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Application of Data-Mining and FMEA Techniques in Maintenance System to Improve Equipment Performance

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ABSTRACT

This study utilized the CMMS database that was reserved maintenance activities work order. Data-mining was applied to discover of knowledge that was hidden in the CMMS database, such as important repair activities and critical equipments. The failure modes and effects analysis (FMEA) was applied to analyze the risks of equipment. There are three indices of FMEA in this work: the occurrence (O) that can be learned from the Number of failures in CMMS database; the likelihood of being detected (D) that refers to the difficulty of detection and severity (S) that can be quantified from the Production stop and the Production of unfit product. The fuzzy analytic hierarchy process (FAHP) was applied to determine the relative weightings of four factors, then a equipment risk priority number (E-RPN) can be calculated for each one of the equipment. Numerical results indicated that through the use of the proposed approach, the rate of the equipments performance can be improved while the E-RPN is above 7.
KEYWORDS: Maintenance, data-mining, clustering, FMEA, FAHP.

INTRODUCTION

Maintenance is a set of activities to preserve, control, and increase useful lives of equipment, devices, and installations (physical assets) in suitable conditions, or changing them to suitable conditions according to standards. This requires a net system including types of common strategies in net industries [1].Computerized Maintenance Management System (CMMS) is a net management tool to import, confirm, plant, and reserve net activities and their costs. In fact, the main task of a CMMS is providing a tool to manage and improve net activities on equipments, installations, and machinery of an organization [5]. Because of profitability and significant results of net planning knowledge, use of new technology and software systems to manage different departments of organizations are not covered for everyone. Therefore, a suitable data analysis system by data-mining and FMEA technique can help achievement of these goals:

- Providing a model to increase efficacy of preventive maintenance planning.
- Recognition of common repair of equipments in order to plan preventive maintenance efficiently.
- Improvement of equipment performance

In section 5 we proceed to methodology of research. In section 6 we execute steps of this methodology and document the discoveries.

2. Knowledge discovery and data-mining (KDD)

Data-mining is the process of extraction of valid, unknown, perceivable, and reliable information from large databases and using them for decision-making in trade activities. Data-mining is the semi-automatic process of large database analysis to find suitable patterns [6]. One of the basic methods of knowledge extraction in framework of logical rules is Association Rules Method (ARM). In this method, some rules are formed upon data records, support criterion, validity of laws, appearance, and accompanying of different items. One of the data-mining methods is clustering. Cluster is a set of similar data. This divides data into clusters with maximum similarity between data of each cluster and minimum similarity between different clusters [6]. K-means is a clustering algorithm. This algorithm has a K parameter that indicates number of clusters. Usually, the centers of first clusters are randomly determined from first samples. Thus, there may be different centers for the first clusters in different clustering. This produces different clusters from two different executions of K-means. Various distance criteria may be used in this algorithm. Performances of these criteria depends types of data. The order of this algorithm is O(I*K*n), in which, I is iterations, K is number of clusters, and n is number of samples.

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3. Failure Modes and Effects Analysis (FMEA)

Failure modes and effects analysis (FMEA) is an analytical technique based on prevention rule to recognize potential failure factors. This is a tool to recognize faults before their occurrences, before appearance of them surprisingly [16]. FMEA first emerged from studies done by NASA in 1963. It eventually spread to the car manufacturing industry where it served to identify and quantify possible potential defects at the design stage of a product [10].Currently, the FMEA is a tool widely used in the automotive, aerospace, and electronics industries to identify, prioritize, and eliminate known potential failures, problems, and errors from systems under design before the product is released [12]. Several industrial FMEA standards, such as those set up by the Society of Automotive Engineers, the US Military of Defense, and the Automotive Industry Action Group; employ Risk Priority Number (RPN) to measure the risk and severity of failures [11]. RPN is an index that can represent the degree of risks that a product may possess. It consists of three indicators: Occurrence (O), Severity (S), and Detection (D). Basically, FMEA consists of two stages; the first phase is to identify the potential failure modes and decide the value of Severity, Occurrence and Detection. In the second phase, the manager should make recommendations for correct actions, and the RPN needs to be re-calculated after correct actions [13].The detailed description of the FMEA creation process can be found in the work of McDermott, Mikulak, and Beauregard (1996). In light of the advantages mentioned above, it should therefore be appropriate to use FMEA to assess the risks associated with equipments.

