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EFFECT OF ADOPTED RULES OF INFERENCE AND METHODS OF DEFUZZIFICATION ON THE FINAL RESULT OF THE EVALUATION OF RELIABILITY MADE USING THE FUZZY LOGIC METHODS

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Abstract

The object of interest is to solve the problem of risk management of marine systems. But the main trouble is a lack of numerous and sure data on the reliability of the components of such systems. The methods based on the fuzzy logic seem to be helpful here. The goal of the article is to check the effect of using different fuzzy inference rules and methods of defuzzification on the final result of reliability assessment. The three rules of inference are taken into account: the Mamdani rule, the Larsen rule and the Tsukamoto rule. The second problem is the method of defuzzification of the result given in the form of fuzzy number into the real number. The several methods of defuzzification are discussed. The examples of using the above inference rules and defuzzification methods are presented.

Key words: *marine systems, reliability data, fuzzy sets, inference rules, defuzzification methods.*

1. Introduction

The fuzzy seems to be a very good tool when we have in our disposal very imprecise data. In contrast with binary logic, where the truth has only two values (1 – true, 0 – false) fuzzy logic variables of truth may vary from 0 to 1. It gives us possibility to deal with reasoning that is approximate rather than precise. And such situation is very typical in reliability analysis of technical system.

It is worth noting, that such imprecise tool like the fuzzy logic is widely used in control systems that require high precision. The idea arise: if the inference based on fuzzy logic works in control systems, it should also be helpful in drawing conclusions about the reliability of technical systems. Fuzzy inference (in another words fuzzy reasoning or approximate reasoning) uses linguistic rules, which are IF – THAN statements and typical logic AND – OR operators.

For example, the four fuzzy inference rules for car speed control system can take a form: 1st : IF the distance to the car in front is small AND the speed is low THAN maintain the speed level. 2nd: IF the distance to the car in front is small AND the speed is high THAN the speed should be reduced. 3rd: IF the distance to the car in front is large AND the speed is low THAN the speed should be increased. 4th: IF the distance to the car in front is large AND the speed is high THAN maintain the speed level. According to the example above, two fuzzy rules can be written for reliability assessment: 1st: IF the technical element is new THEN its reliability is high. 2nd: IF the technical element is old THEN its reliability is low.

To use such fuzzy rules about reliability it is necessary to build four fuzzy numbers: new technical element, old technical element, high reliability, low reliability. Those fuzzy numbers can be constructed on the basis of available reliability data or based on expert opinions. After that we can use the fuzzy rules of inference like: the Mamdani rule, the Larsen rule and the Tsukamoto rule.

Generally fuzzy inference process consists of five steps: creating a database of rules, writing those rules by using fuzzy numbers (fuzzification), drawing conclusion in the form of fuzzy number, changing the fuzzy number into real number (defuzzification).

2. Fuzzy inference rules for the reliability assessment of marine systems

As it has been already stated above, it is proposed to create two fuzzy inference rules for the reliability assessment. Those rules are:

1st rule: IF the technical element is new THEN its reliability is high.

2nd rule: IF the technical element is old THEN its reliability is low.

To build the rules it is necessary to create four fuzzy numbers: a new element, an old element, high reliability, low reliability.

Of course, we need some reliability data about technical elements being under consideration. Let's take as the example the data given in the fuzzy form about ship pipelines according to [1] that an average lifetime of ship's pipelines is:

- 5 – 7 years for galvanized steel pipelines,
- 5 – 9 years for copper pipelines,
- about 20 years for PVC pipelines,
- more than 20 years for cupronickel pipelines.

Now we focus our attention to galvanized steel pipelines. The task is to create two fuzzy numbers: (t_1) - the new pipeline and (t_2) - the old pipeline. An average lifetime of such pipelines is about six years. In that case the six year period will be essential to differentiate between the new pipelines and the old pipelines. Because we don't know the distribution of time to failure of such pipelines, therefore we have to create the simplest and commonly used fuzzy numbers given in the triangular form, shown in the Fig.1.

