THE MCDA* METHODOLOGY APPLIED TO SOLVE COMPLEX TRANSPORTATION DECISION PROBLEMS

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1 INTRODUCTION

Many transportation researchers and practitioners (Tzeng and Shiau 1988; Zak et al. 2001; Zak and Thiel 2001) agree that in the analysis of certain, complex transportation problems several measures of merit should be taken into account. The complexity of the transportation decision problems requires that in many cases different economical, technical, social and environmental aspects must be considered (Tzeng and Shiau 1988; Zak and Thiel 2001). It is also very common for transportation decision problems that interests of different stakeholders and their contradictory points of view must be analyzed. 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 (Roy 1985; Vincke 1992) 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 (Vincke 1992). 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.

* MCDA – Multiple Criteria Decision Aid
The purpose of this research is to present the methodology that helps the DM to solve complex transportation problems. The project involves: the recognition of major transportation decision problems, case study analysis of two problems, mathematical modeling and solving those problems with the application of the MCDA methodology.

2 TRANSPORTATION DECISION PROBLEMS

A questionnaire survey has been carried out to identify major transportation problems. The analysis has been focused on 100 Polish and international transportation companies operating on the Polish market and delivering both passenger and freight transportation services. The sample includes small-, medium-, and large-size companies, with an annual turnover ranging from 0.5 million to 400 million PLN (1 USD = 4 PLN, 1 EURO = 3.6 PLN). The companies employ from 5 to 1750 workers. They represent both new – established entities (2 years on the market) and well experienced enterprises (50 years on the market).

Based on the results of the questionnaire survey 20 transportation decision problems have been recognized. The most important of them are as follows:
- Accepting / rejecting the incoming orders;
- Design and management of the transportation services portfolio;
- Labor 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).

80 % of the respondents suggested that all the above mentioned problems have a multiobjective character. The author of the paper concluded also that some of the problems interact with the others. In such circumstances it is reasonable to solve the interacting problems together. In this paper the MCDA methodology is applied to solve the following problems:
- Accepting / rejecting the incoming orders combined with the definition of the minimal price for the orders and the assignment of vehicles to the orders – CASE 1;
- Labor force sizing and assignment – CASE 2.

3 CASE STUDY ANALYSIS

In this section two case studies referring to the above mentioned decision problems, are presented.
CASE 1

A freight transportation company manages a fleet of vehicles. These vehicles have different: load capacity, loading space, average technical speed, technical condition, average vehicle-kilometre cost etc. At a certain moment of time some of the vehicles carry out specific transportation jobs, others await for their new assignments. Vehicles have different locations in relation to the place of embarkment. The incoming order defines: the place of embarkment, weight and dimensions (volume) of load, a vehicle-kilometre price, final destination (distance to travel) and delivery time. In such a situation the dispatcher’s job is to make the following decisions:

– To accept or reject an order and define the acceptable price;
– To assign the best vehicle (candidate) to carry out the incoming order.

The dispatcher has to take into account several boundary conditions that eliminate some vehicles from further considerations. These conditions are as follows:

1. Value of the load capacity utilization index should not be greater than 1, because vehicles must not be overloaded;
2. The quotient of the load volume and the load-space volume should not be greater than 1, which is important in the case of light products with large volumes;
3. The existing location of the vehicle (distance to travel) and its technical speed must satisfy the boundary condition of the delivery time;
4. Currently busy vehicles should be turned down from the further analysis;
5. The quotient of the vehicle-kilometer price and the vehicle-kilometer cost should not be smaller than predefined profitability ratio of transportation services.

The problem has been defined as a multiobjective ranking problem in which the vehicles compete for the incoming order. When the vehicles not fulfilling the constraints are rejected the remaining ones are evaluated by a certain family of criteria and finally ranked from the best to the worst. The proposed criteria are as follows:

– **Cr01** – Load Capacity Utilization Index; maximized criterion important both for the customer and for the management of the transportation company. It guarantees a good match between the load and the vehicle which results in the better utilization of the available fleet and in the reasonable price for the transportation service.
– **Cr02** – Vehicle-Kilometer Cost; the minimized criterion expressed in monetary units (e.g. PLN). This criterion is very important for the owners and management of the transportation company because it assures a maximum profit for each transportation job at a predefined vehicle-kilometer price.
– **Cr03** – Delivery Time; the minimized criterion expressed in hours. It is important for the customer because it leads to the order fulfillment in the shortest possible time.