4. Fuzzy Analysis Hierarchical Process (FAHP)

This method was suggested by Thomas L.Sa'aty in 1970s. In FAHP, indices may be quantitative or qualitative. This method is based on pair comparisons. In this method, the decision-maker indicates decision-making options and indices by construction of a decision hierarchical tree. Then, he indicates weights of factors by many comparisons [14]:

Step 1: Construction of hierarchy structure

Step 2: Formation of linguistic variables matrix as triangular fuzzy numbers: Decision-makers use them to compare pairs (table 1).

Table 1: Triangular fuzzy numbers for linguistic variables (Lee et al, 2008)

Linguistic variables	Positive triangular fuzzy number	Positive reciprocal triangular fuzzy number
Extremely strong	(9,9,9)	(1/9,1/9,1/9)
Intermediate	(7,8,9)	(1/9,1/8,1/7)
Very strong	(6,7,8)	(1/8,1/7,1/6)
Intermediate	(5,6,7)	(1/7,1/6,1/5)
Strong	(4,5,6)	(1/6,1/5,1/4)
Intermediate	(3,4,5)	(1/5,1/4,1/3)
Moderately strong	(2,3,4)	(1/4,1/3,1/2)
Intermediate	(1,2,3)	(1/3,1/2,1)
Equally strong	(1,1,1)	(1,1,1)

Step 3. Calculation of discord rate

Concord index (CI) is shown as equation 1. Concord ratio (CR) is concord index divided by random index (RI). Concord ratio less than 0.1 shows concord. RI is obtained from table 2.

(1) $$\mathrm{CR} = \frac{CI}{RI}$$ (2) $$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}$$

Table 2: Random Index (RI) (Sa'aty, 1980)

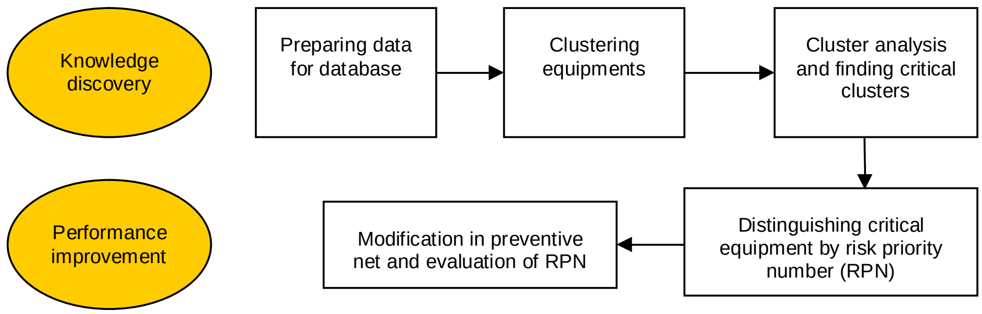
N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Step 4: Calculation of weights of indices: In this step, weight of each index is calculated by approximate method.

5. PROPOSED METHODOLOGY

This research tries to offer a model to describe net system dataset and to improve performances of equipments by clustering them and indicating features of clusters of critical equipments.

Fig. 1: Proposed model



The most successful data-mining projects are executed by standard CRISP-DM process. A data-mining project includes a 6-step life cycle:

1.System recognition 2.Data recognition 3.Data preparation 4.Modeling 5.Evaluation 6.Development [4]

6. Execution of methodology in net system of Arak Petrochemical Co. (ARPC)

Arak Petrochemical Co. is one of the largest petrochemical companies in Iran. Its maintenance department includes mechanical repairs, sensitive machinery, electricity, instrumentation, repair services, and repair planning units. For each repair, an order sheet is issued that includes different data.

6.1 System recognition step

In system recognition step, at first the job is recognized. In this section, we select computerized net management of APC and perform data-mining and knowledge discovery.

6.2. Data recognition step

Data recognition is gathering primary data, data description, data inspection, and data validation. Data of this research comes from repair order sheets of different departments of ARPC.

Only few order sheets are used in this research. This data include unit name (the unit with the defective equipment), tag number (code of each equipment), and description (description of activities to remove the fault). There were about 16,234 records from order sheets. Since net technology has not changed in APC for recent years, this data is reliable and homogenous.

