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Procedia - Social and Behavioral Sciences 111 (2014) 1238 – 1248
Procedia
Social and Behavioral Sciences

EWGT2013 – 16th Meeting of the EURO Working Group on Transportation

The application of dominance-based rough sets theory for the evaluation of transportation systems

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Abstract

The paper presents an original procedure of evaluation of a transportation system, resulting in its assignment into a predefined class, representing the overall standard of the considered system and the level of transportation service. The method relies on the application of the dominance-based rough set theory (DRST), allows for thorough data exploration, evaluation of informational content of the considered characteristics and generation of certain decision rules that support the evaluation process. In the analysis different characteristics (criteria and attributes) describing various aspects of a transportation system operations are taken into account. The assignment of a transportation system to a specific quality class is performed based on the values of characteristics which are compared with the evaluation pattern, i.e. the set of decision rules generated through the analysis of customers' opinions on transportation system. The method is composed of three steps, including: 1) identification of the most important characteristics, 2) generation of the evaluation pattern, 3) assignment of the transportation system to the appropriate class.

Keywords: Dominance-based rough sets; Transportation systems, Evaluation method

1. Introduction

1.1. Definition and evaluation of a transportation system

Any transportation system is a set of coordinated components that provide an organized and controlled movement of passengers or goods from their origins to their destinations. Different authors recognize various components of such a system, depending on the profile and major objective of their research (e.g. Papageorgiou and Pouliezos, 1998). The authors of this paper suggest five key components of a generic transportation system,

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doi:10.1016/j.sbspro.2014.03.727

including: *transportation means* and other technical equipment, *human resources* (drivers, administration, management), *information resources* and means, *transportation infrastructure* (roads, depots, parking areas, terminals, garages), *organizational rules* of the system.

A transportation system is appropriately designed to carry out specific transportation tasks and intended to guarantee the coordination of its key components. The evaluation of transportation projects or systems is a widely discussed topic (Lee, 2000; De Brucker *et al*., 2011; Salucci and Delle Site, 2010). The most commonly used methodologies are Cost-Benfit Analysis - CBA (Marshall, 1920) and multiple criteria analysis - MCA (Figueira *et al.,* 2005). The former consists in calculating and comparing benefits and costs of a transportation project decision or system. Benefits and costs are expressed in a monetary terms and are adjusted for a time value of money. The latter involves a comprehensive, multiple-dimensional analysis of transportation projects or systems. It allows for taking into account many evaluation aspects (criteria) and satisfying subjective interests of different stakeholders. New trends in evaluation of transportation systems are presented in section 1.2 of the paper. The key research issue in this paper is the comprehensive evaluation of a road freight transportation system. The evaluation serves as a description of its current state and/or measure of its potential for future development.

1.2. Literature review on transportation system evaluation

The literature review has revealed certain new trends and approaches concerning the evaluation of transportation systems. In the recent years several research reports have been published concerning evaluation of: city logistics systems (Zhang and Wu, 2009; Yue and Peilini, 2013), transportation systems within the supply chain (Zhao and Xue, 2011) or distribution system (Sawicka and Zak, 2013), shipping systems (Lun *et al.,* 2013) or trunk highway systems (Sun *et al.*, 2013). Most of them concentrate on the overall evaluation of the considered system and propose either the synthetic, numerical representation of the system's evaluation, position in the ranking or its classification. In many cases the evaluation of transportation systems is performed by the application of different artificial intelligence techniques, e.g. fuzzy systems and fuzzy logic (Zhang and Wu, 2009; Zhao and Xue, 2011; Yue and Peilini, 2012), multiple criteria decision aiding (Sawicka and Zak, 2013), entropy analysis (Sun *et al*., 2013) or using analytical formulations (Lun *et al.*, 2013).

Zhang and Wu (2009) evaluate a city logistics system. They construct an overall evaluation index of expert-based non-deterministic (fuzzy) character, being linguistic estimation of certain areas and activities of the analyzed system. They construct a three-level hierarchy in which the first level corresponds to the overall goal of the analysis, second constitutes major fields to be evaluated, while the third is composed of sub-criteria. The index is a product of aggregated weights of all criteria with its sub-criteria and their overall evaluations on a linguistic scale. The generated indexes result in the classification of the considered system.

Zhao and Xue (2011) evaluate a transportation system as a component of a global supply chain. They propose an evaluation index that identifies risk in the whole supply chain. Their approach has a similar hierarchy scheme as presented by Zhang and Wu (2009) and is composed of: mega-criteria, sub-criteria and factors. The authors combine AHP methodology and expert-based fuzzy evaluation to generate the global risk index for the system.

