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Integrating Fuzzy Dematel and SMAA-2 for Maintenance Expenses

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Abstract: *The majority of the allowances being transferred to public institutions are mostly spent for buying new equipment, materials, facilities and their maintenance and repair. Some of the public sectors establish their own plants in order to reduce the maintenance and repair costs and gain ability to perform these activities. However, developing technology and variety of materials make their repair and maintenance activities more expensive for them. In this study, vital criteria for a public institution are determined. By using Fuzzy DEMATEL (Decision Making Trial And Evaluation Laboratory) method the degree of importance is identified by two defuzzification methods and the alternatives are ranked by using SMAA-2 (Stochastic Multi Criteria Acceptability Analysis) in three scenarios. The results show that different defuzzification methods change the order of preferences.*

Keywords: *Fuzzy DEMATEL, Maintenance, SMAA-2*

I. Introduct on

When taking into consideration of the materials owned by public institutions and organizations, it is seemed that allowances transferred for maintenance. In addition to allowances by public institutions establish plants to reduce the maintenance and repair costs. It will be more important for both public institutions and non-profit organizations to use their earning or allowances to activites in terms of services they will provide. Maintenance and repair activities are “costs” for the organizations. For the savings and not to waste the allowance of the state funds, they have to minimize their costs.

By using the data of a public institution, the vital criteria and three alternative spending types that can be used for the maintenance and repair expenses are evaluated. Firstly the criteria that the public institution focused on are determined. By using Fuzzy DEMATEL (Decision Making Trial And Evaluation Laboratory) the degree of importance for criteria are identified and by using SMAA-2 (Stochastic Multicriteria Acceptability Analysis) which is one of the MCDM methods, the alternatives are ranked.

Many times decision makers want to express themselves by using linguistic terms. The main purpose of DEMATEL method is to identify the dependence levels between criteria SMAA-2 method can be used in many real life problems when the information is inaccurate, lost or incomplete. Because of these three reasons, Fuzzy DEMATEL and SMAA-2 Methods are used to solve the problem. In this study, the question of "Which expenditure method may be convenient for different cases" is sought. The difference from the other research works is using both the DEMATEL and SMAA-2 methods for the first time in reducing maintenance costs.

The rest of the paper is organized as follows: Definition of the maintenance and literature review related to maintenance is presented in Section 2. Section 3 gives information on fuzzy DEMATEL and defuzzification methods. SMAA-2 method is described in Section 4. An application based on the real data of an institution is presented in Section 5. Finally, conclusions are discussed in Section 6.

II. Maıntenance

Includes all the planned or unplanned activities to increase the operation of the set up system to an acceptable level or to keep it on such a level in any production or service facilities. Maintenance is typically can be described as "to save the good situation of all beings and objects and to fulfill all the activities to ensure the continuation of the situation". Maintenance is the activity to keep the whole production system or a specific equipment active in terms of the machinery, equipment and production systems. It may also be described as the continuance of the reliability of the safety with the maintenance function repairs, modifications, and transactions with a new exchange if necessary.

There are many studies including maintenance and maintenance planning topics by using both multicriteria decision making methods and mathematical modelling [1-21].

III. Fuzzy Dematel

The method of DEMATEL was developed by the Battelle Memorial Institute of Geneva, Science and the Human Relations between 1972 and 1976. DEMATEL, which is based on the graph theory, was developed to contribute of the identification of the applicable solutions especially for the hierarchical structures and for the complex and intertwined problem groups [23].

The main advantage of the DEMATEL method is determining the structure and relationship between criteria and includes cause-effect model [24].

DEMATEL is a method used for the identification of affected and affecting criteria that have a complex structure. This method basically helps to identify the cause and effect relations and interpret the identified values by visualizing them. However, one may not be able to get clear information from the decision makers / experts or they may not be able to express what they think using numerical scales during the identification of these relations. To overcome this challenge, responses via linguistic expressions may be desired. Fuzzy DEMATEL is a widely used method which facilitates linguistic expressions.

DEMATEL and Fuzzy DEMATEL Methods are used in many studies in the literature [25-42].

Fuzzy logic is based on the neighborhood of numbers. The membership function is formed between 0 and 1 and expressed by $\mu_A(x)$. The triangular membership function is defined with the help of three parameters, $y_1; y_2$ *and* y_3 shown equations (3.1)

$$\mu_A \begin{cases} \frac{x-y_1}{y_2-y_1}, & y_1 \le x \le y_2 \\ \frac{y_3-x}{y_3-y_2}, & y_2 \le x \le y_3 \\ 0, & x > y_3 \ or \ x < y_1 \end{cases} \qquad (3.1)$$

The Phases of Fuzzy DEMATEL are as follows:

Phase 1: Identification of the Criteria and the Fuzzy Scale:

Depending on the type of the problem the criteria may be identified with the use of questionnaires or face-to-face conversations with experts or by referring to the literature.

