

TRANSPORT SYSTEM OPERATION QUALITY ASSESSMENT AS A MULTIOBJECTIVE ANALYSIS ISSUE

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Abstract

The optimisation of exploitation process of complex exploitation system enables to decrease the costs of using and service activities. As an example of such system the transport system is considered. The base of optimisation process is the assessment method. In the case it is necessary to implement the assessment system that can take into consideration the digital and continuous criteria defined in different domains. Unfortunately for transport system the ISO and TQM methods are not sufficient.

In the paper the assessment of transport system operation quality is described as multi-objective analysis issue. The criteria stem from the cardinal features of the transport system identified during the carried out studies. The set of the criteria can be expressed in form of equations and/or inequalities. So, the set of equations and/or inequalities is received. The set can have zero, one or more than one solution. If there is no solution or there is more than one solution it is not possible to assess the transport system operation quality unambiguously. Therefore in the paper the fuzzy extension of multi-objective analysis is implemented. Each criterion was expressed in form of fuzzy set. The support and the shape of the member function for each fuzzy set was defined.

Thanks to the implemented method it is possible to assess the quality of the complex system operation taking into consideration the criteria expressed in different form and defined in different domains.

Keywords: *transport system, operation quality, multi-objective analysis, fuzzy sets, fuzzy logic*

1. Introduction

The most important part of the machine life, from the end-user point of view, is the exploitation phase [9]. This phase is realized in the exploitation system. The complexity of the exploitation system results from the quantity of the system components. The result of exploitation system complexity is the complication of exploitation processes. Nowadays the increase of real industrial exploitation systems complexity could be observed [2].

The exploitation processes flows influence on the level of the user needs fulfilment. They are also the reason of the exploitation phase costs. So, the quality of exploitation processes (quality of exploitation system operation) is the measure of the system usefulness.

In the industry the systems of quality assessment are implemented very often. For the example we can enumerate the ISO norm or TQM method. According to carried out studies [8] we can say that in case of big industrial systems, mentioned above methods are not sufficient.

It could be also noticed that the quality of exploitation system operation can be expressed as a function of the system features. Each feature could be defined for different domain. Additionally

the features could be continuous or digital. So there is a problem of joining all the features in one coherent assessment system.

Introducing the criterion for each feature could solve this problem. The level of criteria fulfilment describes the quality of system operation. The operation quality assessment is then transformed to assessment the defined variant of solution according to the finite amount of criteria. So, the considered issue becomes to be the multi-objective analysis problem [4].

Each criterion could be described by equation or inequality. Therefore the set of equations or inequalities is received. In particular cases the set could have more than one solution or could have not any one. In such cases it is not possible to receive an unambiguous solution [6]. To solve this problem the fuzzy modelling is implemented. Each criterion is expressed in form of fuzzy set. Additionally the weights of criteria are modelled by fuzzy digits. Thanks to it the approximation of weights definition could be taken into consideration.

Proposed method was implemented to assess the quality of transport system operation. During carried out studies the main features of the system and joined criteria was formulated. The domains and ranges of arguments and weights of the criteria were defined. Next the criteria were modelled as fuzzy sets. Thanks to it the coherent assessment system of transport system operation quality was created. The system enables to work out the unambiguous assessment of transport system operation quality.

2. The identification of the most important features and assessment criteria of transport system operation quality

To define the system features and assessment criteria of the complex systems operation quality it is necessary to analyse the literature from the point of view of operators activity, technical objects operation and environment influence quality. According to idea presented in [8], the method of system operation quality assessment consist in the main system features definition and formulation the assessment criteria. The criteria set should enable to assess the system from the operation quality point of view.

It is important to notice the fact that the values of the system features changes in the time. So the values of the features determined in the system examination process describe the quality of the system operation in given moment of time. Therefore, the result of carried out studies depends on the significance, quantity and type of the features taken into consideration.

The significance of the defined qualitative criteria was verified in expert tests executed by group of experts. The group consisted of considered system employes and the scientists who carry out the studies in the area of the system processes optimization.

The calculation of the criteria weights was the next step of the experiment. It was accomplished by implementation the matrix of importance method [5]. On the base of that the model of assessment of considered system operation quality was created. The most important criteria of designed assessment system were determined during the poll where the statistical group consists of the transport system users diverse from the sex, age, education and practiced job point of view. The number of the group $N=300$. The results of the carried out researches were analysed from the statistical point of view. The histogram of received rating distribution was created. To check the correlation of the criteria set the importance test of correlation factor was worked out.

