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Model for port service quality and intermodality assessment applying fuzzy logic

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ABSTRACT

Port terminals, as the starting and ending points of the technological process in the transport of goods, are also logistic centers for the provision of services of loading/unloading and storage of goods. Improving the process of transporting goods and achieving competitiveness is not possible without quality port service and customer satisfaction with the service provided, and reduction of traffic congestion and environmental pollution within the guards in which the ports are positioned.
This scientific research aimed to analyze, using scientific methodology, the factors influencing the assessment of port service quality and intermodality in the Port of Rijeka and to develop a model for port service quality assessment by implementing fuzzy logic. The model was tested by simulation based on the evaluation of the criteria of influential parameters with inaccurate and indeterminate input data. The test results provide an assessment of the quality provided by port service and intermodality. The results of the research will be used to improve the transport service planning process to achieve greater competitiveness for the port.

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1 Introduction

Transport corridors passing through the territory of the Republic of Croatia form a European intermodal transport system component. The Port of Rijeka is the central hub and link between intermodal transport corridors connecting maritime and land transport. The quality of port service and reduction of environmental pollution in the city area are important elements of the port system's competitiveness in the function of attracting intermodal flows of goods.

This scientific research aimed to investigate and analyze the factors of port service quality by using scientific methodology to increase the port's competitiveness.

Accordingly, this research provides an analysis of the criteria for evaluating the factors of port service quality by using fuzzy logic. The analysis of the criteria and variables led the way to a scientific discovery that was used as the basis of a model for port service quality assessment.

2 Previous research overview

There are no complex scientific researches that have led the authors to the results by applying fuzzy logic and this one was conducted based on the criteria set out in this article. A critical scientific analysis of previous researches in both the domestic and foreign professional scientific literature review has shown that the problem of evaluating the quality of port service has been partially scientifically researched and processed.

Previous research work was mainly based on the quality of service, which can be defined by the quality of customer satisfaction and quality suitable for use [1]. Some authors [2] define the quality of service as the value or price that meets the needs of consumers and ensures their competitiveness and profitability, while others [3, 4] define the quality of service as a comprehensive degree of excellence [5]. Satisfaction of the service user, based on the quality of the service provided [6], retains the user for further use of the service provided or returns him to use it

[7]. The author [8] deals in his article with a positive relationship between the quality of the service provided and the satisfaction of the users of the transport service in railway transport. The quality of service can be viewed from the aspect of the organization and users. The user aspect of quality is a set of attributes that evaluate the service and is related to the level of customer satisfaction with the service [9]. The SERVQUAL scale consisting of five SQ dimensions: tangibility, reliability, understanding, security and responsiveness, which has a wider application in various industries, is discussed by the authors [10] in their paper. They also emphasize that the quality of service can be measured either during or after the service's execution, as the functional and technical quality.

No papers have been found aimed at assessing the quality of port service using fuzzy logic. The authors [11], using fuzzy logic and evaluating the input variables in the distribution of goods flows, developed a model for selecting the optimal transport route. Using a system of fuzzy logic, the authors [12] analyze the process of managing a ship's lock on the waterway. The control algorithm is modeled according to a set of language rules that describe the development strategy. Subjective estimates are therefore implemented in the algorithm as fuzzy sets of fuzzy rules, which aggregate the final fuzzy set and by defuzzification (by converting the fuzzy value to the final value) produce a decision.

The Port Services Quality Study (PSQ) [13], calculated using integrals, covers six dimensions of quality determined by 29 criteria. The degree of importance is ranked according to: empathy, material goods, security, reliability, responsiveness, and diversity; proactive measures provision of vessel layout, cargo handling facilities and equipment, detailed structure, accuracy and consistency of design and geographical location. The service attribute (SA) includes the quality of the cargo transportation service, the ability to deal with cargo damage, the willingness to help clients and the provision of special cargo-related services.

Based on the review of previous research works, it is justified to conduct further research to determine additional quality factors and define criteria on which to define a model for measuring the quality of port service using fuzzy logic.

3 Research methodology

The analysis and ranking of the selected criteria were performed by the method of analysis and synthesis and the method of classification. The statistical method was used to process the statistical data and define the input parameters of selected variables. The description of the knowledge and attitudes obtained from the research work was formed by the method of description. The input data for the development of the model were obtained by the survey method, while the model was created using fuzzy logic.