The incoming order has been specified as follows: load – 15 Tons, 21 euro pallets; distance to travel – 350 km; delivery time 14 hours; total price 1150 PLN (3.29 PLN per vehicle-kilometer).
Eighteen vehicles (trucks, tractors – trailer units, tractors – semitrailer units) have been taken into consideration, out of which 10 have not fulfilled constraints. As a result 8 vehicles denominated by alternatives A0001 to A0008 have been evaluated by the above mentioned family of criteria.

The computational experiment has been carried out with the application of ELECTRE III method (Roy 1990; Vincke 1992). In the initial step the performance table has been constructed. It includes (see fig. 1.) the evaluation of all 8 vehicles on three criteria Cr01, Cr02 and Cr03. In the next step the DM has defined his / her preference model (Vincke 1992) based on the weights of particular criteria and the indifference, preference and veto thresholds, representing the DM’s sensitivity for the changes of the criteria values.

Utilizing the DM’s preferences the computational procedure has generated two partial preorders, called descending and ascending distillation (Vincke 1992). The intersection of these preorders is a final ranking of all alternatives, presented in fig. 2 in a graphical form. As one can see the winner of this ranking is vehicle A0005, i.e. tractor VOLVO FH12 with a semitrailer FREUHAUF. This means that the incoming order should be assigned to this vehicle. The vehicle outranks the remaining alternatives on two most important criteria (Cr02 and Cr03) and it guarantees an acceptable result on criterion Cr01.
CASE 2
A large freight transportation company is an exclusive carrier of finished goods i.e. detergents and cosmetics for an international manufacturer based in Warsaw. The transportation process involves: product deliveries from two central warehouses (Warsaw, Wroclaw) to customers and trunking (transfer of products between warehouses). The trunking results from different production portfolios of the manufacturing plants located in Warsaw and Wroclaw.

The transportation service provider wants to know how many employees are required to carry out the whole transportation process in an accurate manner and how the employees should be assigned to particular jobs within the process.

To answer these questions a complex process analysis has been carried out to recognize major jobs (operations) in the transportation process. As a result 15 operations, denominated as PT1, PT2, ..., PT15 have been distinguished. For each operation its labor intensity has been defined.

The decision problem has been formulated in terms of the multiobjective, binary programming problem, in the following form:
Decision variables:

\[ x_{ijkl} = \begin{cases} 
1 & \text{if employee } k \text{ carries out job } i \text{ at a moment } j \text{ on post } l, \\
0 & \text{otherwise}
\end{cases} \]

(1)

Criteria:

1. Number of employees LP

\[ \text{Min } LP = \sum_k P_k \wedge P_k = \begin{cases} 
1 & \text{if } \sum_i \sum_j \sum_l x_{ijkl} > 0, \forall k \\
0 & \text{if } \sum_i \sum_j \sum_l x_{ijkl} = 0, \forall k
\end{cases} \]

(2)

2. Efficiency of the employees’ assignment EP

\[ \text{Max } EP = \sum_i \sum_j \sum_k \sum_l x_{ijkl} \cdot e_{ijk}, \]

(3)

where: \( e_{ijk} \) [points] – efficiency of assigning employee \( k \) to job \( i \) at a moment \( j \); includes work quality, employees experience and qualifications, timeliness and speed of work.

3. Job dispersion (differentiation) PZP

\[ \text{Min } PZP = \sum_i \sum_k PP_{ik} \sum_k P_k, \]

(4)

\[ PP_{ik} = \begin{cases} 
1 & \text{if } \sum_j \sum_l x_{ijk} > 0, \forall i, k, i \neq k \\
0 & \text{if } \sum_j \sum_l x_{ijk} = 0, \forall i, k, i \neq k
\end{cases} \]

(5)

4. Total costs KRP

\[ \text{Min } KRP = \sum_i \sum_j \sum_k \sum_l x_{ijkl} \cdot k_k, \]

(6)

where: \( k_k \) – unit cost of employee \( k \) in interval \( \Delta t \).