Yue and Peilini (2012) similarly to previous research utilize the concept of an overall measure to evaluate a transportation system. They construct a two-level hierarchy for global evaluation. Each component of the hierarchy and its importance are evaluated by experts using a five-grade linguistic scale. These opinions are converted into digital form using fuzzy membership functions. Finally, the global evaluation of a transportation system is expressed as a sum of product weights and evaluations for corresponding components of the hierarchy.

The research presented by Lun *et al.* (2013) deals with classification of shipping network in the analyzed region into specific classes. As opposed to the previous works the authors are independent from experts' opinions and concentrate on analytical formulation of the considered decision problem. Based on the distance between origins and destinations they calculate transportation external costs of container transportation using different shipping modes. Based on external cost approach Lun *et al*. classify the ports in the considered region into three classes:

feeder ports, direct ports, and hub ports.

Sun *et al*. (2013) concentrate on quantitative evaluation of the trunk or arterial highways management system. In the evaluation process they take into account financial and staffing aspects of transportation systems. The authors propose a quantitative method to evaluate the performance of three different structures of management of the highway system, i.e. vertical, regional and mixed vertical-regional. To do this they propose three different measures, including: graph entropy, time efficacy entropy and quality entropy. Based on the values of these three measures they recommend the vertical structure of a highway management system.

The application of simulation techniques and multiple criteria decision making methods to the evaluation of redesign scenarios of the distribution system is proposed by Sawicka and Zak (2013). The authors assess the transportation system as a key component of the distribution system. They generate different redesign scenarios using simulation and then by means of an original multiple criteria stochastic decision aiding method ELECTRE III-st rank. The ranking is generated based on their assessment by a family of 7 criteria and with the application of a specific model of decision maker's (DM's) preferences.

1.3. Objective and content of the research

A complex analysis and evaluation of transportation operations is a less frequently considered topic. However, most of the research in this area focuses on assessing the transportation services and its performance whereas an evaluation of a transportation system is a less frequently considered. The authors of this paper investigate thoroughly the problem of transportation system evaluation and carry out the system's in-depth analysis. As a result they propose an original and universal method of the transportation system overall evaluation. The proposed method allows classifying any transportation system to one of the predefined classes and computing its global evaluation index, which corresponds to the degree of customer's satisfaction. This index quantifies the level of fulfillment of customer's requirements by each and all components of the transportation system that provides a transportation service. The method is based on an assignment of such a system to one of the predefined classes without necessity of transforming the original data on its performance. The assignment of a transportation system is based on the exploration of customers' opinions and their expectations concerning the system and the transportation service offered by the system. The major concept of the method relies on the application of data mining technique, which uses the principles of dominance-based rough set theory (DRST).

The paper is composed of five sections. An introductory part includes general background of the considered topic, literature survey and definition of the research objectives. Section 2 defines the principles of the rough set theory and section 3 describes major steps of the proposed method. Section 4 is devoted to its application focused on the evaluation of the road fright transportation system. Finally, chapter 5 summarizes the paper and includes final conclusions. The references are attached at the end of the paper.

2. Research methodology

The dominance-based rough sets theory - DRST (Greco *et al.,* 1999) is an extension of the rough sets theory RST, originally proposed by Pawlak (1982). It is a mathematical tool for the analysis of imprecise and vague description of objects (actions). Both, RST and DRST use 4 categories of information, presented in the form of an information table. This table is a 4-tuple $S = \langle U, Q, V, f \rangle$, where U is a finite set of *objects*, called universe, and represented by the rows of the table; $Q = \{q_1, q_2, \ldots, q_m\}$ is a finite set of *characteristics* - columns of the table, V is the domain of characteristics q, expressed in the form: $V = \bigcup_{q \in Q} V_q$, and f is the information function assigned to each pair: object x – characteristic q, such that $f : U \times Q \to V$ and $f(x, q) \in V_q, \forall q \in Q, x \in U$. The set of characteristics is composed of criteria $C^{>}$, i.e. characteristics with preference ordered domains, and attributes $C^{=}$, i.e. characteristics with non-ordered domains.

