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Full Length Research Paper

Failure mode and effects analysis (FMEA) with weighting (FAHP) and its comparison with WASPA in the storage of Chabahar oil company

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In the area of manufacturing and service activities, the issues like competition intensity, rising expectations, changing demands and increasing development of technology, result the companies obligation in the field of troubleshooting in a safe and healthy environment and elimination of any deficiencies and deviation in the workplace and its performance. Otherwise, it causes the employees and customers dissatisfaction. To achieve this goal, today's organizations can use a device named FMEA to remove or decreasing potential modes of deficiencies before occurring the accidents and deficiencies. Using this device the companies and organizations assure have provided a healthy and safe environment for workers in order to the workers attempt for the goal of mentioned organization. Using this efficient device can identify and prioritize the potential deficiency modes in the system, procedure product and service, and define and determine the decrease level of potential deficiency modes and finally, to register the result of completed analysis with the goal of preparing a complete reference to solve the future problems. In this study, the verbal variables are used, that later by triangular fuzzy numbers, to fuzzy numbers were applied in order to evaluate ranks and weights of risk factors. To determine each of risk factors through the method of FAHP and ranking and selecting the most important modes of deficiencies the method of WASPAS was used. The proposed model applied to evaluate and rank the potential deficiencies modes in detecting the most important factor of potential risks in the storage of Chabahar oil company.

Keywords: FMEA ,RPN, FUZZY, WASPAS, AHP

INTRODUCTION

Annually, due to lack of safety, we witnessed many events in oil stocks that leads to workers injury or even death, as well as damages that is occasionally imported the equipment, that makes the managers to evaluate the risks and ranking them. Managers are always faced with two parameters, time and financial problems, for this reason myriad of researches accomplished to rank these type of risks, and a variety of methods obtained in this context. Principally, the implementation of FMEA, requires cross-functional teams, in which, a group of

experts and specialists come together with different expertise from various units such as design, production, procedure and quality to test and investigate the relation among deficiencies modes, effects, reasons, current controls, and proposed proceedings. One of the useful methods for this, which is considered by many of managers these days, is the method of failure analysis mode and its effects analysis. FMEA is a systematic approach to identify and prevent potential failures in product design, production process, etc. In this approach the number of risk priority 1 (RPN), the computational result of effectiveness a group (S intensity), the possibility that a cause results defects in relation to risks (O occurence) and the ability of detecting a defect (D detection) is attained before resulting a failure. Briefly, three parameters are used in this method including severity (S), occurrence(O) and detection (D). The way of its implementation is like this that for every one of above parameters, a table should be drawn that for each related subjects to each table the numbers between 1 to 10 is assigned which the number 1 is the best and the number 10 is the worst case. The risk priority or the very RPN is achieved by multiplying the mentioned numbers.

RPN=S*O*D

This method is presented as one of the most important precautionary innovative methods during the stages of a system, procedure, production or service. The main problem in FMEA is that the various combination of occurrence, detection and severity which are obtained from their multiplication, produce for various defects modes and similar RPNs, which may the hidden risk in these modes are completely different from each other. Since the importance of three factors of severity, occurrence and detection is not usually the same. Therefore, using the FMEA method in un-fuzzy way is considerably criticized. For this reason the research is accomplished by FMEA way by using WASPAS which the weights of indexes are attained by AHP in fuzzy environment, evaluates the risks in the environment of stockroom of the oil company, relying on HSE rules of defects and ranking the potential risks modes in the stockroom of Chabahar oil company. Since FMEA is the most effective way to earn the potential crashes and selecting the useful reformation, this way is used with integrated decision-making procedures.

Review of literature

To overcome the resulted traditional losses, (Wang et al., 2009) used the experts to study about the FMEA according to the literature of fuzzy approach of FMEA that explains the risk factors of S, O and D using fuzzy verbal terms. The verbal variables were used as an interpretation of operating scores of FMEA with a traditional ten point scale (1-10) to evaluate three risk factors such as S, O, D.

Right now, FMEA is used widely as critical safety and reliability analysis tool in different industries, especially in aerospace, automotive, nuclear and health care industries.

The traditional FMEA is a systematic, efficient, and effective method, which is able to improve the safety and reliability of systems; however, the RPN trend method by having most of the limitations and problems is criticized.

(Rahul et al., 2016) paid to development of a research approach base on the modes analysis knowledge and its effects in flexible auto parts, using three steps, which the first step is the traditional FMEA and the second step, a decision tree algorithm (J48) and the third step includes user's guide booklet, which was implemented after processing the extracted rules by decision making tree algorithm.