The fuzzy scale may be triangular, trapezoidal or other fuzzy numbers produced. In this study, triangular fuzzy numbers, which are the most frequently preferred in the literature, are selected and shown in Table-1 [25].

Linguistic Terms	*Influence Score*	*Fuzzy Values*
No influence	*0*	*(0,0,0.25)*
Very Low influence	*1*	*(0,0.25,0.50)*
Low influence	*2*	*(0.25,0.50,0.75)*
High influence	*3*	*(0.50,0.75,1)*
Very high influence	*4*	*(0.75,1,1)*

Table-1: Triangular Fuzzy Numbers

Phase 2: Formation of the Fuzzy Direct Relation Matrix:

The decision makers or experts are asked to make pairwise comparisons in order to understand the degrees of relations between the criteria. The decision makers are asked to express their opinion about the direct influence between any two ctiteria by an integer score ranging from 0, 1, 2, 3 and 4. The fuzzy direct relation matrix is not symmetrical and its diagonal elements are 0.

Phase 3: Formation of the Normalized Fuzzy Direct Relation Matrix:

The normalized Fuzzy Direct Relation Matrix is formed by using equations (3.2) and (3.3). Here l_{ij} is the first and the smallest of the triangular fuzzy numbers; m_{ij} is the middle value; and u_{ij} is the largest value.

$$x_{ij} = \left(\frac{C}{r}\right) = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \qquad (3.2)$$

$$r = max_{1 \le i \le n}\left(\sum_{j=1}^{n} l_{ij}\right) \ ; \ r = max_{1 \le i \le n}\left(\sum_{j=1}^{n} m_{ij}\right) \ ; \ r = max_{1 \le i \le n}\left(\sum_{j=1}^{n} u_{ij}\right) \qquad (3.3)$$

Phase 4: Formation of the Fuzzy Total Relation Matrix:

The Fuzzy Total Relation Matrix is formed by using equations (3.4). "I" expresses the identity matrix, and the C express the decreasing indirect effects.

$$lim_{H \to \infty} c + c^2 + c^3 + \cdots \ldots c^H \rightarrow F = C + C^2 + C^3 + \cdots + C^H \rightarrow F = C * (I - C)^{-1} \ (3.4)$$

Phase 5: Defuzzification:

The defuzzification is performed by using an appropriate defuzzification method. Two different defuzzification methods are used to execute for the solution of the problem. The first preferred method is the α-cut method. The operation is as follows.
The optimism degree (index) of the decision maker; λ ; is $0 \leq \alpha \leq 1$. As λ increases it means decision maker is an optimistic and as it decreases a pessimistic one.

Phase 5: Step 1: Identification of lower and upper bound priority values
When fuzzy priority values are taken as (l, m, u) for the k.th alternative, the lower and upper boundary priority values can be found by using the equations (3.5) and (3.6).

Lower Bound (LB) = $\alpha * (m - l) + l$ *(3.5)*
Upper Bound (UB) = $r * (m - l) + l$ *(3.6)*

Phase 5: Step 2: The determined lower and upper bound priority values are merged by using the equations below.
W_{kL}: Lower bound priority value for the k.th alternative
W_{kU} : Upper bound priority value for the k.th alternative

$$W_{kL} = \frac{\sum_{l=1}^{L}(\alpha_l)*(LB_k)_l}{\sum_{l=1}^{L}(\alpha_l)} \quad (3.7)$$

$$W_{kU} = \frac{\sum_{l=1}^{L}(\alpha_l)*(UB_k)_l}{\sum_{l=1}^{L}(\alpha_l)} \quad (3.8)$$

Phase 5: Step 3: Finding defuzzified values.

$$W_d = \lambda * W_{kU} + (1 - \lambda) * W_{kL} \quad (3.9)$$

The second preferred method is the CFCS method. It is a four-step algorithm expressed below [43].

