Applying Fuzzy set method for solving mechanical engineering problems (Determining residual service life)

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Abstract – **In this paper we use fuzzy set method to solve one of the important problems in mechanical engineering (the residual service life). The residual service life for rolling stock can change depending on it's using conditions. The Paper offer's a new method depending on fuzzy set method by using the material mechanical and chemical corrosion mathematical model.**

I. Introduction

The concept of service life means the time period since the beginning of the use of the tool or machine till the time period when it becomes unsafe or non-economic to use. The concept of service life is of great importance for mobile equipment used to transport large quantity of people, such as: Planes and trains and special used equipment (which we are trying to reduce the probability of failure to its possible minimums) such as: military mobile equipment. The service life for the equipment relies on the intensity and quality of the equipment's employment, and consequently the service life of certain equipment changes significantly depending "on these factors. Since the term or concept (density and quality of employment) is not specific or Fuzzy, so we can see that the service life function Fuzzy (non specific) Overall, the service life remaining for certain equipment (T_R) can be determined by the equation number (1).

$$T_R = T_D - T_S \qquad (1)$$

Where T_D - means the service life of the specified equipment as designed (by manufacturer)

T_S - means the service life experienced by the equipment from the date of its inception to the present time (the time of testing).

Reality forced us in many cases to deal with the equipment under non-integrated information on the history of use where equipment come for maintenance without a history log (which are often missing or non-integrated) And there is no precise idea of the system and its future work and after maintenance the remaining service life of the equipment should be determined. The identification of the remaining service life of the equipment currently relies on a study of the equipment without taking into account the Fuzzy factors (non specific) that affect the work of the equipment Therefore, in this paper we present a new theory to determine the remaining service life of the equipment by studying the Fuzzy factors (non specific) That affect service life remaining of the equipment, and this theory relies on the (Fuzzy Set theory).

Perhaps the most important factors that affect the service life of the equipment are (Fig. No.1):

- Mechanical and chemical corrosion (55%)
- Fatigue failure (27%)
- Cracks (18%)

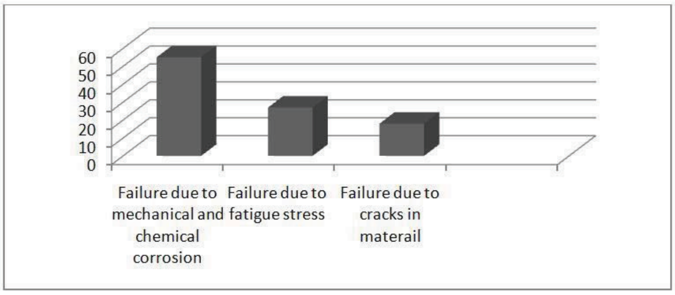


Fig.(1) the most important factors that affect the service life of the equipment

Through the diagram above we note that the mechanical and chemical erosion plays a greater role in determining the remaining service life of the equipment.

II. Fuzzy Set Method:

The emergence of a Fuzzy theory is a revolution in the development of classical algebra and a upgrade to a higher level so that it is now possible to take the information and data that was not specified in the mathematical modeling process, Posing the possibility of absorbing information and more data in a mathematical model to a problem.

The theory is based on the idea of removing the Fuzzy boundaries on the logic of reparation classical groups, Which says that the group contains a specified number of elements each element that does not belong to this group cannot be attributed by any link, Which often contradicts with nature and human behavior. In the past stripping everything around us mathematically was necessary to be able to carry out mathematical simulation of the phenomena we wish to process and control, But it seems that with the accumulation of science, information and discoveries, it became necessary to expand the mathematical abstraction and the tendency to try to simulate the phenomena as it is in nature and away from abstraction for the sake of ease and simplification, And here came the idea of Fuzzy groups in the expression of groups as a way out of the trouble of limited simulation of phenomena. Instead of to express that an element belonging to a group with an answer yes or no, now the question is if the item belongs to a group, what is the degree of its membership, and this degree of membership is the spectrum between the value's zero and one, in other words there's a factor that can describe these value's which is called the "Membership Factor". Now we can say the logic of yes or no - true or false - white or black is a special case of spaces in the gray gradient black or white, which lies between the two, from here came the name "Fuzzy".

Fuzziness theory Allows us to expand the Mathematical simulation of the phenomena, when we know the mechanisms of a project in a specific and classic way, we will come out with only one proverb that gives an idea about the number of these mechanisms, but when we try to know the group of mechanisms and mechanical technicians ready to work, we will fall in the trouble of judging the belonging to this group or not, it is well known that readiness of an equipment is an issue related to the large amount of criteria which its impact differs due to climate conditions and surrounding situations, so How can we formulate this group within the logic of Yes - No, this example shows us that it is imperative to take into account the Fuzzy groups and its presentation.