Since two major categories of characteristics Q are distinguished, i.e. conditional characteristics – C and decision characteristics D, $C \cup D = Q$, the information system is defined as a *decision table*. In addition, denominating the set of conditional criteria by $C^{>}$ and the set of conditional attributes by $C^{=}$, $C^{>} \cup C^{=} = C$ and $C^{>} \cap C^{=} = \emptyset$, the decision table is presented in the following form: $S = \langle U, C^{>} \cup C^{=} \cup D, V, f \rangle$. Analyzing the decision table S, for two objects $x, y \in U$, where x represents reference objects and y compared objects one can define a binary relation R in the following form (Greco *et al.,* 1999):

$$yR_P x,\ \vee x, y \in U\ \ if \begin{cases} yD_q x & \forall q \in P^{>}:\ \ P^{>} = P \cap C^{>} \\ yI_q x & \forall q \in P^{=}:\ \ P^{=} = P \cap C^{=} \end{cases} \quad (1)$$

Assuming that $P \subseteq C$ the relation $yR_P x$ corresponds to two situations, i.e. object y dominates x ($yD_P x$) from the perspective of all considered criteria $P^{>}$ or object y is indiscernible with x ($yI_P x$) from the perspective of all attributes $P^{=}$. Considering any object $x \in U$ and relation R_P one can define a set $R_P^{+}(x)$, which includes the objects $y \in U$, that dominate x from the perspective of all criteria $P^{>}$ and are indiscernible from x for all attributes $P^{=}$. $R_P^{+}(x)$ is called a set of objects dominating object x, and $R_P^{+}(x) = \{y \in U: yR_P x\}$. Similarly, $R_P^{-}(x)$ constitutes a set of those objects $y \in U$ that are dominated by object x from the point of view of considered criteria $P^{>}$ and are indiscernible with x from all attributes $P^{=}$. $R_P^{-}(x)$ is called a set of objects dominated by object x, thus $R_P^{-}(x) = \{y \in U: xR_P y\}$.

All decision characteristics D constitute the partition of the universe U into a finished number of categories $\mathcal{C\ell} = \{Cl_t, t \in T\}$, $T = \{1, 2, \dots, n\}$. It is also assumed that: 1) each object $x \in U$ belongs to one and only one category $Cl_t \in \mathcal{C\ell}$, 2) all t-classes are ordered according to an increasing importance of preferences, which means that objects assigned to class Cl_r are preferred against objects in category Cl_s if $r > s, \forall r, s \in T$. If an object is assigned to class s according to characteristic D and its conditional part C outperforms conditional part of any other object assigned to class r it generates a certain inconsistency in DRST. For this reason the notion of two categories of union of classes have been introduced, i.e. upward and downward unions of classes. *Upward union* of classes $Cl_t^{\geq}$ is a set of objects that belong to class Cl_t or class more preferred than t, while *downward union* of classes $Cl_t^{\leq}$ is a set of objects that belong to class Cl_t or class less preferred than t.

Taking into account $P \subseteq C$ and $t \in T$ object $x \in U$ belongs without any doubt to the upward union of classes $Cl_t^{\geq}$ if $x \in Cl_t^{\geq}$ and $y \in Cl_t^{\geq}$ for all objects $y \in U$ dominating x according to $P^{>}$ and indifferent with x according to $P^{=}$. This means that object $x \in U$ belongs without any doubt to $Cl_t^{\geq}$ if $R_P^{+}(x) \subseteq Cl_t^{\geq}$ and a set of all such objects constitutes a lower approximation of the upward union of classes $\underline{P}(Cl_t^{\geq})$. At the same time the set of objects that probably belong to $Cl_t^{\geq}$ constitutes the upper approximation of the downward union of classes $\overline{P}(Cl_t^{\geq})$. Upper and lower approximations of the upward unions of classes can be presented as follows (Greco *et al.,* 1999, 2001):

$$\underline{P}(Cl_t^{\geq}) = \{x \in U_P:\ R_P^{+}(x) \subseteq Cl_t^{\geq}\}\ \text{ and }\ \overline{P}(Cl_t^{\geq}) = \{x \in U_P: R_P^{-}(x) \cap Cl_t^{\geq} \neq \emptyset\} \quad (2)$$

where U_P^{*} is a set of reference objects. Similar formulas can be developed for the downward unions of classes:

$$\underline{P}(Cl_t^{\leq}) = \{x \in U_P:\ R_P^{+}(x) \cap Cl_t^{\leq} \neq \emptyset\}\ \text{ and }\ \overline{P}(Cl_t^{\leq}) = \{x \in U_P: R_P^{-}(x) \subseteq Cl_t^{\leq}\} \quad (3)$$

The comparison of upper and lower approximations of the union of classes results in the definition of the area of uncertainty, called the boundary region - Bn_P. The boundary region for the upward union of classes is defined as: $Bn_P(Cl_t^{\geq}) = \overline{P}(Cl_t^{\geq}) - \underline{P}(Cl_t^{\geq})$ and for the downward union of classes as: $Bn_P(Cl_t^{\leq}) = \overline{P}(Cl_t^{\leq}) - \underline{P}(Cl_t^{\leq})$.