Phase 5: Step 1: Normalization:

$$xl_{ij}^k = (l_{ij}^k - minl_{ij}^k)/\Delta_{min}^{max} \quad (3.10)$$

$$xm_{ij}^k = (m_{ij}^k - minl_{ij}^k)/\Delta_{min}^{max} \quad (3.11)$$

$$xr_{ij}^k = (r_{ij}^k - minl_{ij}^k)/\Delta_{min}^{max} \quad (3.12)$$

$$\Delta_{min}^{max} = maxr_{ij}^k - minl_{ij}^k \quad (3.13)$$

Phase 5: Step 2: Calculating left (ls) and right (rs) normalized values:

$$xls_{ij}^k = xm_{ij}^k/(1 + xm_{ij}^k - xl_{ij}^k) \quad (3.14)$$

$$xrs_{ij}^k = xr_{ij}^k/(1 + xr_{ij}^k - xm_{ij}^k) \quad (3.15)$$

Phase 5: Step 3: Finding the Total Normalized Value:

$$x_{ij}^k = \frac{[xls_{ij}^k\left(1 - xls_{ij}^k\right) + xrs_{ij}^k * xrs_{ij}^k}{[1 - xls_{ij}^k + xrs_{ij}^k]} \quad (3.16)$$

Phase 5: Step 4: Finding defuzzified values:

$$z_{ij}^k = minl_{ij}^k) + x_{ij}^k \Delta_{min}^{max} \quad (3.17)$$

Phase 6: Identifying Causer and Receiver Groups:
The sum of the ith row of the Fuzzy Total Relation Matrix Di ; shows the sum of the direct and indirect effects send by criterion i to the other criteria. The sum of the column Ri shows the sum of the effects coming from the other criteria to the criterion. The (Di+Ri) index, determined by the sums of the row and column for each

criterion shows the total sent and received value; and the (Di-Ri) value shows the total net effect that the i factor has on the system. If this value is positive it shows that i criterion is a "Net Causer" and when it is negative it means it is a "Net Receiver". The (Di+Ri) value shows the degree of criterion i within the total system Di is the sent effects; Ri is the received effects; (Di+Ri) is the degree of central role and (Di-Ri) is the degree of effect [38].

Phase 7: Identifying Criterion Weights:
Determined by using equation (3.18) and equation (3.19) (Organ, 2013).

$$w_i = \sqrt{[(D_i + R_i)]^2 + [(D_i + R_i)]^2} \quad (3.18)$$

$$w_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (3.19)$$

Finding the threshold value is important in terms of identifying the striking values with higher priority within the Total Relation Matrix. Every element in the Total Relation Matrix represents the effect sent by the i th criterion to the j th criterion in this matrix. If all values in the matrix are taken into account, the possibility of diverging from the goal in the degrees of effect between the criteria that are intended to find the priority of in the problem increases. Likewise, it makes the effect diagram become complicated [44].
The threshold value can be determined by the decision makers or experts, and also by calculating the mean of the Total Relation Matrix. The effect diagram is obtained by showing the points (D+R,D-R) in a coordinate zone with a horizontal axis of D+R and a vertical axis of D-R.

IV. SMAA-2

SMAA (Stochastic Multi Criteria Acceptability Analysis); is a multi-criteria decision support method that can be used when the information is inaccurate, lost or incomplete. The information of problem is uncertain or inaccurate in many real life problems. And sometimes there are incomplete opinions about the topic within the acquired information. At this point, SMAA is a method that can be used as a support instrument.
The main goal of this method is to bring the preferences of the decision makers and the criteria together in order to evaluate the alternatives in the decision model and the main results of the analysis the rank acceptability indices, confidence factors and central weight vectors. Confidence factors define the possibility of an alternative being an acceptable one compared to another alternative; and the central weight vectors define the expected center of weight [45].
With the SMAA method one can execute the operations of sorting, determining the best, the value/utility function and categorizing. The SMAA method simulates uncertain parameters with varying values to identify which alternative is preferred the most.
SMAA Methods are used in many studies in the literature [46-70]. Like multi-criteria decision problems, in SMAA methods the m alternative set $\{x_1, x_2, x_{3,} \ldots\ldots \; x_m\}$ is evaluated with an n number of criteria [49].

Utility Function:

$$u_{ij} = u_j(g_{ij})$$

$$u(x_i, w) = \sum_{j=1}^{n} w_j \, u_{ij}$$

Criterion weights (w) are positive and normalized. Inaccurate and ambiguous criterion values are expressed with the $f(\xi)$ compound probability distributed density function in X space, and the stochastic variable ξ_{ij} [49].
The rank function is defined as follows, with each alternative with a best rank of (=1) and worst (=m).

$$rank\ (i, \xi, w) = 1 + \sum_{k \neq i} \rho(u(\xi_k, w) > u(\xi_i, w)) \qquad \rho(true) = 0 \text{ and } \rho(false) = 1$$