As a result of carried out studies the rating of transport system features was received. The rating was created from the importance point of view. On the base of that the assessment criteria set was determined. The set was the base for the next steps of the studies.

3. Fuzzy criteria of assessment system

The transport system features distinguished during the studies could be divided into three groups, which describe the parts of the system: operator, vehicle and an environment. In the group of the operator assessment criteria the following fuzzy sets were received:

1. Driver work history – digital assessment of the accidents consequence in range $\{0,1,2,3,4,5\}$. The values mean accordingly loss of life, injured, collision, vehicle failure with loss of control, vehicle failure without loss of control and accident without driver mistake. The optimal value of the criterion is the biggest one and the most important differences in level of criterion fulfilment are around the minimum point of the criterion domain (MAXINV type of criterion). The member function of criterion fuzzy set is constructed by linear interpolation of the curve passing the points determined according to formula (1). The shape of the member function of this type is presented on the figure Fig. 1. The criterion takes part in assessment process with weight value equal to 0.28.

$$P_v = P_{\min} + (P_{\max} - P_{\min}) \cdot \frac{2^v}{64}, v = 0,1,\dots,6; g = 10 - v \quad (1)$$

where:

- v - value of criterion function,
- P_{\max} – high range of criterion argument domain,
- P_{\min} - low range of criterion argument domain,
- P_v - the argument of criterion function,
- g - the level of criterion fulfilment.

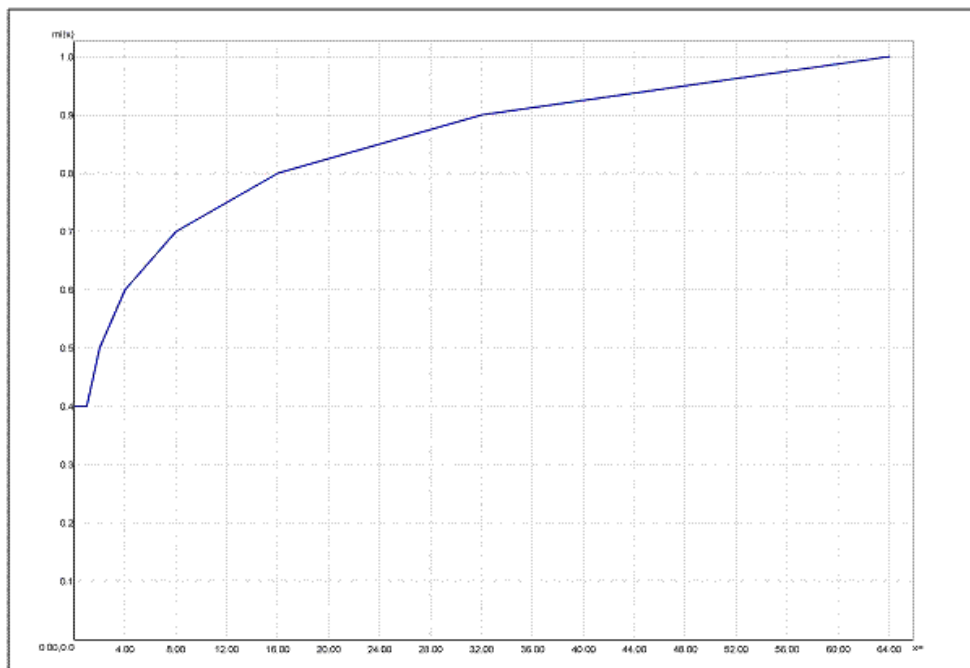


Fig. 1. Fuzzy set for criterion where the optimal value is as big as possible

2. The amount of the kilometres driven by the driver - continuous assessment in range of 0 to 800000km. The optimal value of the criterion and shape of the member function is expressed as previously. The criterion takes part in assessment process with weight value equal to 0.08.
3. Education of the driver – digital assessment of the education level in range $\{0,1,2,3,4\}$. The values mean accordingly no education, primary education, vocational education, secondary education and higher education. The optimal value of the criterion is the biggest one and the most important differences in level of criterion fulfilment are around the maximum

point of the criterion domain (MAXSIMP type of criterion). The member function of the criterion fuzzy set is constructed by linear interpolation of the curve passing the points determined according to formula (2). The shape of the member function of this type is presented on the figure Fig. 2. The criterion takes part in assessment process with weight value equal to 0.04.

$$P_v = P_{\max} - (P_{\max} - P_{\min}) \cdot \frac{2^v}{64}, v = 0, 1, \dots, 6; g = v + 4 \quad (2)$$

