously defined three scenario sighnificantly differ from each other. In weighting scenario "A" all the criteria have the same weighting factors. Transport by bicycle has the best ranking in "A" and "C" scenario perspectives. In scenario "B", social and technical criteria were the most important and the transport by car is identified as the best ranked alternative. The transport by car significantly stands out from the rest alternatives in scenario "B". On the other side, the transport by car has the worst ranking in scenario "A". This is debateble since the first scenario has equal weighting factors which does not include decision maker perspective on weighting factors.

Considering all the three scenarios, transport alternatives by bicycle and scooter have the best ranking and present the optimal transport solutions. On the contrary, the transport by foot is the worst ranked transport alternative according to B and C scenarios.

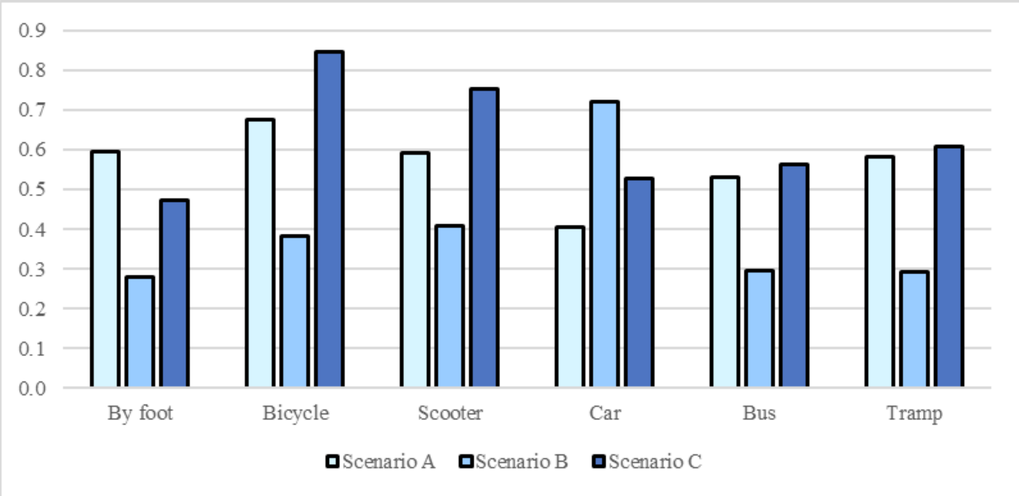

Figure 3 *- Multi-criteria decision making results*

5. CONCLUSIONS

The presented MCDM & LCA model is developed in order to assist companies which activities are occasionally connected to just-in-time delivery business. In illustrative example six transporting alternatives in urban environment have been compared. The results identified the optimal alternatives from three weighting factors scenarios. According to "A" and "B" weighting factor scenarios, transport alternatives by bicycle and scooter had the best ranking, while the car had the best ranking in the "C" scenario.

Future research should include additional factors, such as the traffic jams and how urgent the package delivery is. Since the use of company transport vehiceles is offten a multi purpuse task, the equation for calculation of transporting cost should account that the vehicle can be used for other transporting purposes also. For social criteria, a group decision making is preferable compared to one decision maker since it provides comrehensive evaluation and wider perspective from several decision makers.

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