Evaluating the consistency and quality of information about objects in the decision table two measures i.e. accuracy of approximation and quality of sorting, can be defined. The *accuracy of approximation* of the union of classes is defined as a ratio of the number of objects (*card*) appropriately assigned to a specific union of classes and those that can be probably assigned to this union; it expresses the precision of available knowledge about the classes belonging to the union of classes. *Quality of sorting* $\gamma_P(Cl)$ is the relation between the number of P-right sorted objects ($P \subseteq C$) and a number of all objects in U, which can be formulated by formula (4):

$$\gamma_p(Cl) = \frac{card\left(U - \left(\bigcup_{t\in T} Bn_P(Cl_t^{\leq})\right)\right)}{card(U)} = \frac{card\left(U - \left(\bigcup_{t\in T} Bn_P(Cl_t^{\geq})\right)\right)}{card(U)} \tag{4}$$

Based on the definition of the quality of sorting one can search for the possibility of reducing the amount of superfluous information enclosed in the decision table S. It is assumed that eliminating certain information from the decision table is possible when it does not deteriorates the informational value of the initial decision table. As a result of identification of necessary and unnecessary characteristics the reduct, denominated by $RED_{Cl}(P)$, is constructed. The reduct is composed of the minimal number of characteristics $P \subseteq C$, for which the quality of sorting satisfies condition: $\gamma_P(Cl) = \gamma_C(Cl)$. The intersection of all the reducts is called the core.

An important element in the rough sets theory is the generation of decision rules, based on the lower and upper approximations of the union of classes constituting deterministic (exact) and nondeterministic (approximate) rules, respectively. In general, each decision rule r is a logical statement composed of a conditional part and a decision part in the form: "*if…, then…*". The conditional part includes the values and description of several characteristics of the object while the decision part defines the assignment of the object to one or to several unions of classes.

Two quantitative measures, called absolute and relative strength of the generated rules, characterize their importance and classification suitability. The *absolute strength* of the rule defines the number of objects in the decision table that are consistent with the conditional part of the rule. The *relative strength* of the decision rule is the relationship between the absolute strength of the rule and the number of objects in the decision table that constitute the lower approximation of the union of classes, pointed out by the decision part of the rule.

The generated decision rules are used to search for the recommended assignment of new objects to decision classes. This assignment is based on the comparison of the values of characteristics in the decision part of the decision rule with the values of characteristics of a new object. In the literature different methods of assigning objects to single classes exist. In this article an original approach proposed by Sawicki (2003) is applied. The concept of the proposed assignment is based on the redefinition of the relative strength of the decision rule and introduction of the index of *assignment credibility* $\phi(Cl_i, x)$. It characterizes the credibility of assigning object x to a single class Cl_i, being a component of upward $Cl_t^{\geq}$ or downward $Cl_t^{\leq}$ union of classes. The index is defined as follows:

$$\phi(Cl_i, x) = \sum_{\substack{j=1 \\ r_j \in M(x)^+}}^{m} \left[\frac{card\ (Supp_{Cl_i}(r_j) \cap Cl_t^{\leq})}{card\ \underline{P}(Cl_t^{\leq})} + \frac{card\ (Supp_{Cl_i}(r_j) \cap Cl_t^{\geq})}{card\ \underline{P}(Cl_t^{\geq})}\right] \tag{5}$$

for $t \in T, T = \{1,2,\ldots,n\}$, where: $Supp_{Cl_i}(r_j)$ defines the set of objects supporting decision rule r_j and belonging to decison class Cl_i, within the union class $Cl_t^{\geq}$ or $Cl_t^{\leq}$ indicated by a decision rule r_j; $Cl_t^{\geq} = \bigcup_{i\geq t} Cl_i$ and $Cl_t^{\leq} = \bigcup_{i\leq t} Cl_i$. $M(x)^+$ is the subset of objects x in which all elements of the conditional part of the decision rule r_j have a deterministic character and correspond to the description of object x. The final decision regarding the assignment of an object x to one of the decision classes Cl_i is made based on the maximum value of the $\phi(Cl_i, x)$.

3. The method of evaluation of a transportation system

3.1. The concept of the method

The major feature of the method is the assignment of a transportation system to one of six predefined classes representing different standards of a transportation system. The assignment is performed based on the values of characteristics which are compared with the *evaluation pattern*, i.e. the set of decision rules generated through the analysis of customers' opinions expressed in the survey research. Both, criteria and attributes are taken into account. The method is composed of three major steps, i.e.: Step 1 - identification of the most important characteristics, Step 2 - generation of evaluation pattern expressed by decision rules, Step 3 - assignment of the transportation system to one of the predefined classes. The general scheme of the method and the most important interactions among the major steps are presented in Fig. 1. The method utilizes the *4eMka* software developed for data analysis and data mining based on the principles of DRST presented in section 2.