3.1 The survey method

The survey method was used to collect the views of the traffic process participants on their satisfaction with port service. The survey questionnaire was sent in 2021 to thirty e-mail addresses of port service users. The poll was anonymous. The question was as follows:

Which rating would you use to assess the following factors that affect the quality of services provided in the Port of Rijeka and which of the proposed factors is the most important:

1. *Satisfaction with road transport (variable name – road transport)*
2. *Satisfaction with railway transport (variable name – railway transport)*
3. *Availability of loading/unloading capacities (variable name – loading/unloading capacities)*
4. *Availability of storage capacities (variable name – storage capacities)*
5. *Goods delivered on time,*
6. *Evaluation of satisfaction with the service provided (variable name – customer satisfaction)*

Choose among the following rating:

- *Bad, in the range from 1 to 2,*
- *Less acceptable, in the range from 2 to 5,*
- *More acceptable, in the range from 5 to 8,*
- *Good, in the range from 8 to 10.*

The received answers to the survey question were obtained from ten users of the port service (E1 ... E10) or a total of 33%, which is a representative sample.

3.2 Modeling method – fuzzy logic

Based on the conducted research, the realization was made of the importance of developing a model which would enable the quality of port service to be measured. The modeling was performed using fuzzy logic. Fuzzy logic is a system of modeling in which inaccurate and indeterminate input data are described, based on which an objective judgment is made. The first phase of fuzzy logic modeling is the so-called *fuzzification* procedure, in which the degree of membership is determined by the function of membership: *bad* (B), *less acceptable* (LA), *more acceptable* (MA), and *good* (G), so that the category of *bad* is determined according to the minimum value of a certain criterion. The category *good* determines the maximum possible value of each criterion (Figure 1).

The analytical formula shows the values of the membership function. The values of the membership function denoted as *bad* (B) is represented by a fuzzy set with a minimum value, and the membership function is defined as a function with values of the real variable *x.*

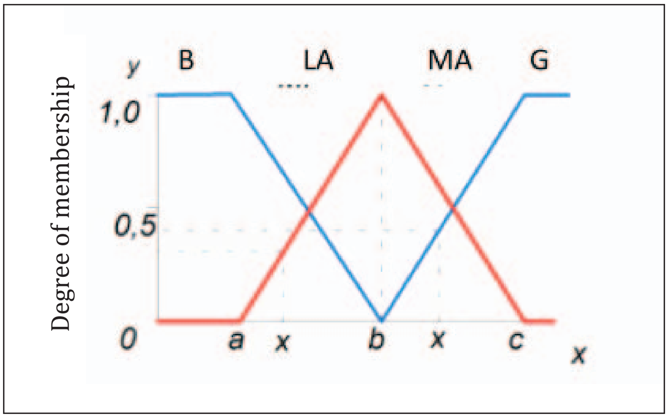

Figure 1 The defined membership function

Source: By authors

$$\mu_L(x)=\begin{cases}1 & 0\le x\le a\\ \dfrac{x-b}{a-b} & a<x\le b\\ 0 & x>b\end{cases} \qquad (1)$$

The range of the membership of the function, labeled as *less acceptable* (LA), is expressed by a formula and has a negative sign of the real variable *x.*

$$\mu_{SL}(x)=\begin{cases}0 & \\ \dfrac{x-a}{1-a} & 0\le x\le a \\ & a<x\le b\\ 1 & x=b\\ 0 & x>b\end{cases} \qquad (2)$$

The range of the membership of function, labeled as *more acceptable* (MA) label, is expressed by a formula and has a positive sign of the real variable *x.*

$$\mu_{SD}(x)=\begin{cases}0 & 0\le x<b\\ 1 & x=b\\ \dfrac{x-c}{b-c} & b<x\le c\\ 0 & x>c\end{cases} \qquad (3)$$

The values of the membership function *good* (G) represent the maximum value and the membership function is defined as a function on the positive values of the real variable *x*.

$$\mu_D(x)=\begin{cases}0 & 0\le x\le b\\ \dfrac{x-b}{c-b} & b<x\le c\\ 1 & x>c\end{cases} \qquad (4)$$

4 Analysis and assessment of variables

A criterion is defined as a measure, a principle (principle, point of view) according to which something is judged, or as the basis of someone's actions and behavior [14]. A variable is used to define an associated value that can be changed by associating another value in different contexts [15]. Each criterion contains at least one variable.