6.3. Data preparation

Data preparation includes data selection, data refining and data preparation for data-mining including selection of certain features, data integration, and data molding. Some fields must be changed to a suitable format before data-mining. Since Description field is a text one, we divide this into several new fields. There are usually 17 repair operations in APC, which are described in Description fields. We assigned a code to each repair operation according to table 3. Each record includes several fields. If the field exists, then it is set to 1; otherwise, it is set to 0. So, Description fields are replaced with zero/one fields.

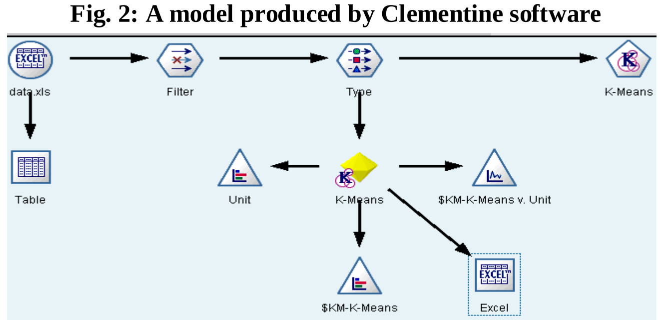
Table 3: Coding of repair activities

Repair	Greasing	Lubrication	Service	Replace	Opening	Checking	Cleaning	Repairing	Charging
Code	G	R	M	S	O	Q	P	F	C
Repair	Installation	Discharge	Welding	Turning	Closing	Measurement	Testing	Montage	
Code	I	D	W	K	Z	J	T	A	

6.4. Modeling step

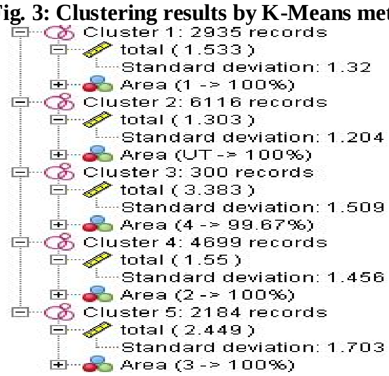
At first, a suitable method should be selected. Then necessary parameters are indicated. After extraction and preparation of data upon failures and their numbers, modeling is done by Clementine software.

Fig. 2: A model produced by Clementine software



All equipments are divided into five clusters including equipment name, the number of repair activities in each failure, the production unit, and the production region. Clusters mostly differ by the number of repair activities in each failure and production regions. Specification of clusters is shown in fig. 3. Analysis of clusters indicated that there were 2817 equipments with 16,234 failures, from which 1015 of failures were for 73 equipments in cluster 3, and 99.67% of these equipments are located in region 4.

Fig. 3: Clustering results by K-Means method



6.5. Evaluation step

Validity of model is evaluated in this step. After modeling, it must be examined if the selected model helps us achievement of goals or not. This is done by evaluation of results produced by the model. Finally, a list of corrective activities is provided as a strategy for decision-making.

Table 4: Evaluation of obtained knowledge

Code	Knowledge title	Evaluation reference
K01	Knowledge 1: 4 repair activities of Q, F, I, and O have the most occurrences.	Experts
K02	Knowledge 2: All equipments are divided into 5 clusters. Clusters mostly differ in the number of repair activities in each failure and production regions in which each equipment is used.	Calculations
K03	Knowledge 3: Cluster 3 with average failure of 3.383, SD of 1.509, and 73 equipments (1.85% of total equipments) has the highest repair activity.	Calculations, experts
K04	Knowledge 4: O was occurred in repair activities A and I, with confidence of 95.9% and support of 11.4%.	Experts
K05	Knowledge 5: O was occurred in repair activities A, with confidence of 94.8% and support of 13.4%.	Experts
K06	Knowledge 6: "I" was occurred in repair activities A and O, with confidence of 86.6% and support of 12.7%.	Experts