Constraints:

– Each worker \( k \) carries out no more than 1 job at a moment \( j \);
– The number of jobs carried out at a moment \( j \) can not exceed the number of posts available;
– The sum of time intervals \( \Delta t \) assigned to job \( i \) must be equal to the labor demand (in man-hours) of each job \( i \);
– Daily work load for each employee \( k \) must be fulfilled in a certain time limit (e.g. shift);
Some jobs must be assigned to specific employees. The computational experiment has been carried out with an application of an original computer program, called PEOPLE (Zak et al. 2001). The assignment matrix produced by program PEOPLE is presented in fig. 3. The program, based on the Pareto Simulating Annealing metaheuristic method (Czyzak and Jaszkiewicz 1998) has generated a sample of solutions, which are a good approximation of Pareto-optimal solutions (Vincke 1992). The sample is composed of 2176 points. The ranges of the criteria values represented by the ideal and nadir points, are shown in table 1.

![Figure 3. Employees – jobs assignment matrix produced by program PEOPLE](image)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>LP</th>
<th>EP</th>
<th>PZP</th>
<th>KRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal point</td>
<td>32</td>
<td>2880.9</td>
<td>1.0</td>
<td>8286.3</td>
</tr>
<tr>
<td>Nadir point</td>
<td>39</td>
<td>2746.7</td>
<td>1.2</td>
<td>9124.3</td>
</tr>
</tbody>
</table>

Table 2. The set of selected (filtered) solutions of the labor force sizing and assignment problem

<table>
<thead>
<tr>
<th>Solution number</th>
<th>The values of the evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>194</td>
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<td>1075</td>
<td>36</td>
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<tr>
<td>1225</td>
<td>32</td>
</tr>
</tbody>
</table>
The sample has been filtered with the application of a multiobjective, interactive procedure called Light Beam Search (LBS) (Jaszkiewicz and Slowinski 1999). According to the DM’s preferences the procedure has generated a filtered set of 20 solutions, presented in table 2. The DM has reviewed and evaluated all these solutions. He / she has defined the reference point which is for him / her the most satisfactory solution.

The DM has realized that he / she should satisfy both the employees and the company’s management interests. Taking this into consideration he / she has suggested the following reference point: LP = 32, EP = 2850.0, PZP = 1.2, KRP = 8300.0. In the neighborhood of the reference point the procedure has searched for the solutions characterized by the similar values of criteria. Finally, the DM has accepted solution 703 as the most satisfactory one. The criteria evaluations of solution 703 are as follows: LP = 33, EP = 2843.5, PZP = 1.2, KRP = 8459.4. In the decision variables space this solution corresponds to a concrete assignment matrix, assuring the allocation of certain jobs to particular employees (see fig. 3). The selected solution reduces the required number of employees by 20% and the total costs by 16%. It maintains the values of the remaining criteria on the existing level.

4 CONCLUSIONS

The presented research project has been focused on the application of the MCDA methodology to solving complex and important transportation decision problems. The two presented case studies prove that in real life situations requirements of different groups of stakeholders, interested in the rational solutions of the existing transportation decision problems, should be taken into account. In such situations the MCDA methodology helps to find a compromise solution that satisfies, at least partially, contradictory points of view.

The case studies have been solved in accordance with the MCDA methodology, with a clear distinction of the major participants of the decision making (aiding) process. The author of the paper played a role of the analyst and the managers of the transportation companies were the decision makers. The analyst constructed the decision models (multiobjective ranking problem in case 1 and a multiobjective choice problem – mathematical programming problem in case 2) and suggested certain decision tools to solve the problems (ELECTRE III method in case 1 and Program PEOPLE and LBS method in case 2).

Based on the B. Roy’s suggestions (Roy 1985) the solution procedure has been divided into the following steps:
- Recognition of the category of the decision problem (ranking problem – case 1; choice problem – case 2).
- Definition of the set of variants (direct definition of the available vehicles in case 1 and indirect, through constraints, definition of the set of feasible solutions in case 2).
- Construction of the consistent family of criteria (3 criteria in case 1 and 4 criteria in case 2).
- Modeling and aggregation of the DM’s preferences (weights and thresholds in case 1; interactive preference modeling in case 2).
- Solving the decision problem (ranking of vehicles and selection of one of them in case 1 and the optimal assignment of duties to employees in case 2).

REFERENCES