The selected variables are defined and grouped into three groups of criteria: *intermodality, logistics and storage, and quality of service,* which consist of the following variables:

- *Road traffic*
- *Railway transport*
- *Loading/unloading capacities*
- *Storage capacities*
- *Goods delivered on time*
- *Satisfaction with the service*

The *road* and *rail transport* variables represent the freight transport modes in the intermodal transport network of the technological process of transport. This variable assesses the degree of satisfaction of service users with a particular mode of transport. The *loading/unloading capacities* variable consists of means of transport for loading/unloading and shifting of cargo, which are used for cargo handling in operational zones. This variable assesses the degree of modernization of transport technology in the port. The *storage capacities* variable is the space for storing goods in the port, which are used for further transport and distribution. This variable assesses the degree of quality of storage of goods in port terminals. The *goods delivered on time* variable implies reliability for the transported goods. This variable assesses the degree of satisfaction with the service of delivery of goods in the agreed time. The *service satisfaction* variable is a set of transport services that contains elements of availability, reliability and flexibility.

The defined rules of fuzzification determine the degree of membership to a particular fuzzy set. The membership function is determined by the percentage of the degree of membership to a certain set with predefined nominal functions. The value of variables (Table 1) is defined by assessing the value of the fuzzy set affiliation function [1, 10]:

- *bad* (B), for scores less than 2 (equivalent to 0-20%),
- *less acceptable* (LA), for scores from 2 to 5 (equivalent to 20-50%),
- *more acceptable* (MA), for scores from 5 to 8 (equivalent to 50-80%),
- *good* (G), for scores from 8 to 10 (equivalent to 80-100%),

Based on the survey conducted among the Port of Rijeka port service users and the conducted analysis of the criteria, an assessment was made of the values that will be

Table 1 Input variables with membership function

	CRITERION	VARIABLES	JM	PONDER	DEFINED RULES				INPUT DATA FROM THE SURVEY
				[1]	[2]				[3]
					bad	less acceptable	more acceptable	good	
					B	LA	MA	G	X_v
1.	INTERMODALITY	ROAD TRANSPORT	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	7.10
2.		RAILWAY TRANSPORT	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	5.80
3.	LOGISTICS AND STORAGE	TRANSHIPMENT CAPACITY	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	7.00
4.		STORAGE CAPACITY	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	6.00
5.	QUALITY OF SERVICE	GOODS DELIVERED ON TIME	rating	0.30	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	4.00
6.		CUSTOMER SATISFACTION	rating	0.50	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	8.00

Source: by authors

Table 2 Results of the data obtained from the survey questionnaire

SERVICE	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Average
ROAD TRANSPORT	6.00	8.00	6.00	9.00	8.00	6.00	8.00	6.00	7.00	7.00	7.10
RAILWAY TRANSPORT	6.00	7.00	5.00	6.00	6.00	7.00	6.00	5.00	5.00	5.00	5.80
TRANSHIPMENT CAPACITY	8.00	8.00	7.00	6.00	6.00	8.00	9.00	7.00	6.00	5.00	7.00
STORAGE CAPACITY	7.00	6.00	6.00	5.00	5.00	4.00	5.00	6.00	7.00	7.00	6.00
GOOD DELIVERED ON TIME	3.00	3.00	3.00	5.00	3.00	4.00	6.00	4.00	4.00	4.00	4.00
CUSTOMER SATISFACTION	8.00	8.00	8.00	7.00	7.00	8.00	9.00	8.00	8.00	8.00	7.90

Source: by authors

used as input variables in the model design and testing (Table 2).

Scoring, ranking and classification of the results obtained were performed according to the Thurston scale[1]. Ranking and evaluation of variables were performed by scoring the results of the arithmetic mean of the scores obtained by the survey. Individual variables are evaluated with values from one to ten. The score of one represents the minimum value (equivalent to 10%), while the maximum value is expressed by the score of ten (which replaces the equivalent of 100%).

Defuzzification is the process of converting the summed values of a fuzzy set into specific, output values (Table 3). By the maximum value method, the coefficients are defined as follows:

– if the value of the function is *bad* (B), then it is multiplied by -1,0;
– if the value of the function is *less acceptable* (LA), then it is multiplied by -0,75;

[1] Thurston's scale gives respondents ready-made answers related to the field of research, and they are expected to make one of the statements closest to what they themselves feel or think about that particular object. It is not general, but very concise, and summarizes all possible views on the subject of research in just a few statements that move from one extreme to another.