6.6. Development step

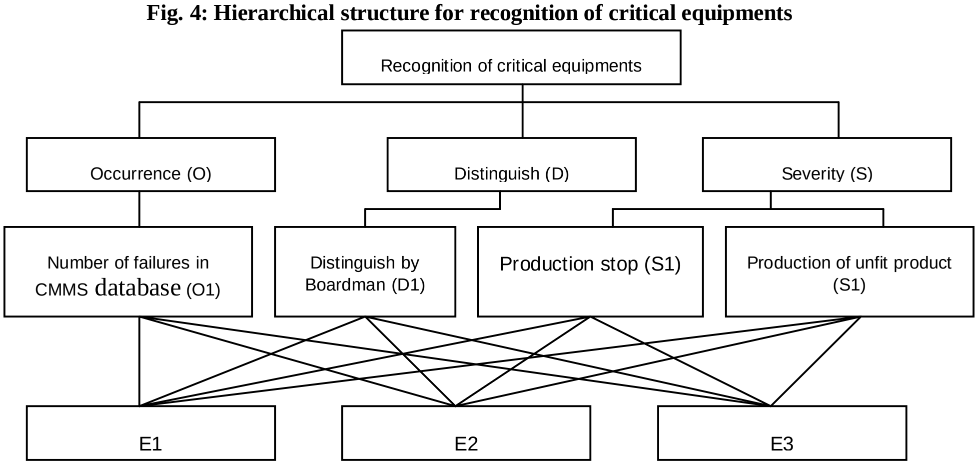
In this step, a team of 6 experts of net unit are formed. Then strategies to prioritize equipments by FAHP and FMEA according to RPN number are proposed to provide a suitable periodical preventive net. Its steps are:

Step 1: Review of equipments: Clusters are reviewed to recognize equipments and selection of critical equipment clusters.

Step 2: Brain-storming to recognize potential failure pattern: The experts concentrate on equipments and provide a list of potential failure effects or FMEA indices (fig. 4).

Step 3: Formation of hierarchical analysis structure: The hierarchical structure for FMEA is provided to recognize critical equipments.

Fig. 4: Hierarchical structure for recognition of critical equipments



Step 4: Weighting decision-making indices: After using FAHP method, weight of each index is determined by pair comparison matrix of table 5. The results are shown in table 6.

Table 5: Pair comparison matrix to determine zones of inices

	O1	D1	S1	S2
O1	(1, 1, 1)	(6, 7, 8)	(2, 2.236, 2.449)	(4.899, 5.916, 6.928)
D1	(1.8, 1.7, 1.6)	(1,1,1)	(0.144, 0.169, 0.204)	(0.25, 0.333, 0.316)
S1	(0.408, 0.447, 0.5)	(4.899, 5.916, 6.928)	(1, 1, 1)	(6, 7, 8)
S2	(0.177,0.169,0.167)	(2, 3, 4)	(0.125, 0.143, 0.167)	(1, 1, 1)

$\lambda_{max} = 4.255$, $CI = 0.0850$, $CR = 0.0759$

Table 6: Weights of indices

FMEA index	Criterion	Weight
Occurrence probability	O1	0.517
Distinguish rank	D1	0.049
Severity rank	S1	0.347
	S2	0.087

Step 5: Assigning a severity rank to each effect: In this step, a severity rank is assigned to each repair activity. Severity is a criterion to evaluate seriousness of a failure. Table 7 was used to grant a rank.

Table 7: The guide to select failure rank

Effect	Criterion: severity	Rank
Risky without previous warning	High: Affect safety of operator, factory, or repair personnel	10
Short stop or defective production	Stop between 0.5-1 h, or defective production up to 1 h	5
Neutral	Parametric variation is under control limits. Other controls are not needed, or they can be checked without production stop	1

Step 6: Assigning an occurrence rank to each failure pattern: In this step, an occurrence rank is assigned to each pattern. The number of failures or errors shows occurrence rate. The number of recorded failures in a certain period is used to determine occurrence rank. Table 8 shows the proposed guideline.

Table 8: The proposed guideline to select occurrence rank

Failure probability	Failure rate	Rank	Occurrence
Critical failure	> 10	10	Exactly
Occasional failure	2-10	5	Low
No failure	< 2	1	Impossible

Step 7: Assigning a recovery rank to each potential failure pattern or its effect: Recovery rank shows occurrence probability of a failure or its effect (discovery probability before occurrence). Table 9 is a proposed guideline.

Table 9: The proposed guideline to select failure distinguish rank

Distinguish	Criterion: distinguish probability by control/machine	Distinguish
Unknown	Controls cannot distinguish failure reason	10
Average	Controls may distinguish failure reason	5
Exact	Controls can distinguish failure reason	1

Step 8: Assigning a risk priority number (RPN) to each failure pattern: Conventionally, risk priority number was obtained by multiplication of severity rank by occurrence rank by recovery rank. In this research, we used weighted FMEA instead of conventional FMEA, in which there is a weight for each index. Thus, RPN is calculated by the following formula ($1<RPN<10$):[2]