(Francesco et al., 2015) presented a new multi-criteria decision making method (MCDM) named GDSS to arrange the failure mode to prioritized classes related to several decision makers.

(Rafie and Samimi, 2015) in a research for developing RPNs of FMEA, achieved S and D out of fuzzy rules and gained O using artificial neural network (ANN), to evaluate the suitability of this FMEA method, they compared the real world data by this way and the results showed that this method can be useful in predicting the risk.

In fuzzy FMEA literatures, the studies are often related to the approach of fuzzy base using if-then rules (Chin et al., 2008).

WASPAS is a new method which has presented recently and as one of the modest proposed methods by well-known experts. This new method is base on the weight sum model (WSM) and weight product model .

(Zavadskas et al., 2012) are the innovators of this new method and they proved that the accuracy of the collected methods is better alone than the accuracy of each one of them.

(Zavadskas et al., 2016) performed in a literature base on the concept of (passive house) and (active house) Europe union standards (EU) and Lithuania country which according to the presented concept from desirable environment, the MADM-OPT method, which is stable by the desirable replacement concept, used six apartments in brick houses to evaluate the interior environment, using WASPAS method.

(Sarfaraz et al., 2013) imposed an article with the object of two multiple decision making criteria (MCDM) of the methods in the model. And imposed the weight of evaluation step by step than the analysis of (SWARA) to decision making in order to prioritize and computation of the relative importance of criteria. Then, used the total weight of product evaluation (WASPAS)to evaluate the potential replacement.

(Edmundas Kazimieras Zavadskas, 2014) proposed a developed version of (WASPAS) method that can be imposed in unknown decision making environment. In the

Table 1: Fuzzy judgment matrix

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \begin{Bmatrix} \tilde{a}\ 121 \\ \tilde{a}\ 122 \\ \tilde{a}\ 12p_{12} \end{Bmatrix} & \begin{Bmatrix} \tilde{a}\ 1n1 \\ \tilde{a}\ 1n2 \\ \tilde{a}\ 1np_{1n} \end{Bmatrix} \\ \begin{Bmatrix} \tilde{a}\ 211 \\ \tilde{a}\ 212 \\ \tilde{a}\ 21p_{21} \end{Bmatrix} & (1,1,1) & \begin{Bmatrix} \tilde{a}\ 2n1 \\ \tilde{a}\ 2n2 \\ \tilde{a}2np_{2n} \end{Bmatrix} \\ \begin{Bmatrix} \tilde{a}\ n11 \\ \tilde{a}\ n12 \\ \tilde{a}\ n1p_{n1} \end{Bmatrix} & \begin{Bmatrix} \tilde{a}\ n21 \\ \tilde{a}\ n22 \\ \tilde{a}\ n2p_{n2} \end{Bmatrix} & (1,1,1) \end{bmatrix}$$

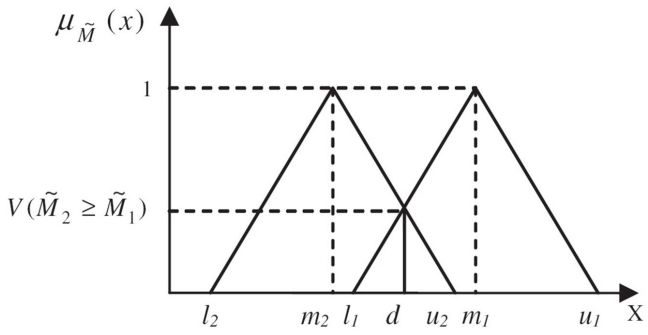

Fig. 1. The intersection between $\tilde{M}_1$ and $\tilde{M}_2$

proposed method of WASPAS method, the lack of reliability of decision makers is expressed in the expression of their judgment and evaluation to the importance of criteria and / or the performance of choices on the interval criteria of intuitive fuzzy numbers. Two numerical numbers are represented in the ranking of abandoned buildings of the decisions of redevelopment and the replacement of investment.

Despite the fact that a lot of effort has been done to improve the RPN, the improved methods have argued that the properties and / or determining the weights of risk factor is not easy because different decision makers (DMS) may possess separate judges and/ or priorities. For example, (Wang et al., 2009) emphasized more on the risk factor D in the following of S and the less weight for O; while observed that the failure reason is so high with severity but too low occurrence may be less critical than the cause reason that has occurred frequently and at the result of failure possibility, is considered more important than the other factors.