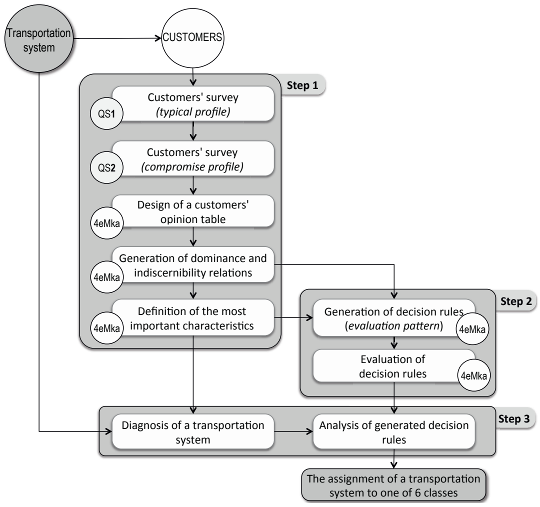

Fig. 1. Major steps of the proposed method for evaluation of transportation systems

3.2. Step 1 – Identification of the most important characteristics

In the first step of the method the customers' requirements and expectations concerning the transportation system's performance and the standard of its key components are identified through the survey research. To guarantee the credibility of this analysis the surveyed sample has to be carefully selected based on a detailed categorization of the customers' population. The customers participating in the survey have to be selected based on the analysis of their four major features, including: customers' *category*, i.e. individual vs. institutional and private vs. public, *vehicle type* utilized in the customers' service, customers' *size* in terms of work force and turnover, i.e. small and medium vs. large companies, customers' *location*, i.e. location of the loading and unloading activities. It must be guaranteed that all the categories participating in the survey represent the spectrum of collected opinions.

Two kinds of questionnaire are applied in the survey research. The first identifies a *typical profile* of different standards of a transportation system (QS1). The second examines customers' sensitivity on changes in a typical profile, by defining a *compromise profile* of different standards of a transportation system (QS2). In the first questionnaire the customers have to select those characteristics that in their opinion have an important impact on its overall evaluation. They are requested to define such values of characteristics, which allow distinguishing different classes of a transportation system with respect to each of them. In the second questionnaire the customers define a compromise profile either through: a) increasing the values of several measures characterizing the transportation system and compensating it by decreasing the values of others, b) decreasing the values of several characteristics without increasing the values of others. The result of both questionnaire surveys constitutes the input for a customers' opinion table composed of the set of customers' opinions on typical and compromise profiles, i.e.:

- the set of characteristics Q composed of conditional characteristics (both criteria $C^{>}$ and attributes $C^{=}$) and decision characteristic D, representing the classes of a transportation system $(Cl_1, \dots, Cl_i, \dots, Cl_t)$,
- information function $f(x_i, q_i)$, which defines the value of a characteristic - q_i expressed by customer - x_i participating in the survey research,
- a domain V containing a set of values of characteristics (both criteria $C^{>}$ and attributes $C^{=}$).

Each single row in the customers' opinion table corresponds to a single customer's opinion concerning the transportation system assigned to a particular class - Cl_i. In the proposed approach six different classes (standards) of a transportation system are proposed, including: excellent, very good, good, average, unsatisfactory and poor.

Based on collected opinions and according to principle of DRST, both upper and lower approximations of the unions of classes are generated. This means that for considered six classes of a transportation system five approximated downward unions of classes (i.e. *at most*: poor, unsatisfactory, average, good and very good standards) and five upward unions of classes (i.e. *at least*: excellent, very good, good, average and unsatisfactory standards) are defined. Based on upper and lower approximations of the union of classes the quantitative measures of accuracy of approximations and quality of sorting in S are calculated. Finally, the importance of characteristics is evaluated, and as a result a set of reducts is generated. The final selection of the most important evaluation characteristics is based on a computational procedure resulting in the generation of the dynamic reduct (e.g. Bażan, 1998). Such a reduct is an input for steps 2 and 3, corresponding to creation of the evaluation pattern and diagnosis of a real world transportation system.

3.3. Step 2 – Definition of the evaluation pattern

In the second step of the method the evaluation pattern of transportation systems is generated. The pattern contains a generic description of the required standards of the transportation system for each of the six classes. This pattern is expressed by a set of dynamic decision rules generated in step 1, performed with the application of the strategy of a minimal set of rules that cover all the opinions in table S (Stefanowski, 1998). Next, all the non-deterministic decision rules should be excluded from further considerations to base the assignment on the most credible decision rules. All the remaining decision rules, i.e. *deterministic* ones, are then evaluated in terms of their relative and absolute strengths.

