A FUZZY MODEL REGARDING THE MANAGEMENT OF PREVENTIVE MAINTENANCE OF SOME MEANS OF TRANSPORTATION BELONGING TO S.C. ORADEA TRANSPORT LOCAL S.A.

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Abstract - To keep in (active) reserve some technical entities equates with the action of stocking them; specifying that such an action should be interpreted as being a case of "waiting", therefore a retention "stock" for a limited period. Referring to such equipment, identical to those in working conditions, the retention may become, at any time, "by rotation", operating, according to a schedule established by the managerial forum. It is the case of a "mobile" retention, defined by a quantity, usually a constant of "the stock". Obviously, exceptions are those entities upon which the decider factor decides the intervention of maintenance.

Keywords: scale of assessments, scale semantics, level, experton, mathematical expectation, fuzzy logical operators, logical conjunction, logical disjunction, performance function.

1. INTRODUCTION

An urban transportation unit decided that a certain group of vehicles should circulate, during the "normal" period (off-peak hours), on any route, and a few vehicles be kept in reserve; but any means of transportation could be in both situations. Vehicles in reserve are periodically subject to analysis regarding their operational condition, appreciated by a group of experts. Their opinions are expressed under a linguistic, non-numerical form, on a scale having a number of steps. This "case study" intends to identify those means of transportation, being in reserve and which could be the subject of some imminent maintenance actions. If under normal circumstances, the nominal operational regime is of the form "*n* from *n+k*" [1], [2], in case an entity deteriorates, the operating mode becomes of the type "*n* from *n(k-1)*". (*n* represents the number of entities in operation, and *k* the number of entities in reserve).

1. CASE STUDY

Within the urban transportation unit, five buses were distributed for any route: three operational, and two being in reserve, a solution corresponding to the operating mode during off-peak hours. At the same time, the managerial factor decided the carrying-out of an analysis regarding the working condition of these means of transportation. The results of the action undertaken by a group of experts are presented under a non-numerical form and belong to a linear scale having seven scales [3] - table 1. Such a septenary scale is represented in figure 1, and the experts' opinions appear in table 2.

Table 1 Septenary scale used in computing

k	Semantics	Simbol	Level α_K	Step $\Delta\alpha_K$
1	Unsatisfactory	U	0	0
2	Almost unsatisfactory	AU	0,167	0,167
3	Little unsatisfactory	LS	0,333	0,167
4	Satisfactory	S	0,5	0,167
5	Good	G	0,667	0,167
6	Almost very good	AVG	0,833	0,167
7	Very good	VG	1	0,167

In this table, step $\Delta\alpha_K$ is constant:

$$\Delta\alpha_k = \alpha_k - \alpha_{k-1} \quad (1)$$

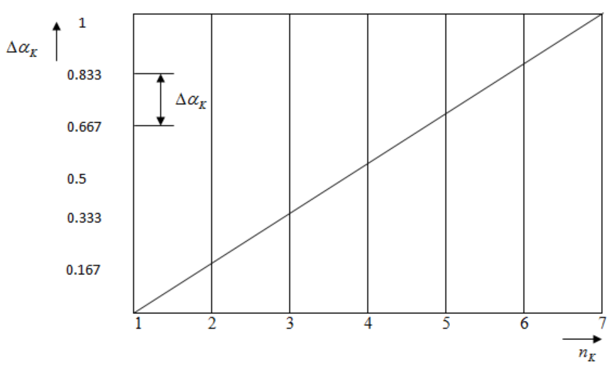


Fig. 1. Septenary scale

Table 2 Experts' opinions

E_i	E_1		E_2		E_3		E_4		E_5	
e_j	A_{1j}	I_{1j}	A_{1j}	I_{2j}	A_{3j}	I_{13}	A_{4j}	I_{4j}	A_{5j}	I_{5j}
e_1	G;AVG	0,667;0,833	AVG	0,833	G;AVG	0,667;0,833	AVG;VG	0,833; 1	G;AVG	0,667;0,833
e_2	VG	1	G; AVG	0,667;0,833	AVG; VG	0,833; 1	AVG	0,833	G; AVG	0,667;0,833
e_3	G	0,667	G; AVG	0,667;0,833	S	0,5	S;G	0,5; 0,667	G	0,667
e_4	G; AVG	0,667;0,833	AVG	0,833	VG	1	AVG	0,833	VG	1
$m(E_i)$	0,750;	0,833	0,750;	0,833	0,750;	0,833	0,750;	0,833	0,750;	0,833