Table 3 Output variables with affiliation function

FUZZY FUNCTION OF BELONGING				DEFUZZIFICATION			
[5]				[6]			
B	LA	MA	G	B	LA	MA	G
				-1.00	-0.75	0.75	1.00
0.00	0.00	0.64	0.36	0.00	0.00	0.48	0.36
0.00	0.00	0.93	0.07	0.00	0.00	0.70	0.07
0.00	0.00	0.67	0.33	0.00	0.00	0.50	0.33
0.00	0.00	0.89	0.11	0.00	0.00	0.67	0.11
0.33	0.67	0.00	0.00	-0.33	-0.55	0.00	0.00
0.00	0.00	0.44	0.56	0.00	0.00	0.33	0.56

Source: by authors

– if the value of the function *is more acceptable* (MA), then it is multiplied by 0,75;
– if the value of the function is *good* (G), then it is multiplied by 1,00.

By multiplying the data from the membership function by the coefficients defined, the output results are obtained of the conducted assessment of the quality of port service according to the given criteria and defined rules.

5 Port service quality assessment model

Based on the conducted research, the realization of the importance of model development was made, which would enable the assessment of the quality of port service. From the six input variables, three linguistic variables in the structure of the *Fuzzy Inference Syste*m (FIS) were selected defining the appropriate and representative IF-THEN fuzzy rules using operators AND, OR and NOT. In general, an arbitrarily chosen IF-THEN rule of fuzzy inference system with *n* input variables ($x_1, x_2, ..., x_3$), *m* linguistic variables (LV) and one output variable (y) can be described using only the AND operator, which is also a very important feature of the FIS approach as follows:

$$\text{IF } (x_1 \text{ is } A_1) \text{ AND } (x_2 \text{ is } A_2) \text{ AND } ... \; ... \text{ AND } (x_n \text{ is } A_n) \text{ THEN } (y \text{ is } B) \quad (5)$$

Input variables for the first FIS model are *road transport* (ROT) and *rail transport* (RAT). In contrast, the output variable is the *Intermodality Criteria Index* (INT) which assesses the degree of influence of Intermodality on the overall *index and selection of benefit preferences* (ISBP). Input variables for the second FIS model are *transshipment capacity* (TRC) and *storage capacity* (STC), while the output variable is the *Logistics and Storage Criteria Index* (LOG) assesses the degree of influence of the Logistics and

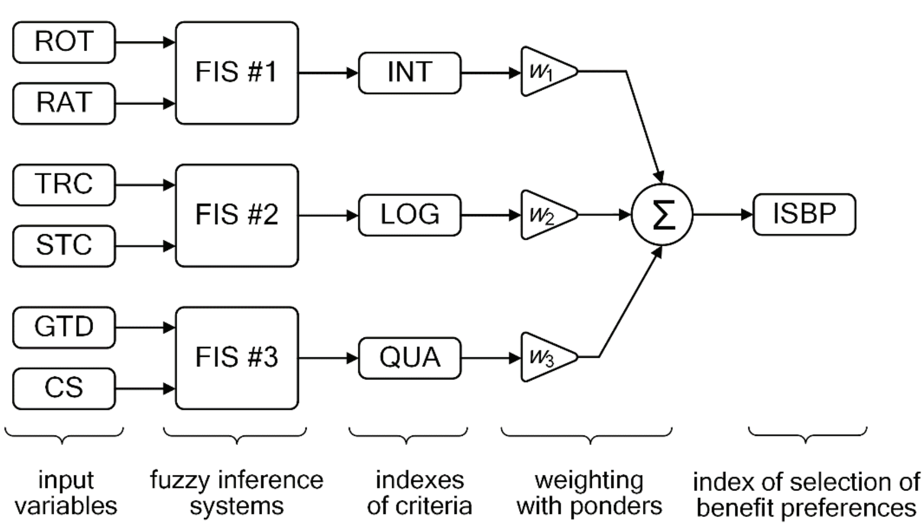

Figure 2 Illustration of a model with a fuzzy conclusion-making system

Source: by authors

Storage Criteria on the overall *index of a selection of benefit preferences* (ISBP). Input variables for the third FIS model are *goods delivered on time* (GDT) and *customer satisfaction* (CS). In contrast, the output variable is the *quality of service index* (QUA) which assesses the degree of impact of quality of service on the overall *index of a selection of benefit preferences* (ISBP) (Figure 2).

Index of selection of benefit preferences (ISBP) is expressed:

$$ISBP = w_1 \cdot INT + w_2 \cdot LOG + w_3 \cdot QUA \tag{6}$$

Where the weights w_1, w_2 and w_3 are defined by experts or about currently/valid, future criteria, in this way, the model's additional adaptability is enabled regarding changes in individual standards and their impact on the final result.