Rank Acceptability Index is calculated by multi-dimensional integrals as follows:

$$b_i^r = \int_{\xi \epsilon x} f_x(\xi) \int_{w \epsilon W_i^r(\xi)} f_w(w) dw d\xi$$

The central weight vector w_i^c is defined as the expected center of weight of the appropriate weight set. Central weight vector defines the assumed preference model and the preferences of the decision makers that supports this alternative [49].

$$w_i^c = \int_x f(\xi) \int_{W_{i(\xi)}} f(w) w dw d\xi / a_i$$

The confidence factor, p_i^c, defines the probability of an alternative being the preferred alternative in the case that the central weight vector is selected. Safety factors measure if the criterion measurements are sufficiently correct in distinguishing the efficient alternatives [49].

$$p_i^c = \int_{\xi: u(\xi_i, w_i^c) \geq (\xi_k, w_i^c)} f(\xi) d\xi$$

SMAA is based on inverse weight space analysis using Monte Carlo Simulation. Since simulation is used, SMAA methods cannot be calculated manually in practice. Thus a JSMAA software is presented [68]. In this study JSMAA is used for calculations.

V. Applıcatıon

The alternatives and criteria are determined by literature review and expert views who have worked in institution's maintenance organization.

5.1 Criteria

The six prominent criteria and their explanations are below.

K-1 Costs:

This criterion includes the costs of the facility, equipment, staff, materials, labor, executive expenses, storage/stock expenses, maintenance expenses, transportation, waste and waste expenses, labor and spare parts.

Staff and facility expenses are always constant for the public organization. Because there will exist building and facility expenses whether or not there is any work done in the plants and the personnel will receive their salaries.

K-2 Time:

This is the time that has passed from the beginning of the fault and until the end of it. It includes labor activities, the time for obtaining the spare part and the transportation of the malfunctioning unit.

For example; the time for labor activities for a service vehicle fault if the spare part is available is different than the time needed for obtaining the spare part when it is not available.

K-3 Security:

The expenses for obtaining spare parts and labor should be carried out without revealing the current fault percentage or the statistical information of the organization. Thus this criterion is taken into account. The revealing of such kind of information can be unfavorable in the long run since it exposes both the current inventory and lack of capabilities.

K-4 Acquirement of Capabilities:

Every activity done in institution's plant helps the technical staff to increase and enhance their capabilities. When the same fault or a similar one reoccurs, there is no cost of labor if the capability is acquired.

K-5 Priority:

This is the order of maintenance and repair in light of the current objective of the organization and technical details. Operational reasons are other factors that effect priority.

K-6 Sense of Liability of the Maintenance/Repair Staff:

The staff of the organization have to improve themselves. Hence this criterion must also be taken into consideration for a unit that will be repaired in the market.

5.2 Alternatives

The maintenance and repair activities are generally done in three ways.

A-1 Repairing the Malfunctioning Unit by Service Procurement for the Market:

This is the act of repairing the unit which is not prohibited and out of warranty in market with the approval of the spending authority as long as there is appropriation.

This is the fastest in terms of time. The operation is carried out by authorized companies under warranty. It decreases acquirement of capability.

A-2 Obtaining the Spare Part from the Local Market and Repairing the Malfunctioning Unit in Institution's Own Plants.

This is the act of repairing the unit obtaining the spare parts from local market with the approval of the spending authority as long as there is appropriation The time is longer than the first alternative. Acquirement of capability is high. Since there will be no labor expenses, the cost is less than the first alternative. It is important that the obtained spare part is under warranty.

A-3 Waiting the Tendering Process and Repairing the Malfunctioning Unit in Institution's Own Plants.

The technicians ask for the spare part from their own accounting when repairment activity starts. If the part is present than repairment activity immediately starts. If they do not have from their own accounting, accountcany has this demand as a loan. Accountcany will call for tenders with the other spare part loans. This demand will be paid when tendering process finishes. This is the longest in terms of time but has the least cost and is also the safest.

9 volunteer experts in their fields who have participated in repairing organizations were asked to carry out pairwise comparison regarding the effect of the criteria. 9 separate linguistic evaluations were converted into fuzzy numbers. One of the experts opinion is presented in Table-2.

	K1	K2	K3	K4	K5	K6
K1	0	2	1	2	4	4
K2	2	0	1	3	3	4
K3	1	3	0	1	1	1
K4	2	2	1	0	3	4
K5	4	4	1	4	0	4
K6	4	4	2	4	3	0

Table-2: Expert-1 Pairwise Comparison

After the expert opinions were obtained, the pairwise comparison matrix were summed and divided by the number of experts and had formed the fuzzy direct relation matrix. Eq.(1) and Eq. (2) were used and the Normalized Fuzzy Direct Relation Matrix is obtained, shown in Table 3.