(3) $RPN = W(O_1)\times S(O_1)+W(D_1)\times S(D_1)+W(S_1)\times S(S_1) +W(S_2)\times S(S_2)$

$W(O_1) +W(D_1) +W(S_1) +W(S_2) =1$

In each FMEA project, acceptable level for RPN must be indicated. After determination of performances of equipments of critical cluster, RPN is calculated for each equipment, as shown in table 10. In this research, 10 equipments are selected from cluster 3. Risk of critical equipments are indicated by RPN numbers. According to the failure pattern for RPN limit, a necessary action is needed to issue PM. It should be noted that failure severity is very important. If the severity of a level is 9-10, its reason must be investigated without regarding to RPN. RPN is calculated as an index to classify equipments and doing preventive and corrective actions.

Table 10: Determination of RPN for equipments of critical cluster

UNIT	TAG-NO	Function	Total	$W(O_1)=0.517$	$W(D_1)=0.049$	$W(S_1)=0.347$	$W(S_2)=0.87$	RPN
CP	51-P-107	REAGENT .NB 20 INJ. PUMPS	13	10	5	10	10	9.755
CP	51-P-501A	DRYING LOOP COMPRESSOR	27	10	8	10	10	9.902
CP	51-P-504A	POWDER TRANSFER TO STORAGE	41	10	8	10	10	9.902
CP	51-P-506	GAS RECOVERY	31	10	8	10	10	9.902
CP	51-MP-503D	GAS RECOVERY	3	3	8	10	10	6.283
CP	51-MP-504H	Steam Condensate Pump	3	3	8	10	10	6.283
CP	51-P-تخلیه پارفین	GAS RECOVERY	3	3	8	10	10	6.283
CP	51-P-1001B	ETHYLENE COMPRESSOR	2	2	8	10	10	5.766
CP	51-P-502A	Serum Transfer Pump	28	10	8	8	10	9.208
CP	51-P-504B	ETHYLENE COMPRESSOR	16	10	8	8	8	9.034

SPSS and Pareto Principle, which says 80% of failure comes from 20% of equipments, were used to recognize critical equipments. Here RPN was 7, namely, RPN>7 are prioritized for corrective actions. In fact, prioritize of critical equipments provides a way for experts to concentrate on critical equipment in order to decrease failures.

Step 9: Actions to delete of decrease potential failure patterns

Step 10: Calculation of RPN after deletion or decrement of potential failure patterns: RPN will decrease after doing corrective actions. Otherwise, actions will not decrease occurrence or recovery probabilities. Then RPN is recalculated after corrective actions and preventive repairs.

Table 11: Improvement of RPN

UNIT	TAG-NO	RPN before corrective actions	RPN after corrective actions	Improvement rate
CP	51-P-107	9.755	7.589	22.20%
CP	51-P-501A	9.902	4.17	57.90%
CP	51-P-504A	9.902	4.638	53.20%
CP	51-P-506	9.902	4.132	58.30%
CP	51-MP-503D	6.283	7.366	-17.20%
CP	51-MP-504H	6.283	6.819	-8.50%
CP	51-P-150	6.283	3.449	45.10%
CP	51-P-1001B	5.766	2.532	56.10%
CP	51-P-502A	9.208	6.887	25.20%
CP	51-P-504B	9.034	4.329	52.10%

As you see in table 11, RPN of some equipment will decrease significantly after corrective actions, which shows efficacy of the proposed method. If there is no improvement in performance, PM must be revised.

6. Conclusion and proposals

This study was executed according to standard CRISP-DM methodology. A conceptual framework and operational model incorporating data mining and FMEA has been presented. By identifying common repair, critical equipments and by identifying the four criteria under FMEA and determining the relative weights using FAHP, the proposed framework was applied in the given example.

Compared to previous investigations, the proposed method has the following contributions. First, a new model for evaluating equipments risk with emphasis on common repair issues has been developed. Such a framework has never been found in previous literature. Based on the example, this model shows its potential advantage in detecting high risk equipments systematically and effectively. Second, incorporating the FMEA and FAHP methodology to assess the risk of equipments can hardly be found in previous studies. The results of this numerical analysis have indicated that the detected rate of high risk equipments can be improved up to within the E-RPN range between 7 and 10 by using the proposed methodology. Specifically, the equipments performance has been improved. Finally, it is proposed use the pattern to recognize defective equipments that need preventive or corrective actions. Also, the equipments that need overhaul should be recognized by this pattern and effective planning must be done.

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