For this paper, the ISBP in the interval [0,1] is valid, but the choice of an alternative with a higher ISBP is more favorable. Therefore, all indices (INT, LOG and QUA) are defined by the same interval and modeled similarly to maintain their unambiguity in the final decision. When creating the appropriate FIS, the following was done:

(a) for each input and output variable (var), specify the name and range of a function [min (var) max (var)];

(b) for each linguistic variable (ROT, RAT, TRC, STC, GTD and CS) of their input variable, determined by the parameters (a, b, c, d) forming the trapezoidal function

(c) for each linguistic variable (ROT, RAT, TRC, STC, GTD and CS) of their output variable, determine the parameters (a, b, c) of the triangular function;

(d) prepare and implement IF-THEN rules regarding the number of input variables.

The Matlab software system (The MathWorks, 2017a) was used to support the development of some fuzzy inference systems, i.e., the FuzzyLogic Toolbox system (The MathWorks, 2017b) which was built into it. For example, the membership function (MF) describes the degree of membership of an element to an indistinct set, with the degree of affiliation valid.

When modeling the membership functions f(x) for the linguistic variables (ROT, RAT, TRC, STC, GTD and CS) of the input FIS, trapezoidal functions of the form were used:

$$f(x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases} \tag{7}$$

where parameters *a* and *d* determine the position of the bottom base, and parameters *b* and *c* the position of the top base of the "trapezoid" as shown in Figure 3.

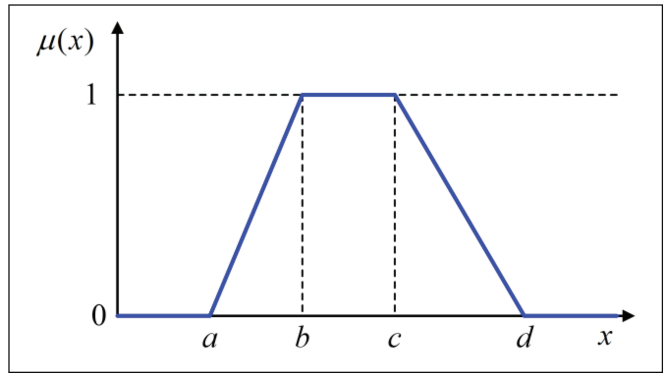

Figure 3 Representation of the trapezoidal function

Source: by authors

When modeling functions for variables (ROT, RAT, TRC, STC, GTD and CS) of the output FIS variable, triangular membership functions were formed using:

$$f(\mathrm{x}) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \tag{8}$$

Parameters a and c determine the position of the base, and parameter b is the maximum, as shown in Figure 4.

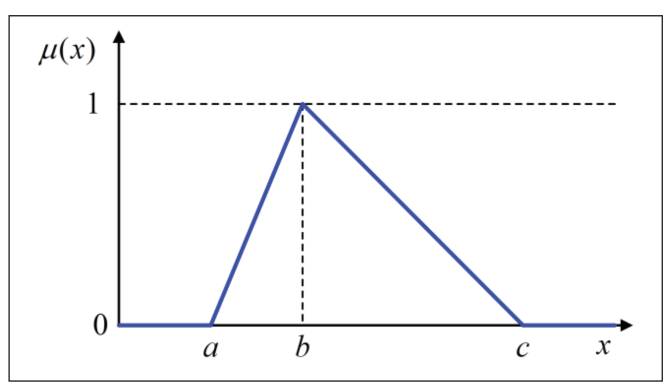

Figure 4 Representation of the data as a function

Source: by authors

The model's evaluation result is shown in Table 4. Which contains all the previously described and defined functions and the assessment done by using fuzzy logic. The evaluation of the conducted model testing indicates that the existing port service quality in the Port of Rijeka is *good* (with an acceptability equivalent of 50% -80%).