In this table E_i is the entity i, $i=\overline{1;5}$; E_j - expert j, $j=\overline{1;4}$; $m(E_i)$- average of intervals $\left[a_{ij}^{\inf};a_{ij}^{\sup}\right]$;

$$m(E_i)=\frac{\sum_j a_{ij}^{\inf}}{4};\frac{\sum_j a_{ij}^{\sup}}{4} \qquad (2)$$

s being the number of experts $(s=5)$, and $a_{ij}^{\inf};a_{ij}^{\sup}$ lower/upper limit of intervals associated to assessments,

$$a_{ij}^{\inf} \le a_{ij}^{\sup} \qquad (3)$$

In case $a_{ij}^{\inf}, a_{ij}^{\sup}$, the value of the interval associated to these assessments will appear once in the middle of that line. Next, the concept "experton" will be used.

The experton represents a number of lines equal to the number of the steps of the scale and on each line the cumulated relative frequency is represented, under the form of an interval:

$$f_k^{rc}=\left[f_k^{rc,\inf};f_k^{rc,\sup}\right] \qquad (4)$$

where $f_k^{rc,\inf} \le f_k^{rc,\sup}$.

The defining value of an experton is the mathematical expectation **[4]**, also expressed under the form of an interval:

$$E(E_X(Z))=\left[E^{\inf}(E_X(Z)); E^{\sup}(E_X(Z))\right] \qquad (5)$$

$E(Z)$ being the experton of any entity Z. For example, let the intervals be associated to the assessments of the group of experts e_j, for entity E_1, represented in table 2.

e_j	A_{1j}	I_{1j}
e_1	G; AVG	0,667;0,833
e_2	VG	1
e_3	G	0,667
e_4	G; AVG	0,667;0,833
$m(E_i)$	0,750;	0,833

The experton $E_X(E_1)$ is built according the following phases, preceded by levels α_k (table 3):

Table 3 Edit construction mode an experton

k	α_k	f_k^a		f_k^{ac}		$E_X(E_1)$
1	0	0		4		1
2	0,167	0		4		1
3	0,333	0	→	4	→	1
4	0,5	0		4		1
5	0,667	3 1		4		1
6	0,883	0 2		1 3		0,25 0,75
7	1	1		1		0,25

- the absolute frequencies table is built, f_k^a, corresponding to the value of assessments of experts: 0,667 appears three times on the left and once on the right; value 0,833 appears twice only on the left side, and value 1 appears on both sides; for the other levels digit 0 is written;
- the cumulated absolute frequencies table is created, f_k^{ac}, summing up the frequencies f_k^{ac}, starting from bottom to top;
- the cumulated relative frequencies table is created, f_k^{rc}, according to the relation:

$$f_k^{rc}=\frac{f_k^{ac}}{s} \qquad (6)$$

s being the number of experts $(s=4)$.

The table of these cumulated relative frequencies represents the experton of the entity E_1: $E_X(E_1)$.

The mathematical expectation of this experton results from the relation:

$$E(E_X(E_1))=\left[E^{\inf}(E_X(E_1)); E^{\sup}(E_X(E_1))\right] \qquad (7)$$

where $E^{\inf}(E_X(E_1))=\frac{\sum_k f_k^{rc,\inf}}{n_k-1}$ (8)

$$E^{\sup}(E_X(E_1)) = \frac{\sum_k f_k^{rc,\sup}}{n_k - 1} \qquad (9)$$

n_k being the number of steps of the scale, and the summing operations do not include digit 1 as well, corresponding to level $\alpha = 0$.

The mathematical expectation is deduced:

$E^{\inf}(E_X(E_1)) = 1+1+1+1+0{,}25+0{,}25;$

$E^{\sup}(E_X(E_1)) = 1+1+1+1+0{,}75+0{,}25.$

$E(E_X(E_1)) = [0{,}75;0{,}833]$, value identical to the average $m(E_1)$.

Likewise the expertons for the other entities were created as well - table 4.