The primary objective of the Fuzzy theory, not the removal of Fuzzy ambiguity but also to recognize its existence and its impact on the mathematical model.

At the very beginning there was confusion between the concept of possibilities and Fuzzy groups, because of the similarity between the distribution factors and membership factors, that's why it is necessary to put the difference in mind. While through statistics we are trying to predict the future, through the search for values that are more frequent, by simulating the Fuzzy groups we disclosure the elements of the mathematical model, which has no digital reflection and define it as a Fuzzy set.

We Say about the group to be Fuzzy (Fuzzy) A in X and is expressed as follows:

$$A = \{(x, \mu_A(x))|x \in X\} \quad (2)$$

Where $\mu_A(x)$ is the degree of belonging to the element x to the Fuzzy group A which its value's are between [0,1].

It is mathematically common to find for each group a membership factor of its own, where as the form and nature of the membership factor has a major impact on defining a group, Here begins the subjective element to intervene in the matter, and to alleviate it must take into account possible standards available that influence the formation of membership factor.

We may generally distinguish two types of factors, linear and nonlinear, in the case of non-linear the concave or curvature has a role in the expression of optimism or pessimism in the evaluation process that we have, through the mathematical model.

III. Mechanical and chemical corrosion as a Fuzzy function (non specific)

Usually we always rely in our account of the mechanical and chemical erosion at the expense of the corrosion rate (equation (3)) which in turn depends on the thickness of the metal as a key factor.

$$a = \frac{s_1 - s_2}{k_1 k_2 (t_2 - t_1)} \quad (3)$$

- Where S_1 represents the thickness of the metal at the exit of the equipment from the factory (or after the last maintenance), mm.
- S_2 represents the thickness of the metal when the test is taken (currently), mm.
- k_1 factor represents the amount of slope in corrosion scheme rate and time on the horizon.
- k_2 factor represents the type of relation between corrosion speed and time (Linear or nonlinear).
- t_1 Represents the service life at the beginning of use, years.
- t_2 represents the service life when selected, in years.

By observing equation (3) we find that it contains factors that could be adopted as Fuzzy factors (non specific) as follows:

The first thickness of the metal (S_1): the first thickness of the metal depends on the thickness of iron slices, according to standard specifications there is the permittivity of productivity in thickness (+0.3, -0.75) for the slices of metal, so this factor can be considered ambiguous factor.

Thickness (S_2) measured at time t_2: that this thickness depends on the accuracy of measurement and depends on the accuracy of measuring devices and the experience of the examiner. According to the standard specifications there is measurement permittivity (+1, -1) and thus this factor can be considered as Fuzzy. Factors k_1, k_2 have different values as follows:

k_1= (0.5 – 1.5)

k_2= (0.75 – 1.25)

Thus, these two factors can be considered as Fuzzy factors.

IV. Applying the theory

From a Number of mobile equipment we selected equipment called "Hopper Ballast Wagon for transport and lying ballast", where this equipment is used to fresh gravel when making or maintaining new or old railway lines. This equipment operates in harsh working conditions: weather conditions such as humidity and high temperatures, rain and other extreme load conditions, On the other hand the nature of its work is distributing gravel on all parts of the railway or road, this kind of work gives some parts of the equipment very high stresses and pressure which leads to a reduction of service work and raises the specter of failure, and to apply our theory we selected the most important part of the equipment which is the part of loading and unloading gravel (Hopper). Figure (2) represents the general appearance of the equipment.

1. Collect initial information:

	Type of information	Collection method	What will get
1	The original design parameters.	• Design documentation, • Really measurements, • Analysis of results thickness.	• The size of elements, • The thickness of the elements, • Thickness tolerance.
2	Parameters of operation of the rolling stock.	• Passport of machines, • operational documentation.	• Mean time (Hours or kilometers. Of using) in the working and transport modes.
3	Parameters of loading the rolling stock • in transport mode, • in working mode.	• Equations, • Really measurements, • Mathematical models.	• Rated load, • Experimental load.
4	Properties of the material of construction of the rolling stock.	• Legal documentation, • Non-destructive testing, • Destructive testing, • Mathematical modeling.	• Experimental material properties, • Calculated properties of the material, • The residual service life in standard
5	Results of technical diagnosis.	• Measurement of the elements, • Non-destructive testing.	• The actual size of the elements and it is geometrically deviation from the standard. • The actual thickness according to the mechanical and chemical corrosion, • Estimating the size of internal defects.
6	Unknown factors	• Overall testing of the machine.	• Distribution of vertical load, • Acceleration of the body