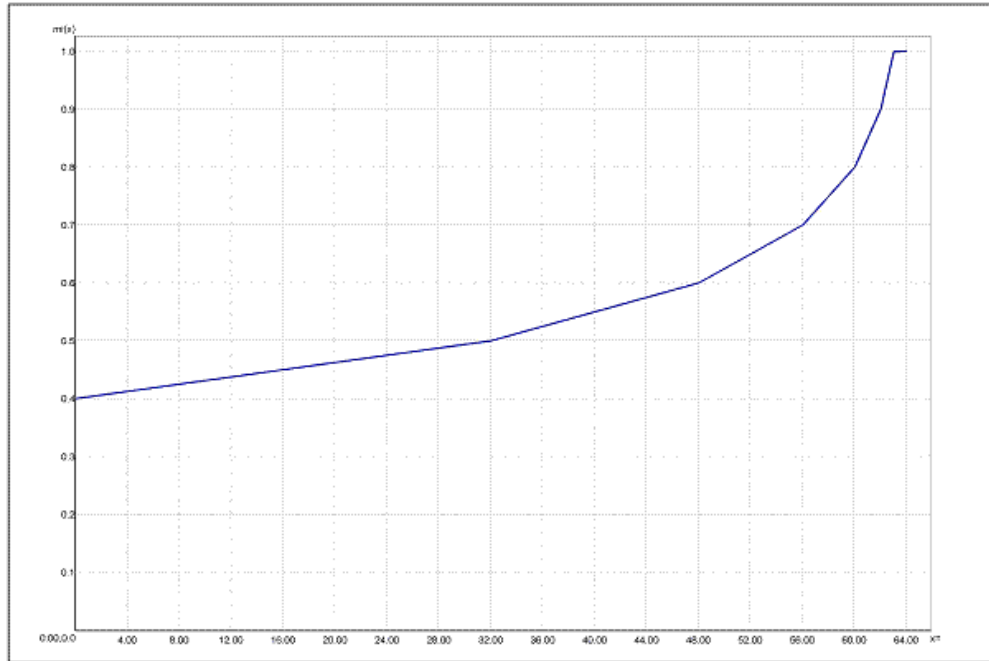


Fig. 2. Fuzzy set for criterion where the optimal value is the biggest one

In the group of the vehicle assessment criteria the following fuzzy sets were received:

1. Safety equipment – MAXINV criterion formulated for digital assessment calculated as an amount of safety equipment operating in the vehicle. The criterion takes into consideration the following equipment: airbag, power steering, ABS, ASR, bus stop break, auto-reverse, transverse tilt, EDC. The range of the criterion arguments is described by the set $\{0, 1, 2, 3, 4, 5, 6, 7, 8\}$. The criterion takes part in assessment process with weight value equal to 0.052.
2. Condition of tyres – MAXSIMP criterion formulated for continuous assessment where the height of tire treads acts as criterion argument. The value of the argument can change in range 2 - 12 mm. The criterion takes part in assessment process with weight value equal to 0.08.
3. Communication equipment - MAXINV criterion formulated for digital assessment calculated as an amount of communication equipment operating in the vehicle. The criterion takes into consideration the following equipment: CB-radio, video cameras and location transmitter. The range of the criterion arguments is described by the set $\{0, 1, 2, 3\}$. The criterion takes part in assessment process with weight value equal to 0.02.
4. Exploitation costs – MINSIMP criterion formulated for continuous assessment estimated on the basis of the exploitation costs expressed in PLN per one kilometre of vehicle operation. The support of the fuzzy set is closed sharp set limited by the values 1.5 and 3.0. The optimal value of the criterion is the smallest one and the most important differences in

level of criterion fulfilment are around the minimum point of the criterion domain (MINSIMP type of criterion). The member function of criterion fuzzy set is constructed by linear interpolation of the curve passing the points determined according to formula (3). The shape of the member function of this type is presented on the figure Fig. 3. The criterion takes part in assessment process with weight value equal to 0.048.

$$P_v = P_{\min} + (P_{\max} - P_{\min}) \cdot \frac{2^v}{64}, v = 0, 1, \dots, 6; g = 4 + v \quad (3)$$