In a similar way the next two fuzzy numbers: (R_1) - high reliability and (R_2) - low reliability can be determined. It is obvious that high reliability expressed as a fuzzy number takes the form of "about one". Low reliability takes the form of "about zero". Those fuzzy numbers are presented in the Fig.1. Their membership functions have also typical triangular forms. The rule is that the opposite fuzzy numbers should be partly overlapped.

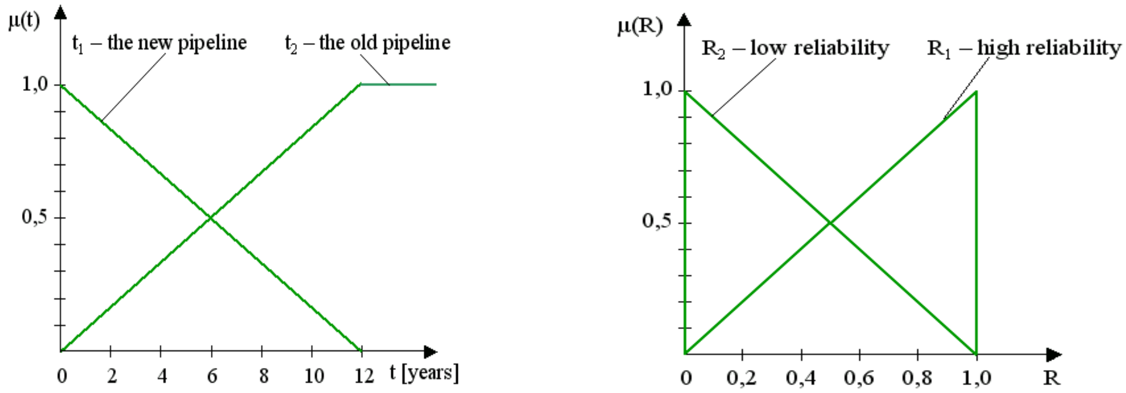

Fig. 1. Fuzzy numbers' membership functions: the new pipeline and the old pipeline

The applicability of fuzzy inference to assess the reliability will be presented with such an example: **to find the reliability of galvanized steel pipeline for the period of time: two years since the moment of installing as a quite new on board**. The two described above rules will be used. 1st rule: IF the pipeline is new THEN its reliability is high. 2nd rule: IF the pipeline is old THEN its reliability is low. And the three methods of inference will be taken into account: the Mamdani method, the Larsen method and the Tsukamoto method [2, 3], used in Fig. 2.