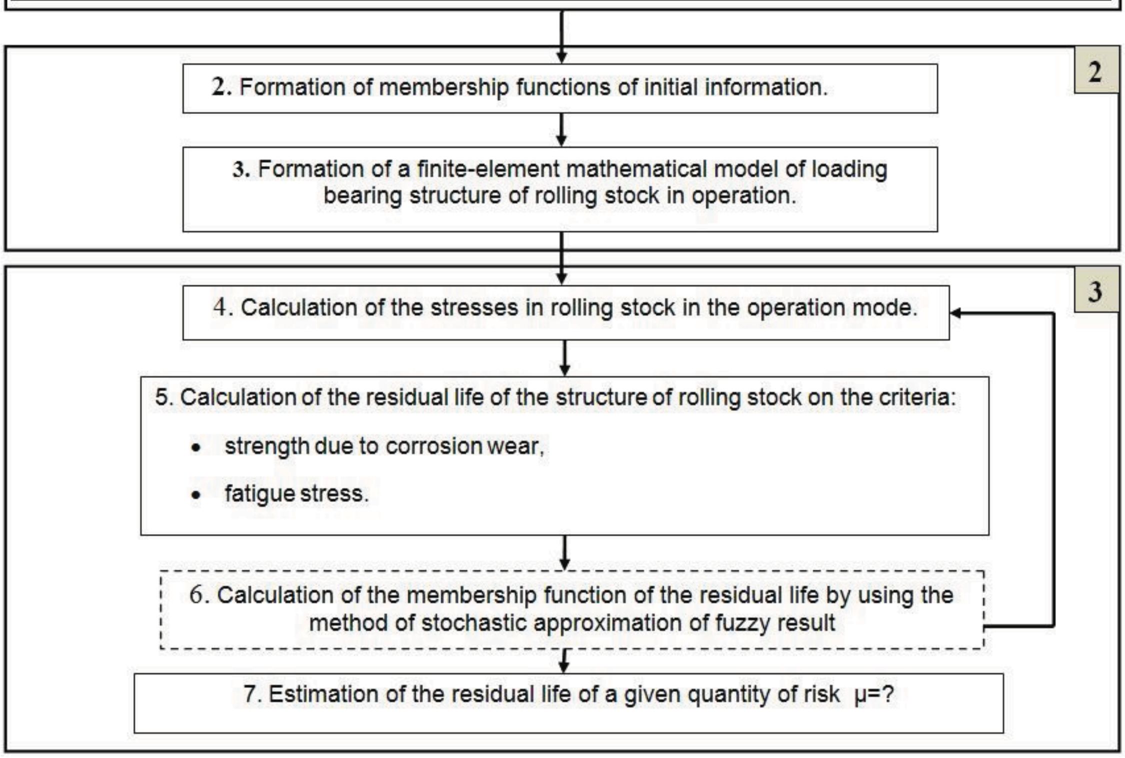


Fig.(2). Flow chart for estimating the residual service life of rolling stock structures that work in uncertain conditions.

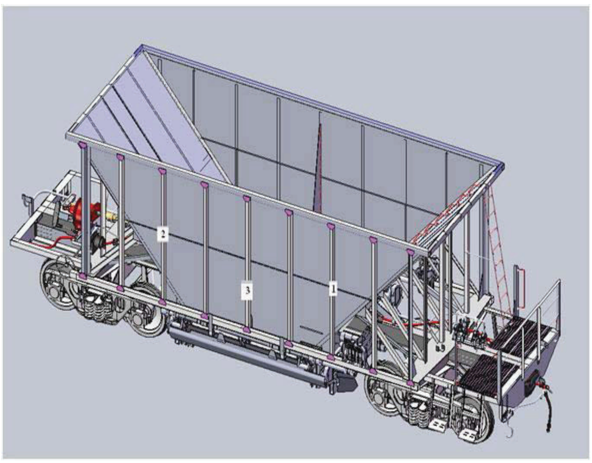
Figure (3) represents the overall appearance of the equipment.

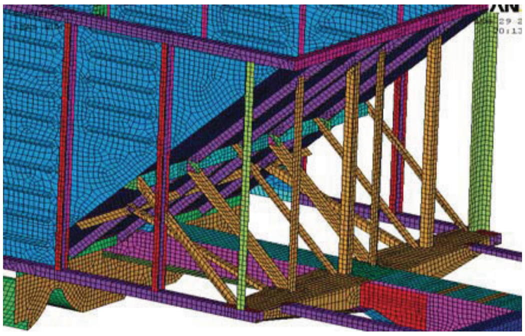
Phase 1: Through studying the style of the machines work and noticing the density of its use during the different stages of work and studying all documents available (by design and operation) and making the required tests, we appointed the factors ,and it's membership functions, which affect in the strength of the machine and its service life.