	K1			K2			K3			K4			K5			K6		
K1	0,00	0,00	0,00	0,20	0,20	0,19	0,03	0,06	0,11	0,13	0,15	0,18	0,19	0,20	0,07	0,17	0,18	0,18
K2	0,17	0,18	0,18	0,00	0,00	0,00	0,11	0,14	0,16	0,23	0,23	0,22	0,11	0,14	0,05	0,25	0,24	0,21
K3	0,09	0,12	0,15	0,15	0,17	0,18	0,00	0,00	0,00	0,08	0,12	0,15	0,03	0,08	0,04	0,05	0,08	0,13
K4	0,19	0,20	0,21	0,20	0,21	0,21	0,04	0,08	0,13	0,00	0,00	0,00	0,23	0,23	0,08	0,08	0,12	0,15
K5	0,18	0,18	0,18	0,19	0,18	0,19	0,03	0,07	0,11	0,23	0,23	0,22	0,00	0,00	0,00	0,17	0,18	0,18
K6	0,15	0,18	0,18	0,25	0,24	0,22	0,08	0,10	0,14	0,10	0,14	0,16	0,14	0,17	0,06	0,00	0,00	0,00

Table-3: Normalized Fuzzy Direct Relation Matrix

By using Eq.(3) the Fuzzy Total Relation Matrix is obtained and presented in Table-4.

	K1			K2			K3			K4			K5			K6		
K1	0,40	0,64	0,48	0,65	0,90	0,68	0,18	0,42	0,46	0,52	0,79	0,64	0,54	0,79	0,24	0,53	0,78	0,61
K2	0,59	0,87	0,68	0,55	0,82	0,58	0,28	0,53	0,54	0,64	0,92	0,72	0,53	0,83	0,25	0,64	0,90	0,68
K3	0,30	0,57	0,56	0,40	0,67	0,63	0,09	0,26	0,33	0,29	0,57	0,57	0,23	0,52	0,20	0,27	0,53	0,52
K4	0,57	0,84	0,68	0,66	0,93	0,72	0,19	0,45	0,49	0,42	0,69	0,51	0,58	0,84	0,25	0,47	0,76	0,60
K5	0,58	0,84	0,72	0,68	0,93	0,78	0,20	0,45	0,53	0,62	0,88	0,77	0,41	0,67	0,21	0,56	0,82	0,69
K6	0,52	0,81	0,66	0,69	0,95	0,73	0,23	0,47	0,50	0,49	0,80	0,65	0,49	0,79	0,24	0,39	0,65	0,48

Table-4: Fuzzy Total Relation Matrix

Using the first defuzzification method (The α-cut method), with the help of equations (4)-(8), defuzzified total relation matrix are presented in Tables 5, 6 and 7 according to the degrees of optimism (1), (0.5) and (0). (The cut value is taken as 0.7; 0,8 and 0,9.)

	K1	K2	K3	K4	K5	K6
K1	0,612	0,854	0,426	0,757	0,686	0,743
K2	0,836	0,775	0,533	0,879	0,716	0,853
K3	0,565	0,658	0,275	0,573	0,457	0,525
K4	0,809	0,892	0,461	0,652	0,728	0,730
K5	0,816	0,899	0,462	0,856	0,578	0,791
K6	0,784	0,908	0,473	0,773	0,683	0,615

Table-5 Optimism Degree (1) Defuzzified Total Relation Matrix

	K1	K2	K3	K4	K5	K6
K1	0,604	0,851	0,400	0,745	0,715	0,736
K2	0,827	0,773	0,507	0,870	0,743	0,850
K3	0,540	0,636	0,252	0,546	0,461	0,501
K4	0,799	0,887	0,432	0,643	0,759	0,718
K5	0,802	0,890	0,430	0,842	0,597	0,779
K6	0,771	0,904	0,447	0,757	0,706	0,607

Table-6 Optimism Degree (0,5) Defuzzified Total Relation Matrix

	K1	K2	K3	K4	K5	K6
K1	0,596	0,848	0,373	0,733	0,743	0,729
K2	0,819	0,770	0,482	0,862	0,771	0,847
K3	0,515	0,614	0,229	0,519	0,464	0,477
K4	0,789	0,881	0,404	0,634	0,790	0,706
K5	0,789	0,880	0,397	0,828	0,617	0,766
K6	0,758	0,899	0,420	0,742	0,730	0,599

Table-7 Optimism Degree (0) Defuzzified Total Relation Matrix

Equations (9)-(16) were used for the second defuzzification method CFCS and the defuzzified total relation matrix is presented in Table-8.