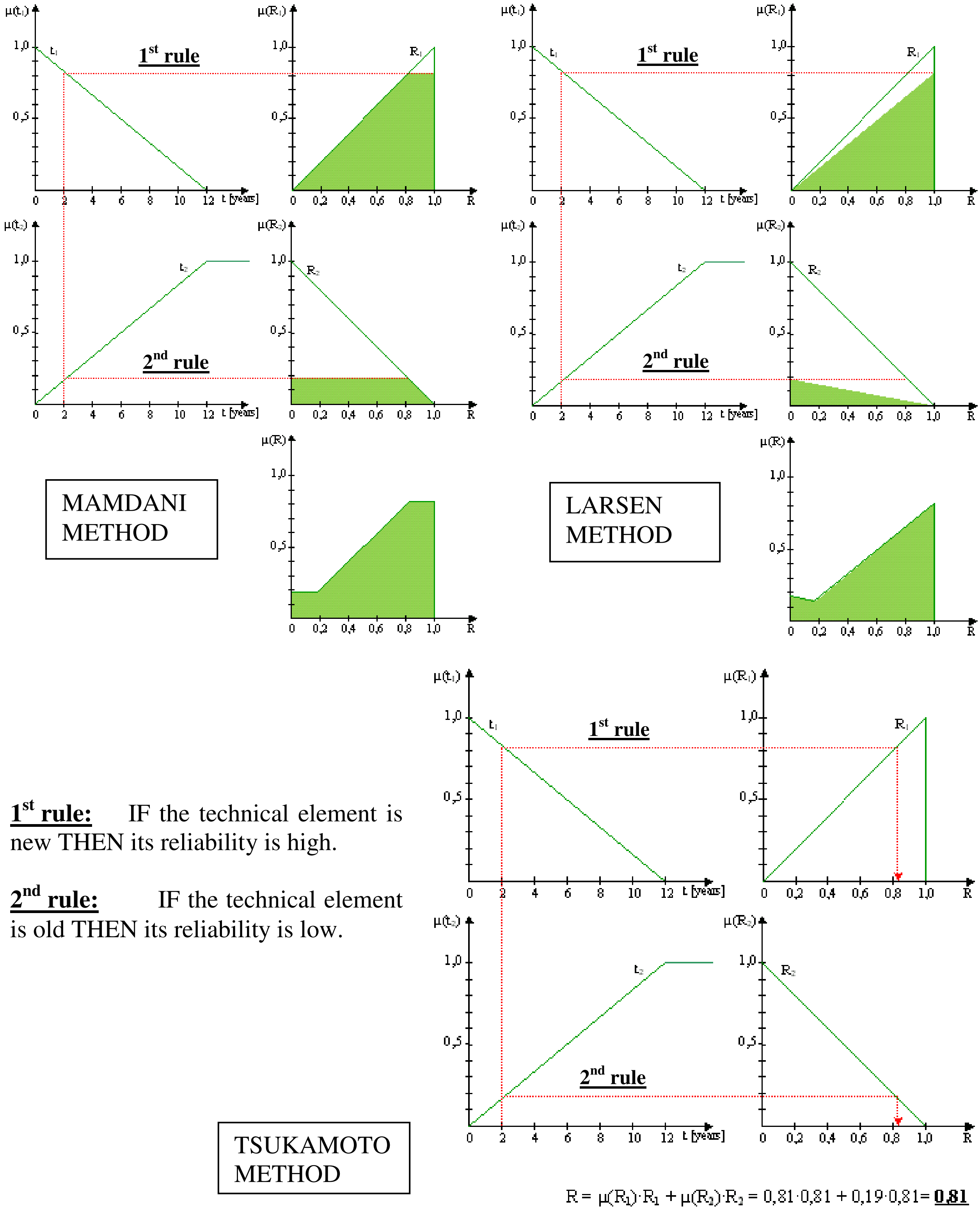

Fig. 2. Reliability of galvanized steel pipeline for two years period of time assessed with fuzzy inference methods

3. Comparison of obtained results

The comparison of obtained results is presented in Fig. 3. We can notice that the results are similar. The Mamdani method and the Larsen method give us results in the form of fuzzy numbers. The Tsukamoto method gives so called crisp value – it means the result is given in the form of real number. The problem is how to understand results, especially those in the form of fuzzy numbers. Looking for the Fig. 3. we can say that the reliability value obtained with the use of the Mamdani method is "about 0.8 – 1"; the reliability value obtained with the use of the Larsen method is "about 1"; the reliability value obtained with the use of the Tsukamoto method is 0.81.