The mathematical expectations of the five expertons are equal to the averages of intervals associated to the experts' assessments. Always, in the case of linear scales, subsists to the relation:

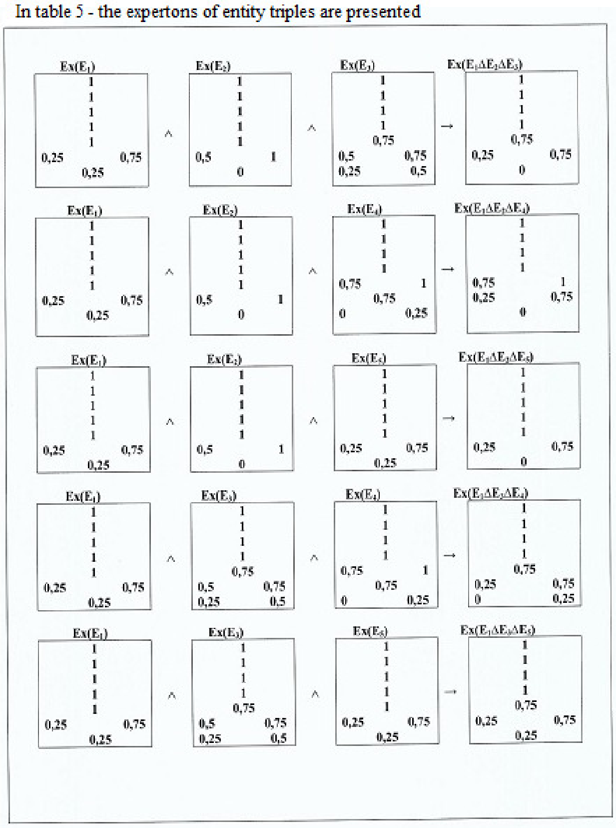
$$m(Z) = E(E_X(Z)), \qquad (10)$$

Z being any entity.

Table 4 give to the five entities the expertons

E_i	α_i	*	f_i^a	*	f_i^c	*	$E_X(E_i)$	*
E_1	0 0,167 0,333 0,5 0,667 0,833 1		0 0 0 0 3 1 0 2 1		4 4 4 4 4 1 3 1		1 1 1 1 1 0,25 0,75 0,25	
E_2	0 0,167 0,333 0,5 0,667 0,833 1		0 0 0 0 2 0 2 4 0		4 4 4 4 4 2 4 0		1 1 1 1 1 0,5 1 0	
E_3	0 0,167 0,333 0,5 0,667 0,833 1		0 0 0 1 1 0 1 1 2		4 4 4 4 3 2 3 1 2		1 1 1 1 0,75 0,5 0,75 0,25 0,5	
E_4	0 0,167 0,333 0,5 0,667 0,833 1		0 0 0 1 0 0 1 3 2 0 1		4 4 4 4 3 4 3 0 1		1 1 1 1 0,75 1 0,75 0 0,25	
E_5	0 0,167 0,333 0,5 0,667 0,833 1		0 0 0 0 3 1 0 2 1		4 4 4 4 4 1 3 1		1 1 1 1 1 0,25 0,75 0,25	