	K1	K2	K3	K4	K5	K6
K1	0,563	0,917	0,380	0,743	0,785	0,735
K2	0,868	0,801	0,479	0,935	0,984	0,919
K3	0,509	0,608	0,250	0,514	0,358	0,470
K4	0,821	0,973	0,409	0,610	1,096	0,707
K5	0,814	0,944	0,414	0,864	0,472	0,785
K6	0,778	1,004	0,424	0,756	0,750	0,565

Table-8 Defuzzified Total Relation Matrix by the CFCS Method

The Causer and Receiver Groups are calculated and presented in Table-9.

1,0		0,5		0,0		CFCS	
D+R	D-R	D+R	D-R	D+R	D-R	D+R	D-R
8,499	-0,343	8,393	-0,293	8,287	-0,242	8,476	-0,229
9,579	-0,394	9,510	-0,368	9,442	-0,342	10,23	-0,259
5,682	0,423	5,403	0,467	5,124	0,511	5,064	0,351
8,761	-0,216	8,642	-0,165	8,522	-0,113	9,038	0,194
8,250	0,554	8,321	0,358	8,391	0,162	8,736	-0,153
8,495	-0,023	8,383	0,001	8,271	0,025	8,459	0,097

Table-9 D+R ve D-R Values

While the D values are the sum of the rows of the defuzzified total relation matrix, R values are the sum of the columns of the same matrix. When we consider D+R values, according to the degree of optimism (1) Criterion 2, Criterion 4 and Criterion 1 are more important than the other criteria with the values of 9,579; 8,761 and 8,499, respectively. When we consider the degree of optimism (0,5) Criterion 2, Criterion 4 and Criterion 1 have more importance in comparison with the values of 9,510; 8,642 and 8,393, respectively. When we consider the degree of optimism (0) Criterion 2, Criterion 4 and Criterion 5 have more importance in comparison with the values of 9,442; 8,522 and 8,391, respectively.

The negative D-R values indicate the affected criteria and positive values indicate the affecting criteria.

When the degree of optimism is 1 Criterion 1 with the value of -0,343; Criterion 2 with the value of -0,394; Criterion 4 with the value of -0,216, Criterion 6 with the value of -0,023 constitute the affected group (Receiver); Criterion 3 with the value of 0,423 and Criterion 5 with the value of 0,554 constitute the affecting group (Causer). When the degree of optimism is 0,5; Criterion 1 with the value of -0,293; Criterion 2 with the value of -0,368; Criterion 4 with the value of -0,165, constitute the affected group (Receiver); Criterion 3 with the value of 0,467; Criterion 5 with the value of 0,358; and Criterion 6 with the value of 0,001 constitute the affecting group (Causer). When the degree of optimism is 0; Criterion 1 with the value of -0,242; Criterion 2 with the value of -0,342; Criterion 4 with the value of -0,113, constitute the affected group (Receiver); Criterion 3 with the value of 0,511; Criterion 5 with the value of 0,162; and Criterion 6 with the value of 0,025 constitute the affecting group (Causer).

If the values are examined according to the CFCS defuzzification method Criterion 2, Criterion 4 and Criterion 5 have more importance in comparison with the values of 10,234; 9,038 and 8,736, respectively. Criterion 2 with the value of -0,259; Criterion 1 with the value of -0,229; Criterion 5 with the value of -0,153, constitute the affected group (Receiver); Criterion 3 with the value of 0,351; Criterion 4 with the value of 0,194; and Criterion 6 with the value of 0,097 constitute the affecting group (Causer).

The degrees of importance by using equations (18) and (19) are presented in Table-10.

	Degree of Optimism			CFCS
	1	0.5	0	
C1	0,17248	0,17247	0,17245	0,1695
C2	0,19439	0,19546	0,19653	0,2046
C3	0,11552	0,11137	0,10711	0,1015
C4	0,17769	0,17750	0,17729	0,1807
C5	0,16765	0,17103	0,17458	0,1746
C6	0,17226	0,17216	0,17204	0,1691