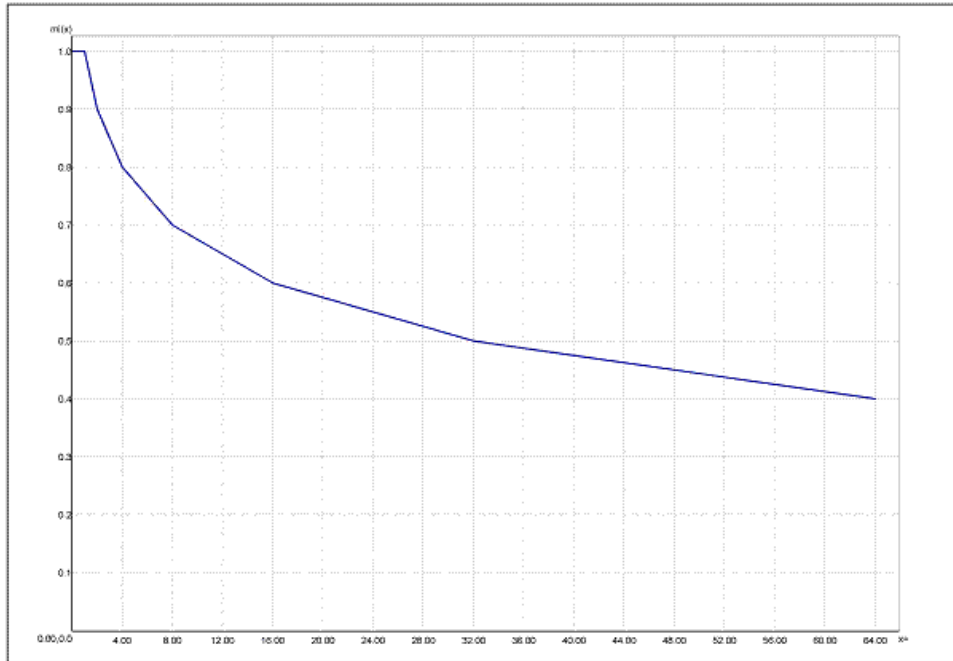


Fig. 3. Fuzzy set for criterion where the optimal value is the smallest one

5. Ergonomics of the vehicle - MAXINV criterion formulated for digital assessment calculated as an amount of the equipment installed for ergonomics increase. The criterion takes into consideration the following equipment: accommodation for disabled people, light signalling equipment, voice signalling equipment, air-conditioning, heat isolating widow panes, get off signalling and ticket automat. The range of the criterion arguments is described by the set $\{0, 1, 2, 3, 4, 5, 6, 7\}$. The criterion takes part in assessment process with weight value equal to 0.02.
6. Transport capacity – MAXINV criterion formulated for continuous assessment expressed by the sitting/standing places quantity in vehicle in range 10-150. The criterion takes part in assessment process with weight value equal to 0.024.
7. Operation control equipment – MAXINV criterion formulated for digital assessment calculated as an amount of the control equipment. The criterion takes into consideration the following equipment: oil level indicator, fuel level indicator, rotation speed indication, tachometer, indicator of engine temperature, open door indicator, ABS/ASR monitor, and clock. The range of the criterion argument is described by the set $\{0, 1, 2, 3, 4, 5, 6, 7, 8\}$. The criterion takes part in assessment process with weight value equal to 0.012.
8. Transport tasks execution - MAXSIMP criterion formulated for continuous assessment of argument's values calculated as an amount of executed transport tasks divided by an amount of scheduled ones. The support of the fuzzy set is the sharp set of real numbers in

range $\langle 0,100 \rangle$. The criterion takes part in assessment process with weight value equal to 0.092.

9. Emissions of pollution in exhaust gasses - MINSIMP criterion formulated for continuous assessment expressed by the light absorption factor of exhaust gasses. The argument value is measured by the devices calibrated in range from 0 to 10. The nominal value is then equal to 3. On the bases of that the range of argument is defined in form $\langle 2,10 \rangle$. The criterion takes part in assessment process with weight value equal to 0.028.
10. Noise emission - MINSIMP criterion formulated for continuous assessment of the noise level in range 60-90dB. The criterion takes part in assessment process with weight value equal to 0.024.

In a group of the environment assessment criteria the following fuzzy sets were received:

1. Thermal comfort – MAXSIMP criterion. In this case the value of member function of II type fuzzy set (4) acts as a criterion argument so the range of the criterion argument values starts from value 0 and ends in value 1. The fuzzy set is implemented to model the lack of sharp difference between conditions experienced as thermal comfort and discomfort. The thermal comfort depends on the temperature, relative humidity and speed of air and the temperature of the surface in the vehicle [3]. Despite of that, the thermal comfort zone was described only as a function of air temperature. It could be done because the influence of remaining parameters on range of comfortable temperature is not very big [1].

$$FS_{II}(x) = \begin{cases} 0 & \Leftrightarrow x \leq lrs \vee x \geq rrs \\ \frac{x - lrs}{lrk - lrs} & \Leftrightarrow lrs < x \leq lrk \\ 1 & \Leftrightarrow lrk < x \leq rrk \\ \frac{rrs - x}{rrs - rrk} & \Leftrightarrow rrk < x < rrs \end{cases} ; \quad (4)$$

where:

- $FS_{II}(x)$ – member function of II type fuzzy set,
 lrk – the lowest value of the fuzzy set kernel,
 lrs – the lowest value of the fuzzy set support,
 rrk – the biggest value of the fuzzy set kernel,
 rrs – the biggest value of the fuzzy set support.