Finally, the set of deterministic decision rules is tested with respect to its prediction ability, i.e. ability to assign precisely a certain transportation system to one of the considered classes based on generated decision rules. To this end, *N-fold* cross validation test is utilized (e.g. Weiss and Kulikowski, 1990). As a consequence, a set of dynamic decision rules is generated. It is constructed with the application of the systematic generation of the rules based on 10 randomly selected customers' opinions tables constituting 90% of their original sizes.

3.4. Step 3 – The assignment of a transportation system to one of the predefined classes

The last step of the method contributes to the final evaluation of a transportation system and consists in its assignment to one of the six predefined classes. Based on a finally selected dynamic reduct (step 2) the evaluation of a considered real world transportation system is carried out. This system is described using all the characteristics included in the selected dynamic reduct. Based on both, deterministic decision rules (see step 2) and values of characteristics of a transportation system originated from a dynamic reduct all the decision rules of $M(x)^+$ type are isolated from others. Finally, the assignment of a transportation system - x to one of the considered class Cl_i is based on the value of the credibility index $\phi(Cl_i, x)$ - see equation (5).

4. Application of the method – evaluation of the road freight transportation system

4.1. Step 1 – Identification of the most important characteristics

In two parts of questionnaire survey 24 evaluation characteristics of a transportation system have been proposed, including both criteria and attributes. All those characteristics have been associated with the features of major components of a transportation system with the following assignment to its respective areas:

- *Organizational rules*: average processing time, acceptable delay of delivery, opening hours, acceptable level of cargo damage, credibility of the system, flexibility of the system, and experience at the Polish market.

- *Human resources*: employees' appearance, forwarders' and drivers' training, experience, competence, skills and education, average length of employment.
- *Information resources*: availability of customer-staff communication means (incl.: IT systems, web page, EDI, phone or sms), the way the customer is informed (incl.: standard documentation, periodical reporting, day-by-day reporting, tracking and tracing), the way the operator acquires information (incl.: phone contact with drivers, vehicle monitoring, advanced IT systems).
- *Transportation means*: fleet composition, appearance, age and efficiency, cleanness and tidiness.
- *Infrastructure and technical equipment*: availability and features of loading and storage equipment, availability in the transportation depot, number of hubs, avg. distance from a hub to the nearest customer.

All the customers' opinions from the first and second part of the questionnaire survey have been collected and a customers' opinion table with 1066 objects has been constructed. The objects representing the rows of the table included 552 units coming from the first part of the questionnaire and 514 from its second part. Based on the customers' opinion table a sequence of computations has been performed, starting from the upper and lower approximations of the union of quality classes. Next, all the quantitative measures of data consistency concerning the customers' opinions about the standard of the general road freight transportation systems have been calculated. Table 1 presents all the generated unions of classes (5 downward and 5 upward unions) and its accuracy of approximations. In the majority of unions of classes, the cardinality of upper and lower approximations is identical and equal 1. In some instances (see such unions of classes as: at most poor standard, at most unsatisfactory standard and at least unsatisfactory standard) the customers' opinions are slightly inconsistent, i.e. their conditional and decision parts are contradictory. The result of such inconsistency is a decreasing the accuracy of approximations. However, an overall measure of the precision of collected opinions expressed by the quality of sorting, equals 0,99, which is high. This means that customers' opinions collected in a questionnaire, both for the typical and the compromised profile, are very coherent. Finally, as a result of step 1 of the method, the dynamic reduct – RED_1, composed of 12 most important characteristics has been determined. This means that out of 24 initially considered measures only 12 play an important role in the global evaluation of a transportation system. These are as follows: $RED_1 = \{q_1, q_3, q_6, q_{12}, q_{13}, q_{14}, q_{15}, q_{16}, q_{17}, q_{18}, q_{21}, q_{23}\}$. Their names are presented in Table 2.