Table-10 The Degree of Importance

When the degree of optimism is (1) and (0,5) the order of the criteria with respect to the degree of importance is K2>K4>K1>K6>K5>K3; when the degree of optimism is (0) the order of the criteria with respect to the degree of importance is K2>K4>K5>K1>K6>K3.
After the defuzzification by the CFCS Method; the order of importance for the criteria is: K2>K4>K5>K1>K6>K3.
When we calculate the means of the total relation matrix for the degree of optimism (1) the threshold value is: 0,684; for the degree of optimism (0.5) the threshold value is: 0,676; for the degree of optimism (0) the threshold value is: 0,667. And according to the defuzzied total relation matrix by the CFCS Method the threshold value is 0,695.
By determining the threshold value, one can operate ignoring the complicated view in the effect diagram and effects that are below the determined value. Any values below this value are neglected. As for the effect diagram, the x-axis represents the D+R value; and the y-axis represents the D-R value.
For the SMAA-2 method, the open source JSMAA version 1.0.2 software, which provides great ease of use, is used. The rank of the criteria is identified by the fuzzy DEMATEL method. In preferences section of the software; three types of Preference information can be used as an input. In this study; Ordinal and Missing Preferance Types are used. Ordinal inputs are received from the fuzzy DEMATEL results. The rank of criteria is used as an Ordinal Preferance in JSMAA.
The inputs are for Scenario 1 is presented in Table-11

Alternatives	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Criterion 6**
	Costs ($)	Time (hour)	Security (1-3)	Acquirement of Capabilities (1-2)	Priority (1-3)	Sense of Liability of the Maintenance/Repair Staff (1-2)
A1	1000	2-8	1	1-2	1	1
A2	750	2-24	1-2	2	2	2
A3	0	1-720	3	2	2-3	2
	Δ ± %10					

Table-11 Scenario 1 Inputs

The cost criterion is identified by obtaining labor and spare part prices from authorized services of a company that provides maintenance and repair support to the institute. This condition may change depending on the situation of the industry and transportation in the region of the institute and the varying workmanship prices of companies.
The time criterion is identified using the work-time limits of the same company and the work-time limits determined in the plants of the institute.
The values of the other criteria were allocated as 1-3. A staff member currently working on maintenance and repair was asked to evaluate them.
1 represents the worst case; while 2 represents the mediocre; and 3 represents the best.
The rank of criteria obtained using DEMATEL method are entered in the Preferences section in JSMAA. When the degree of optimism is (1) and (0,5) the order is K2>K4>K1>K6>K5>K3; when the degree of optimism is (0), that is pessimistic and defuzificaition is made by CFCS the order is K2>K4>K5>K1>K6>K3.
The inputs of Scenario 2 and Scenrio 3 are presented in Table-12 and Table-13. In Scenario-3 the cost criterion has last importance degree.

Alternatives	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6
	Costs ($)	Time (hour)	Security (1-3)	Acquirement of Capabilities (1-2)	Priority (1-3)	Sense of Liability of the Maintenance/Repair Staff (1-2)
A1	1000	2-4	1-2	1	3	1
A2	750	2-8	1-2	2	2	2
A3	0	1-72	3	2	1	2
	Δ ± %10					

Table-12 Scenario 2 Inputs

Alternatives	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6
	Costs ($)	Time (hour)	Security (1-3)	Acquirement of Capabilities (1-2)	Priority (1-3)	Sense of Liability of the Maintenance/Repair Staff (1-2)
A1	1000	2-4	1-2	1	1	1
A2	750	2-8	1-2	2	2	2
A3	0	1-72	3	2	2-3	2
	□ ± **%10**					

Table-13 Scenario 3 Inputs

Results are presented in Table-14. When analyzed Scenario 1, Alternative 2 will be preferred in the 1st place because of the rank acceptability indices. In optimism degree (1) and (0,5) column; rank acceptability indice is 0,60 and confidence factor is 0,70. It means that the rate of the reliability for the possibility that the alternative 2 will be in the first preference for the decision maker is 70%. In optimism degree (0) and CFCS defuzzification method column; rank acceptability indice is 0,63 and confidence factor is 0,72. It means that the rate of the reliability for the possibility that the alternative 2 will be in the first preference for the decision maker is 72 %. In missing preference the result changes. Rank acceptability indice is 0,88 and confidence factor is 1,00 for the Alternative 3. It means that the rate of the reliability for the possibility that the alternative 3 will be in the first preference for the decision maker is 100 %.