Table 4 Affiliation function defining and degree of membership assessment by fuzzy logic

	CRITERION	VARIABLES	JM	PONDER	DEFINED RULES				INPUT DATA FROM THE SURVEY
				[1]	[2]				[3]
					bad	less acceptable	more acceptable	good	
					B	LA	MA	G	X_v
1.	INTERMODALITY	ROAD TRANSPORT	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	7.10
2.		RAILWAY TRANSPORT	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	5.80
3.	LOGISTICS AND STORAGE	TRANSHIPMENT CAPACITY	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	7.00
4.		STORAGE CAPACITY	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	6.00
5.	QUALITY OF SERVICE	GOODS DELIVERED ON TIME	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	4.00
6.		CUSTOMER SATISFACTION	rating	0.05	> 2.00	2.0-5.0	5.0-8.0	8.0-10.0	8.00

GROUPING RULES			FUZZY FUNCTION OF BELONGING				DEFUZZIFICATION			
[4]			[5]				[6]			
min	medium	max	B	LA	MA	G	B	LA	MA	G
a	b	c					-1.00	-0.75	0.75	1.00
1.00	5.50	10.00	0.00	0.00	0.64	0.36	0.00	0.00	0.48	0.36
1.00	5.50	10.00	0.00	0.00	0.93	0.07	0.00	0.00	0.70	0.07
1.00	5.50	10.00	0.00	0.00	0.67	0.33	0.00	0.00	0.50	0.33
1.00	5.50	10.00	0.00	0.00	0.89	0.11	0.00	0.00	0.67	0.11
1.00	5.50	10.00	0.33	0.67	0.00	0.00	-0.33	-0.55	0.00	0.00
1.00	5.50	10.00	0.00	0.00	0.44	0.56	0.00	0.00	0.33	0.56

RESULTS			
[7]			
BAD	LESS ACCEPTABLE	MORE ACCEPTABLE	GOOD
[6]*[1]	[6]*[1]	[6]*[1]	[6]*[1]
0.00	0.00	0.02	0.02
0.00	0.00	0.04	0.00
0.00	0.00	0.03	0.02
0.00	0.00	0.03	0.01
-0.10	-0.15	0.00	0.00
0.00	0.00	0.17	0.28

-0.10	-0.15	0.28	0.32
RESULTS OF TESTING: **GOOD**			

Source: by authors

6 Model evaluation and discussion of results

Based on the results of the research and the parameters set, a model for assessing the quality of port service was developed, using fuzzy logic. By testing the model, the result of the evaluation of the quality of port service in the port of Rijeka was obtained, taking into account the selected variables and defined rules.

By ranking the output value parameters of the scores (ISBP) of the *index of a selection of benefit preferences* (for *bad* -0.10; for *less acceptable* -0.15; for *more acceptab*le 0.28 and *good* 0.32), with the set input values of variables, results of the assessment *good* in the current conditions of port service quality, with testing of the set variables *road traffic, rail transport, loading/unloading capacity, storage capacity, goods delivered on time and service satisfaction* is the optimal choice of the port service quality assessment parameter (Table 4). The weighting value of variables was determined based on a survey of users who stated that their *satisfaction with the service* and the *goods delivered* on time was the most important criteria for evaluating the quality of port service.

7 Conclusion

According to the given conditions and with selected influential factors, a model for assessing the quality of port service was developed using the system of fuzzy logic. For model creation and testing, the criteria of *intermodality, logistics and warehousing,* as well as *the quality of service* were approved. The *intermodality* criterion contains *road and rail transport* variables*,* the *logistics and warehousing* criterion contains *transshipment capacity and storage capacity* influential variables, while the *quality of service* criterion contains *goods delivered on time* and *service satisfaction* variables. Based on the conducted survey of service users, parameters were reached for ranking the quality of service and weighting. According to the survey, the most important variable for service users in the provision of port service is *satisfaction with the service*, which was ranked with the highest weight, followed by the *goods delivered on time* variable and then by other offered variables. Model testing was performed by classifying ratings and data obtained from service users by the survey.

The results of the conducted model testing indicate that the existing quality of port service in the Port of Rijeka is *good* (with an acceptability equivalent of 50% -80%). A larger number of service users stated that the road transport mode was a better choice for them in the current conditions. Although the obtained results indicate greater satisfaction of service users with road transport of goods, sustainable development must encourage alternative forms of energy use in the transport system and further development of rail transport, with a tendency to reduce negative impacts on human health and the environment, especially in urban areas and larger cities.

The model will enable users of transport service planning to create a more efficient plan of port service quality while improving the technological process of transport and sustainability. The limitation of the model for assessing the quality of port service and the results obtained is the relatively small number of input data collected by the survey from port service users and the narrowed number of selected variables that affect the assessment of service quality in the Port of Rijeka. The obtained results and the developed model for assessing the quality and intermodality of port services are the basis for further scientific research, aimed at improving the technological process of transport and finding better transport solutions for better sustainability, and reducing greenhouse gas emissions in urban areas where ports are positioned.

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