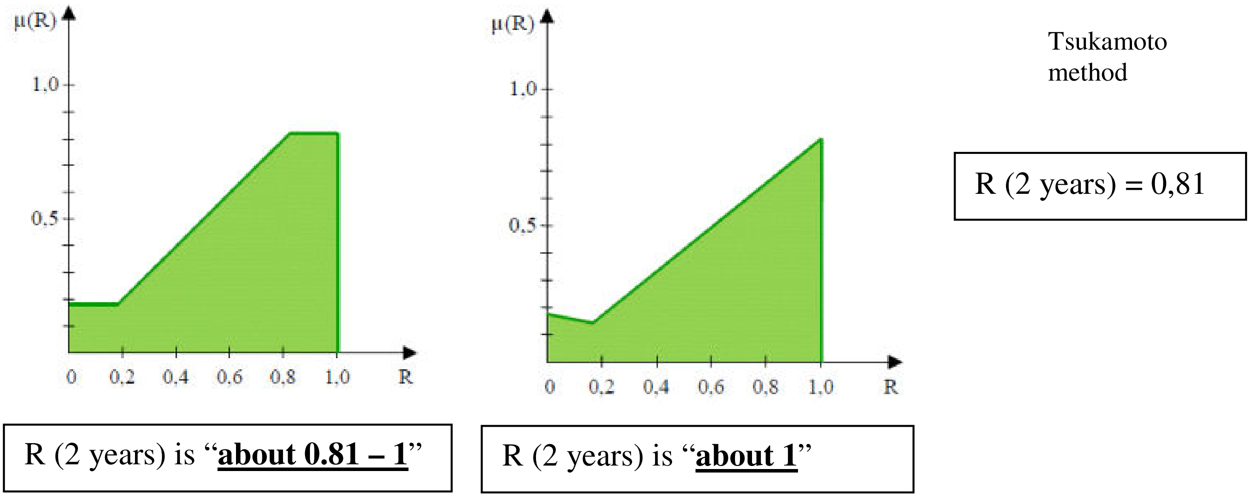

Fig. 3. Comparison of reliability assessment made with the use of Mamdani, Larsen, Tsukamoto inference rules

The results are not contradictory. The question is: which of those methods should be chosen in reliability analysis of marine systems? At first glance, Tsukamoto method seems to be most convenient. It gives a particular result in a form of real number. But we must realize that it is almost impossible the reliability value will be exactly like that. Especially in a situation when we have to our disposal very imprecise data. And such situation is typical in reliability assessment of marine systems.

The results given in the form of fuzzy numbers are imprecise. Thanks to that, they better illustrate the problem we try to solve. Looking at the fuzzy numbers shown above, we can draw conclusions useful in practice. We can conclude: it is most likely that the reliability of the pipeline reach value about 0.81 – 1. But we have to remember that the reliability can also reach the value about 0 – 0.19 what is much less likely. Fuzzy number gives us an idea about the uncertainty of estimation has been made. The consideration can be as follows: the reliability of the pipeline is about 0.81 – 1 with the possibility measure (not probability) 81%.

The Mamdani method is more pessimistic than the Larsen method. Thus applying the principle of worst-case, in the author's opinion the Mamdani method seems to be a good tool to solve a problem of reliability assessment, when available reliability data are very imprecise.

4. Methods of defuzzification

The result obtained in the form of fuzzy number gives the best view of the problem. However, it may be required to provide a result in the form of real number (crisp value). Then some methods of defuzzification can be helpful. Defuzzification is just a transformation from a fuzzy number to a crisp number. There are several methods of defuzzification described in the literature [4, 5, 6]. Some of them will be used to change the reliability calculation result given in the form of fuzzy number into crisp values. The application of those methods for the example being considerate in the article is given in Fig. 4. The results are compared in Tab. 1.