Table-14 Results

lternatives		Scenario 1						Scenario 2						Scenario 3			
		Ordinal				Missing		Ordinal				Missing		Ordinal		Missing	
		Opt. Degree 1 ve 0,5		Opt. Degree 0 ve CFCS				Opt. Degree 1 ve 0,5		Opt. Degree 0 ve CFCS							
		Conf. F.	Rank Accept. Indices	Conf. F.	Rank Accept. Indices	Conf. F.	Rank Accept. Indices	Conf. F..	Rank Accept. Indices	Conf. F.	Rank Accept. Indices	Conf. F..	Rank Accept. Indices	Conf. F.	Rank Accept. Indices	Conf. F..	Rank Accept. Indices
A-1	Rank 1	1,00	0,00	1,00	0,00	1,00	0,00	0,28	0,00	0,36	0,00	1,00	0,06	0,11	0,00	0,03	0,00
	Rank 2	-	0,13	-	0,14	-	0,02	-	0,10	-	0,33	-	0,10	-	0,07	-	0,11
	Rank 3		0,87		0,86		0,98		0,90		0,67		0,83		0,93		0,89
A-2	Rank 1	0,70	0,60	0,72	0,63	0,59	0,12	0,75	0,70	0,94	0,91	0,87	0,29	0,52	0,37	0,56	0,02
	Rank 2	-	0,40	-	0,37	-	0,88	-	0,30	-	0,09	-	0,67	-	0,63	-	0,88
	Rank 3		0,00		0,00		0,00		0,00		0,00		0,04		0,00		0,10
A-3	Rank 1	0,44	0,40	0,42	0,37	1,00	0,88	0,32	0,30	0,14	0,09	1,00	0,64	0,66	0,63	1,00	0,98
	Rank 2	-	0,47	-	0,49	-	0,11	-	0,60	-	0,58	-	0,23	-	0,30	-	0,00
	Rank 3		0,13		0,14		0,02		0,10		0,33		0,13		0,07		0,01
Results		A2>A3>A1				A3>A2>A1		A2>A3>A1				A3>A2>A1					

The central weight vectors are given for the Scenario 1 for the optimism degree (1) and (0,5) in Table-15. NA means "Not Applicable". Alternative 1 will not be the first preference as it mentioned in Table-15 (Rank acceptability indice: 0,00). The central weight vectors defines the assumed preference model and the preferences of the decision makers that supports this alternative. For example in Table-15; "Time" criterion affects the second alternative 43 % being preferred in the first rank. And affects Alternative 3 36 % being preferred in the first rank.

Alternatives	Costs	Time	Security	Acquirement of Capabilities	Priority	Sense of Liability of the Maintenance/Repair Staff
A1	NA	NA	NA	NA	NA	NA
A2	0,15	0,43	0,02	0,24	0,06	0,10
A3	0,17	0,36	0,03	0,24	0,07	0,11

Table-15 Scenario 1 Central Weight Vectors for Optimism Degree (1) and (0.5)

VI. Conclus□on

The maintenance and repair costs are a substantial subject of research in the aspects of high cost, time and planning of work force. Especially for non-profit organizations and state institutions, these costs reach high amounts. In state institutions, it is essential that the material, equipment, devices, software and systems stay active in the longest time and best cost possible during their life cycles. It is not enough to hire staff and provide place and time to achieve this. Especially with the developing technology, the variety and the number of units entering the inventory increase day by day and it becomes necessary to carry out the maintenance and repair activities outside the institution because of the capacities of the facility, capabilities of the staff, inadequacy of the sets, devices and tools and technical reasons.

Two multi-criteria decision making methods were used for the solution of this problem. The criteria identified by the first of these methods, Fuzzy DEMATEL, were put in order according to their degrees of importance and the data obtained have been provided as input to the SMAA-2 method to acquire the preference orders of the alternatives.

Since real life is closer to the concept of fuzzy logic. For this reason the fuzzy numbers were used in order for the decision makers to express themselves more easily via linguistic expressions and results are obtained using the multi-criteria decision support method SMAA-2.

Finally, two different orderings from two methods of defuzzification are tested with the SMAA-2 method.

Although criterion importance orders are same for degrees of optimism (1) and (0.5), it is confirmed that the criterion weights are different, though very minimally.

With the degree of optimism (0) and defuzzification by the CFCS method the orders of importance of the criteria were confirmed to be the same but the values are different.

It is confirmed that different defuzzification methods can change the degrees of importance of the criteria.

It is confirmed that the time criterion affects the alternatives substantially.

The distinctive aspect of this study is that the Fuzzy DEMATEL and the SMAA-2 methods are used together for the first time. Another distinction is that the costs affecting maintenance have been evaluated with these methods for the first time.

With the light of the information obtained, reaching the solution with two different methods and using mathematical methods provide support for the decision makers at the point of decision.

An interface can be created to be used together with Fuzzy DEMATEL and SMAA-2 which can be used as a Decision Support System.

Since it provides the information of which alternatives are preferable in what rates instead of presenting the decision makers the best one among the alternatives, the SMAA-2 method, with this feature, is a multi-criteria decision making method appropriate especially for the public sector.

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