In table 5 - the expertons of entity triples are presented



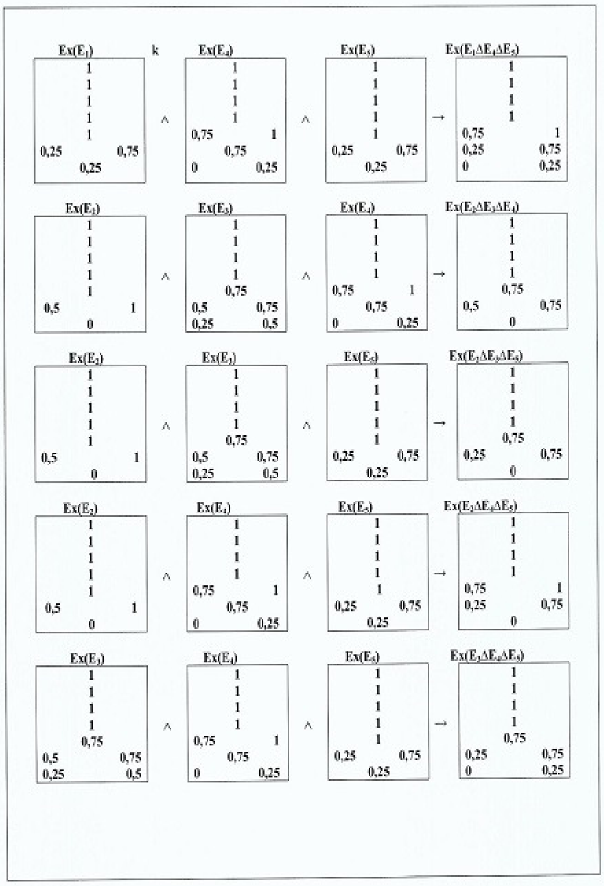


Table 6 Reproduces the mathematical expertations

l	Variant	Mathematical expectation	Average
1	$E(E_X(E_1\Delta E_2\Delta E_3))$	0,667; 0,750	0,708
2	$E(E_X(E_1\Delta E_2\Delta E_4))$	0,667; 0.792	0,730
3	$E(E_X(E_1\Delta E_2\Delta E_5))$	0,708; 0.792	0,750
4	$E(E_X(E_1\Delta E_3\Delta E_4))$	0,667: 0,792	0,730
5	$E(E_X(E_1\Delta E_3\Delta E_5))$	0,708; 0,792	0,750
6	$E(E_X(E_1\Delta E_4\Delta E_5))$	0,667; 0.833	0,750
7	$E(E_X(E_2\Delta E_3\Delta E_4))$	0,708; 0,750	0,730
8	$E(E_X(E_2\Delta E_3\Delta E_5))$	0,667; 0.750	0,708
9	$E(E_X(E_2\Delta E_4\Delta E_5))$	0,667; 0,792	0,730
10	$E(E_X(E_3\Delta E_4\Delta E_5))$	0,667; 0,792	0,730

In order to make a difference of the functional performances related to entities E_i fuzzy operations will be used: 1- logical conjunction; 2- logical disjunction [5], [6]:

$$1\text{-}\quad a_i \wedge b_i = \min(a_i \Delta b_i) \qquad (11)$$

where a_i, b_i are elements belonging to the lines of the same level α_i, for expertons $E_X(A)$ and $E_X(B)$, A, B being two any given entities; "$\wedge$" is the fuzzy logical operator "AND", and the result of the logical conjunction operation, in the case of the two entities, is defined by the minimum value between elements a_i, b_i.
Also, in the case of the fuzzy operation, the logical disjunction:

$$2\text{-} c_j \vee d_j = \max(c_j \nabla d_j) \qquad (12)$$

Elements c_j, d_j belong to the lines of level α_j, in the case of expertons $E_X(C)$ and $E_X(D)$; ∇ represents the logical fuzzy operator „OR", and the result of the logical disjunction is expressed by the maximum value between elements c_j, d_j.
Notations delta (Δ) and nabla (∇) are logical symbols and have meaning only to identify units that are subject to analysis.
In table 5 the expertons of entity triples are presented, and table 6 reproduces the mathematical expectations appropriate for the nominal rjegime ***"3 of 5".***
According to the averages of triples E_i entities, the following locations are obtained:
-triples $E(E_X(E_1\Delta E_2\Delta E_5))$, $E(E_X(E_1\Delta E_3\Delta E_5))$, $E(E_X(E_1\Delta E_4\Delta E_5))$, are on the first rank;
-triples $E(E_X(E_1\Delta E_2\Delta E_4))$, $E(E_X(E_1\Delta E_3\Delta E_4))$, $E(E_X(E_2\Delta E_3\Delta E_4))$, $E(E_X(E_2\Delta E_4\Delta E_5))$, $E(E_X(E_3\Delta E_4\Delta E_5))$ are on the second rank,
-triples $E(E_X(E_1\Delta E_2\Delta E_3))$ and $E(E_X(E_2\Delta E_3\Delta E_5))$ are the last, in each entity they fill the locations mentioned in table 7.