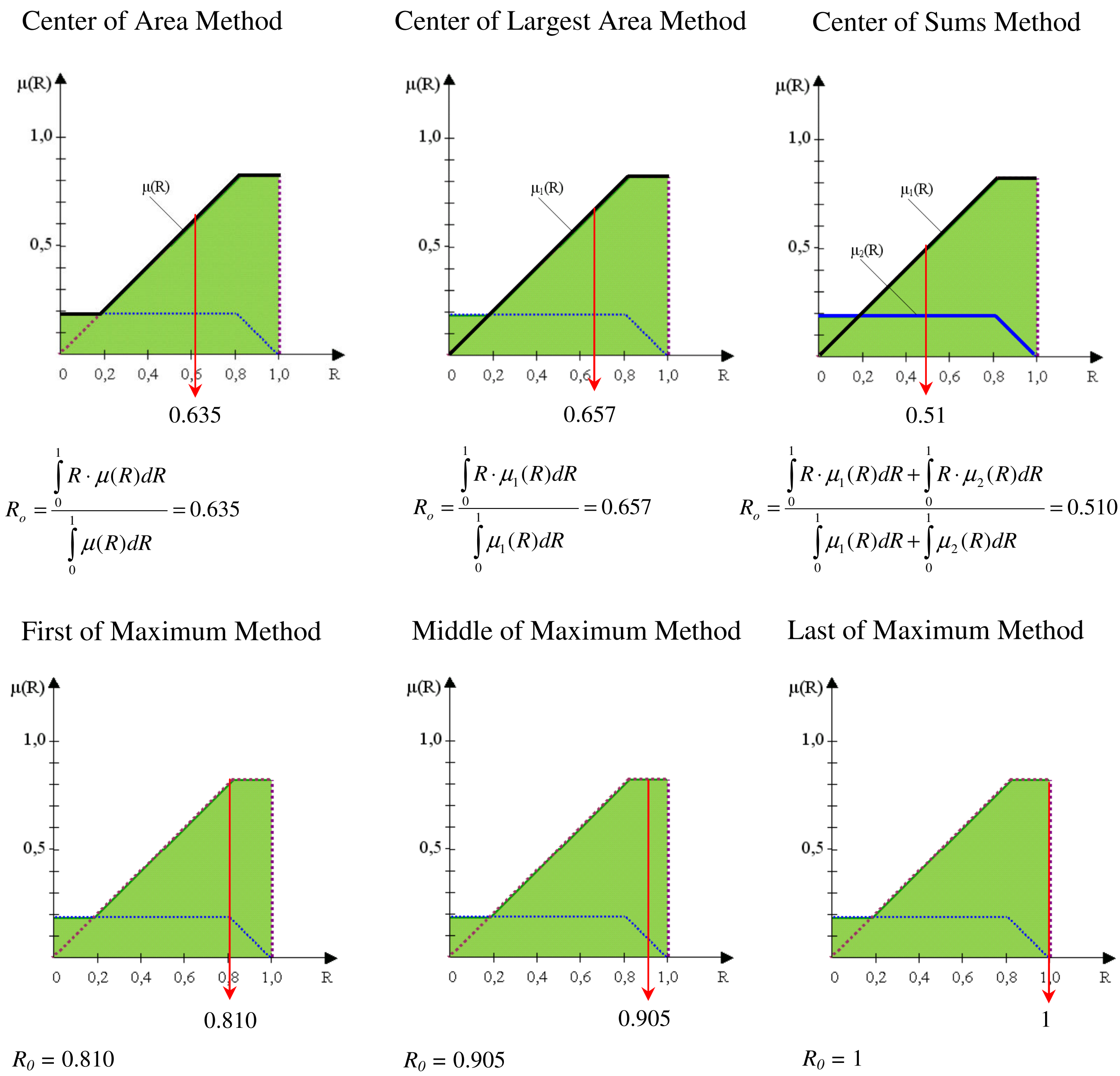

Fig. 4. Methods of defuzzification used to get a crisp value of reliability

Tab. 1. Comparison of reliability assessment results R_0 given in the form of crisp values, with the use of different methods of defuzzification

Defuzzification Method	$\mathbf{R_0}$
Center of Sums	0.510
Center of Area	0.635
Center of Largest Area	0.657
First of Maximum	0.810
Tsukamoto	0.810
Middle of Maximum	0.905
Last of Maximum	1

5. Final remarks

In the author's opinion, it is possible to draw out useful in practice conclusions about reliability of technical items from imprecise data using fuzzy logic inference rules. Such an example has been shown in the article.

For the considered example - the results obtained with the use of the Mamdani method, the Larsen method and the Tsukamoto method are not contradictory. So it is hard to say, which of those methods the best is.

The Mamdani method is a little bit more pessimistic than the Larsen method. Thus applying the principle of worst-case it seems to be an appropriate tool to solve a problem of reliability assessment.

If someone needs the result of calculations in the crisp form, he can use the Tsukamoto method or use the methods of defuzzification of fuzzy number. But the results differ significantly depending on the chosen method, as it has been shown in Tab. 1.

The results given in the form of fuzzy numbers are imprecise, but they much better illustrate the problem of reliability assessment. Fuzzy number gives us an idea about the uncertainty of estimation has been made.

The best way to express the estimated reliability for the given above example is the conclusion: The reliability of the pipeline is about 0.81 – 1 with the possibility measure 81% (against to the conclusion: the reliability of the pipeline is about 0 – 0.19 with the possibility measure 19%).

With the very small data set it is very difficult to talk about probability in the classical sense, even from statistical point of view. We should rather to use fuzzy inference methods, as it has been shown in the article.

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