Phase 2: Using computer software like (Solid Works) and (Ansys) we built a model shown in Figure (4), where we entered all the factors that affect the machine during work, Also at this stage we find the input belonging function through the identification of Fuzzy factors that affect the service life of the machine and its relationship with the inputs data.

Phase 3: depending on the (Ansys) program, we calculated stresses on the equipment's hopper, to find the relationship between the thickness of the metal and the stress on the equipment's hopper was calculated stresses at different thicknesses of the metal in three points of the hopper, Fig. (5) shows this relationship.

(A)





(B)

Fig.(4). (A) the model under study (as Solid works model)
(B) the model, divided by Finite Elements Method
(by using Ansys)

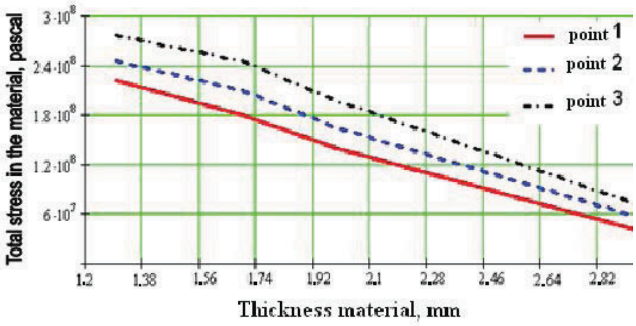


Figure No. 5. The relationship between the thickness of the metal and the total stress.

Depending on equation number (3) we configured the following mathematical model:

$$S(t_3) \geq [S]$$

$$a = \frac{S_{\phi}(t_1) - S_{\phi}(t_2)}{(t_2 - t_1)K_1 K_2}$$

$$S(t_3) = S_{\phi}(t_2) - a(t_3 - t_2)$$

Where:

$[S]$ Represents the least thickness of the metal that is allowed.

$S_{\phi}(t_1)$ Represents the thickness of the metal when the equipment first left the maker factory, as a Fuzzy function, mm.

$S_{\phi}(t_2)$ Represents the thickness of metal when tested as Fuzzy function, mm.

$S(t_3)$ Represents the thickness of the metal after the service life t_3 (future), mm.

Phase 4: Depending on the model above and the MATLAB program, we can get the thickness of the metal at the service life t_3 and through the Fig. No. 5. We can find the stress at that thickness and then by compare this value with the maximum allowable stress on the metal, and by repeating this process we can determine the remaining service life of the equipment.

V. Results:

For the focus of study example, the service life for the equipment is 20 years, but through the application of this theory (where the maximum allowable stress of the metal is 190 MN \ m^2) we found out that the equipment can work for an additional 5 years more with using risk 31% (where risk=1- reliability) as in fig.(6). By using this cure we can find the residual service life for machine, under study, with the amount of risk when using it. From curve below, very clear the machine can works for 2 years with reliability 100%.

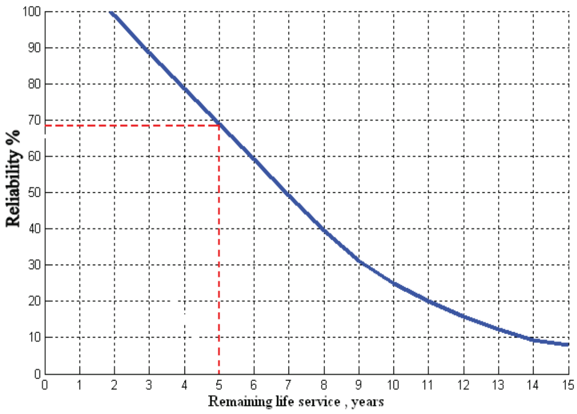


Fig.(6). The remaining service life for the studied machine

VI. Discussion and conclusions:

As we told above, by using the above cure we can find the residual service life for machine, under study, with the amount of risk when using it or we can determine the amount of risk, at first, depends on the intensive of machine work and then from it we can find the residual service life for machine.

In this paper, we studied the effect of one factor (mechanical and chemical corrosion) to calculate the residual service life for machine and neglected the effect of others factors (fatigue failure and cracks). For future studies, we recommend to development new method to calculate the residual service life with study the effect of all these factors (mechanical and chemical corrosion, fatigue failure and cracks) depends into Fussy set method.

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