Table 7 Give the ranking entity triples considering the location

E_i	Ranks in the preferential sequence
E_1	3 ranks I, 2 ranks II, 1 rank III
E_2	1 rank I, 3 ranks II, 2 ranks III
E_3	1 rank I, 3 ranks II, 2 ranks III
E_4	1 rank I and 5 ranks II
E_5	1 rank I, 3 ranks II, 2 ranks III

The ranking of entities results: E_1, E_5 are on the first rank; E_4 is on the second rank; E_2, E_3 are on the third rank.
THE OPTIMAL DECISION: entities E_1, E_5, E_4 are kept operational and E_2 and E_3 are to be successively subject to some preventive inspections at the right times.
The performance function [7] of the five entity group results from the expression:

$$\begin{aligned}\phi(S) &= E(E_X(E_1\Delta E_2\Delta E_3)) \vee E(E_X(E_1\Delta E_2\Delta E_4)) \\ &\vee E(E_X(E_1\Delta E_2\Delta E_5)) \vee E(E_X(E_1\Delta E_3\Delta E_4)) \\ &\vee E(E_X(E_2\Delta E_3\Delta E_4)) \vee E(E_X(E_2\Delta E_3\Delta E_5)) \\ &\vee E(E_X(E_2\Delta E_4\Delta E_5)) \vee E(E_X(E_3\Delta E_4\Delta E_5)).\end{aligned}$$

It results:

$$\phi(S) = \max\left(E^{\inf}; E^{\sup}\right) \qquad (13)$$

where $\max E^{\inf}$ is the maximum value from the number of lower limits of mathematical expectations associated to the expertons triples; value $\max E_{\inf}$ is defined in a similar manner.
Therefore,

$$\max E^{\inf} = 0{,}708,$$

$$\max E^{\sup} = 0{,}833;$$

and the performance function of the system (group of entities) will be:

$$\phi(S) = [0{,}708; 0{,}833],$$

its average

$$m\phi(S) = 0{,}7705,$$

belonging in proportion of approximately 93% to the semantic level on a septenary linear scale, "ALMOST VERY GOOD" ($\alpha_{AFB} = 0{,}833$).

On the assumption that one of the two entities in reserve E_2 and E_3, the managerial factor decides to perform certain corrective interventions on a sufficiently limited period, upon entity E_2, for example; such a variant imposes the assessment of the operational state based on the following experton triples:
$E(E_X(E_1\Delta E_3\Delta E_4))$, $E(E_X(E_1\Delta E_3\Delta E_5))$, $E(E_X(E_1\Delta E_4\Delta E_5))$, $E(E_X(E_3\Delta E_4\Delta E_5))$, whose mathematical expectations are extracted from table 6:

$E(E_X(E_1\Delta E_3\Delta E_4))$=[0,667; 0,792]; m = 0,730;
$E(E_X(E_1\Delta E_3\Delta E_5))$=[0,708; 0,792], m = 0,750;
$E(E_X(E_1\Delta E_4\Delta E_5))$=[0,667; 0,833], m = 0,750;
$E(E_X(E_3\Delta E_4\Delta E_5))$=[0,667; 0,792], m = 0,730.

The performance function will be:

$\phi(S)_{3/4} = [0{,}708;0{,}833]$, with the average value,

$$m\phi(S) = 0{,}7705,$$

therefore, these last two sizes maintain at the same values. Identical results are also obtained in case entity E_3 becomes unavailable, the reserve being accomplished in this case by entity E_2.

Accepting a value of reliability of any entity, $R_i = 0{,}9$, the reliability of the system in the variant of the operational regime can be deduced:

$R(S)_{3/5} = R^5 + 5R^4(1-R) + 10R^3(1-R)^2$ or

$R(S)_{3/5} = 6R^5 - 15R^4 + 10R^3$

It results

$$R(S)_{3/5} = 0{,}99114,$$

and in the variant of the operating mode with a single entity in reserve, the reliability of the system becomes of type ***"n from n+1"***:

$$R(S)_{3/4} = (n+1)R^n - nR^{n+1} \quad (14)$$

or $R(S)_{3/4} = 5R^4 - 4R^5$.

For $R_i = 0{,}9$ it is obtained: $R(S)_{3/4} = 0{,}9427$, which means a reduction of reliability with approximately 4.5%, comparatively to the previous case.

3. CONCLUSIONS

The successive identification of those means of local transportation, on which the profile unit decides the carrying out of certain possible maintenance operations, constitutes a beneficial solution for the improvement of the operational potential of the system (a sensitive increase in the availability of the group of equipment subject to analysis).

The nominal regime of exploit is affected in proportion of approximately 5% - in the analysed case – during this period – sufficiently covering – where eventual maintenance actions appear.

Based on the statistical conclusions, resulted in the case of carrying such analysis, the beneficiary may prepare a framework - program focused on planning the periodical interventions for the entire batch of similar equipment, being owned by that unit.

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