Table 1. Accuracy of approximation of the unions of classes

Union of classes	Cardinality of approximations of the union of classes		Accuracy of approximations
	Lower approx.	Upper approx.	
At most poor standard	198	204	0,97
At most unsatisfactory standard	357	360	0,99
At most average standard	528	528	1,00
At most good standard	720	720	1,00
At most very good standard	918	918	1,00
At least excellent standard	148	148	1,00
At least very good standard	346	346	1,00
At least good standard	538	538	1,00
At least average standard	708	708	1,00
At least unsatisfactory standard	862	868	0,99

4.2. Step 2 – Definition of the evaluation pattern

In step 2 of the method an evaluation pattern has been constructed. The evaluation pattern is expressed as a set of decision rules, generated with the application of the DOMLEM (e.g. Stefanowski, 1998) algorithm. This algorithm aims at searching for a minimal number of decision rules based on the customers' opinions table. All the computations have been carried out using a dynamic reduct RED_1, consisted of 12 most important evaluation characteristics. Finally, a set of 4285 dynamic decision rules has been generated, including 4276 deterministic decision rules. Several exemplary dynamic decision rules (extracted in step 3) are presented below. They are described as follows: the initial number is the ordinal number of the decision rule, and the numbers in the brackets are absolute and relative strengths of the rule, respectively). The rules are given in the following form:

- 902: if $q_6 = 10001000$ and $q_{17} = 1010$ then D is at most poor standard (2; 1.10%),
- 1013: if $q_6 = 10001000$ and $q_2 \geq 0.01$ then D is at most very good standard (61; 7.44%),
- 1428: if $q_{14} = 110100$ then D is at most very good standard (23, 2.78%),
- 1549: if $q_{14} = 110100$ and $q_2 \leq 20{,}0$ then D is at least good standard (20; 4.09%),
- 1640: if $q_{14} = 110100$ then D is at least unsatisfactory standard (23; 2.95%),
- 2345: if $q_{13} = 1111111$ and $q_{15} = 1100010$ then D is at least excellent standard (10; 7.63%),
- 3325: if $q_6 = 10001000$ and $q_{16} = 011001010$ then D is at least average standard (15; 2.37%),
- 3820: if $q_6 = 00011000$ and $q_2 \leq 50.0$ then D is at least unsatisfactory standard (17; 2.20%).

Rule #902 can be interpreted as follows: if a transportation system evaluated to characteristic q_6 offers the deliveries only inside Poland (digit 1 at the first position) and is able to slightly change the route (digit 1 at the fifth position) and evaluated according to q_{17} offers clean loading space and logos on the vehicles' body (digit 1 at the first and third positions, respectively), then the standard of a transportation system (D) is at most poor. Rule #902 is supported by two objects (customers' opinions) from the table, and those objects constitute around 1% of all objects (198 units) belonging for sure to the union of classes representing at most poor standard (see Table 1).

4.3. Step 3 – The assignment of a transportation system to one of the predefined classes

In step 3 the evaluation of a real road freight transportation system operated by AB-Trans company has been performed. The detailed diagnosis of this system has been carried out using the characteristics included in RED_1. The result of the diagnosis coded in the format readable by 4eMka software has been presented in Table 2.

Table 2. Value of the characteristics of transportation system AB-Trans

No.	Quality characteristics included in RED_1	Coded value
1.	Acceptable delay $\{q_1\}$	2
2.	Opening hours $\{q_3\}$	01000000000010000
3.	Flexibility of the system $\{q_6\}$	10001000
4.	Staff experience $\{q_{12}\}$	3
5.	Availability of customer-staff communication means $\{q_{13}\}$	0010111
6.	Availability of information $\{q_{14}\}$	110100
7.	Acquisition and processing of information by the operator $\{q_{15}\}$	1000100
8.	Fleet composition $\{q_{16}\}$	011101000
9.	Fleet appearance $\{q_{17}\}$	1010
10.	Age of vehicles $\{q_{18}\}$	7
11.	Availability of loading / unloading / storage equipment $\{q_{21}\}$	010110000
12.	Number of hubs across the country $\{q_{23}\}$	4

The assignment of the considered AB-Trans transportation system to one of the six classes has been preceded by the analysis of the usefulness of each decision rule. The subset of dynamic decision rules for which the conditional part of the rule and characteristic of AB-Trans system are adequate, has been extracted. As a result a subset of 63 out of 4276 decision rules of $M(x)^+$ type has been selected. Then a selected subset of decision rules has been analyzed taking into consideration the relative strength of the rule. Only rules with the highest strength measure within each suggested union of classes have been selected. As a result 12 out of 63 decision rules have been extracted. The final assignment of AB-Trans system to one of the predefined classes has been carried out with the application of a credibility index $\phi(Cl_i, x)$. Its value has been computed using the scheme presented in Table 3.