The cardinal values of the fuzzy set were established as a function of the seasons. The fuzzy set was defined for temperature value in range from -30 to 60°C . The support of the fuzzy set equals to $\langle 6,14 \rangle$ for wintertime, $\langle 17,26 \rangle$ for summer time and $\langle 10,21 \rangle$ for autumn and spring. The fuzzy set kernel was calculated using fuzzification in range 2°C . The shape of fuzzy sets for different seasons was presented below (Fig.4). The criterion takes part in assessment process with weight value equal to 0.04.

2. Pavement condition – MAXSIMP criterion formulated for digital assessment presented in table Tab. 1. The criterion takes part in assessment process with weight value equal to 0.035.

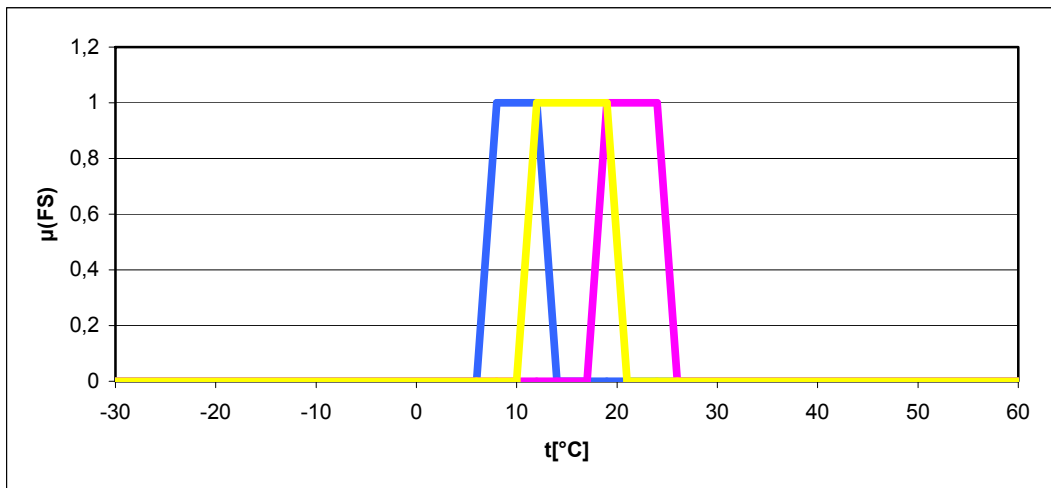


Fig. 4. Fuzzy set of thermal comfort temperature (blue – winter, yellow – summer, pink – autumn/spring)

Assessment	Condition
10	Ideal
9	Very good
8	Good
7	Fair
6	Acceptable
5	Bed
4	Very bed

Tab. 1. Values of pavement condition assessment

3. Pavement cleanness - MAXSIMP criterion formulated for digital assessment calculated as an amount of the contaminations. The criterion takes into consideration the following contaminations: sand, oil, water, mud, snow and ice. The range of the criterion argument is described by the set $\{0,1,2,3,4,5,6\}$. The criterion takes part in assessment process with weight value equal to 0.035.
4. Visibility - MAXINV criterion formulated for continuous assessment of the visibility distance expressed in meters in range from 0 to 10000. The criterion takes part in assessment process with weight value equal to 0.035.
5. Bus stop bay factor - MAXSIMP criterion formulated for continuous assessment of argument's values calculated as an amount of bus stop bay divided by the amount of all bus stops. The support of the fuzzy set is the set of real numbers in range $\langle 0,100 \rangle$. The criterion takes part in assessment process with weight value equal to 0.002

4. Summary

In the paper the coherent assessment system of complex exploitation system operation quality was presented. The assessment system was implemented to assess the transport system operation quality. The developed method enables to consider the continuous and digital type of criteria. Thanks to it the unambiguous assessment of analysed exploitation strategy could be determined.

The assessment system could be the base for optimization process, which can be used to determine the optimal strategy of carried out exploitation processes. The implementation of the developed method to transport system operation quality assessment is only the example. The method is universal and could be used to assess the operation quality of the systems from any domain of multi-objective analysis.

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