Table 3. The scheme of calculating the credibility index

Union of classes	Ordinal number	Classes of transportation system												Strength		Lower approx. of union of classes
		Poor		Unsatisfactory		Average		Good		Very good		Excellent		absolute	relative	
		card[1]	stgh[2]	card	stgh	card	stgh	card	stgh	card	stgh	card	stgh			
At most poor	902	2	,012	-	-	-	-	-	-	-	-	-	-	2	,011	177
At most very good	1013	4	,005	0	0	20	,024	27	,033	10	,012	-	-	61	,074	820
At most very good	1428	0	0	0	0	2	,002	11	,013	10	,012	-	-	23	,028	829
At most very good	2290	0	0	0	0	2	,002	10	,012	10	,012	-	-	22	,026	829
At least good	767	-	-	-	-	-	-	10	,016	1	,002	0	0	11	,017	634
At least good	1549	-	-	-	-	-	-	10	,020	10	,020	0	0	20	,041	489
At least good	3289	-	-	-	-	-	-	11	,023	2	,004	0	0	13	,027	477
At least average	1579	-	-	-	-	2	,003	11	,017	10	,016	0	0	23	,036	641
At least average	3325	-	-	-	-	4	,006	10	,016	4	,006	0	0	18	,028	633
At least unsatisfactory	820	-	-	0	0	1	,003	8	,025	4	,012	0	0	13	,040	323
At least unsatisfactory	1640	-	-	0	0	2	,003	11	,014	10	,013	0	0	23	,026	779
At least unsatisfactory	2345	-	-	3	,004	4	,005	10	,013	15	,020	12	,015	44	,056	779
Relative strenght	sum	-	,017	-	,004	-	,048	-	,202	-	,129	-	,015	-	,410	-
	%	-	3,90	-	0,9	-	11,9	-	48,6	-	31,0	-	3,7	-	100	-
Absolute strenght	sum	6	-	3	-	37	-	129	-	86	-	12	-	273	-	-
	%	2,2	-	1,1	-	13,6	-	47,3	-	31,5	-	4,4	-	100	-	-

[1] *cardinality*, [2] *strenght*

It includes 6 classes (from poor to excellent), in columns, as well as selected decision rules, in rows, suggesting a potential assignment of AB-Trans system to one of the union of classes. Calculation of credibility index ϕ is based on the analysis of each single rule and its absolute strength. In practical terms, the absolute strength of a decision rule suggesting an assignment of AB-Trans system to a certain union of classes is distributed among specific single classes included in this union. For example an absolute strength of decision rule #1013 (see row 2) equals 61 objects supporting this rule and it is distributed among: poor, average, good and very good standard, which its cardinality per each class equal: 4, 20, 27 and 10 objects, respectively.

The sum of relative strengths for all decision rules that supports the assignment of AB-Trans system to any union of classes equals 0,410. However, a conversion of this value into the single classes (from poor to excellent) expresses a value of the considered credibility index. Thus, the credibility of assignment of AB-Trans system to one of the selected class from poor to excellent equals: 0,017, 0,004, 0,048, 0,202, 0,129 and 0,015 respectively.

Taking these values into account it is recommended, that class good is a suggested evaluation of the AB-Trans system. Roughly 50% (48,6%) of all corresponding opinions covered by decision rules support this evaluation. A more comprehensive analysis of the neighboring classes suggests that other potential assignments of AB-Trans system are also possible, however, less probable. AB-Trans system has more potential to be allocated to a class of a very good quality (ϕ = 0,129, i.e. 31% of all opinions) than to a class of average quality (ϕ = 0,050, i.e. 12% of all opinions).

5. Conclusions

This paper deals with the problem of evaluation of transportation systems. The authors have proposed an evaluation method of transportation system consists of three major steps, including: 1) Identification of the most important characteristics for evaluation of transportation systems. In the analysed case study 12 out of 24 characteristics have been selected as the most important in the evaluation of the road freight transportation system, 2) Definition and development of the evaluation pattern. In the analysed case a set of dynamic decision rules has been selected for further assignment. 3) Allocation of the real world transportation system to the predefined class. Here the selected decision rules and their relative strength are converted into the credibility index and finally, based on its value a suggested assignment is pointed out.

The proposed method has been experimentally verified and its application to the evaluation of a road freight transportation system has been demonstrated. The method has a universal character and its field of application is widespread. It can be used to assess different types of transportation systems, operated by different modes (road, rail, air and water) and providing both passengers' and freight transportation services. In such a case the list of the evaluation characteristics should be defined again, specifically to the profile of considered transportation mode. In addition to the above mentioned benefits the proposed approach is also characterized by several features of traditional quality evaluation methods, such as: a) provision of a comprehensive, multi-dimensional evaluation of a transportation system based on the analysis of characteristics describing many aspects of its operations, b) generating aggregated and synthetic index suggesting an overall evaluation of a transportation system.

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