The AHP and WASPAS method are known as decision making techniques in which the research these two techniques are applied in fuzzy environment in order to efficient increase and their accuracy. In the following we explain these 3 methods in details:

Fuzzy AHP method:

Chang in 1992 represented a simple method for Fuzzy failure modes and effects process in fuzzy environment. It is a mean of other expert opinions and normalize method by trilingual fuzzy numbers.The steps are in this way:

Step1: hierarchical tree design

Step2: couple compared matrix: $\tilde{T}ij = (a_{ij}, b_{ij}, C_{ij})$

Step 3: measure mean of opinions via matrix

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \tilde{a}_{2n} \\ \tilde{a}_{n1} & \tilde{a}_{n2} & (1,1,1) \end{bmatrix}$$

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{p_{ij}} a_{ijk}}{p_{ij}} \qquad ij = 1,2,\dots,n \tag{1}$$

Step 4: accounting of line sets:

$$\tilde{s}_j = \sum_{j=1}^{n} \tilde{a}\ ij \quad ij = 1,2,\cdots,n \tag{2}$$

Step 5: normalizing the line sets:

$$\tilde{M}_i = \tilde{s}_i \otimes \left[\Sigma_{i=1}^{n} \tilde{s_i}\right]^{-1} \qquad i = 1,2,\cdots n \tag{3}$$

$$\tilde{m}_i = \left(\frac{i_j}{\sum_{i=1}^{n} u_j}, \frac{m_i}{\sum_{i=1}^{n} m_j}, \frac{u_i}{\sum_{i=1}^{n} l_j}\right) \tag{4}$$

Step6: determination of bigger possibility:the maximum possibility is d(Ai) which is evaluated as

$$v(m_2 > m_1) = sub_{y \geq x}\left[\min\left(\mu x_1(x), \mu_{x_2}(y)\right)\right] \tag{5}$$

Table 2: Potential risks storage of Chabahar oil company

Operation	The potential failure mode	Operation	The potential failure mode
FM1	Carelessness and lack of attention workers on how to properly do the job	**FM10**	Incomplete or improper design workshop or machinery
FM2	Lack of inspection, control and oversight and ensure that they are healthy	**FM11**	The absence of appropriate safeguards on dangerous parts of machinery and apparatus
FM3	Failure to install automatic fire control pills in tanks	**FM12**	Not to provide personal protective equipment to workers according to their work
FM4	Technical defects or a component of the workshop	**FM13**	There's no warning devices in the workplace
FM5	The bite of poisonous gas inhalation (lack of oxygen)	**FM14**	Without regard to the manner and procedure between human safety and security tools
FM6	Falling and hitting objects slipping and sliding	**FM15**	Painting and Restoration of loading platforms and tanks
FM7	electrocution	**FM16**	Lack of surveillance cameras on tanks to prevent accident
FM8	Burn	**FM17**	Lack of standard storage devices to establish worn
FM9	The incident caused clashes with the different machines and tools (tear, bruise, crush)	**FM18**	Avoid dropping waste in the warehouse

The relationships can be defined in this way as well:

$$V\left(\widetilde{M}_2 \geq \widetilde{M}_1\right) = \mu(d) = \begin{cases} 1, \\ 0, \\ \frac{l_2 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \ other\ wise \end{cases} \quad (6)$$

Wherein d is highest point of common region.
Figure 1.
V(M2 ≥ M1) , V(M1≥M2 are essential to compare M_1 and M_2. The bigger possibility is analyzed in this way):
$d'(M) = V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1), (M \geq M_2), \ldots, (M \geq M_k)] = \min V(M \geq M_i)$ i = 1,2,…,k (7)

step7: normalizing to make weight bidders:

$$w = \left[\frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)'} \ \frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)'} \ \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_n)'} \right]^T \quad (8)$$

The above weights are non-fuzzy. Matrix weights are evaluated by repetition.
Step8: weight compounds to make the final weights.

$$\tilde{u}_i = \sum_{i=1}^{n} \widetilde{w}_i \, \tilde{r}_{ij} \qquad \forall i \quad (9)$$

WASPAS method

Waspas or (weight Aggregates Sum Product Assessment) is one of the modern techniques of decision making. This model is presented in 2012 and as one of the strong known MCDM methods. This method is combined from total weighted model (WSM) and multiplication weight model (WPM).

The Stages of WASAPAS

1-Normalization of data
If the indicator is positive:

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \quad j = 1,2,3,\ldots,n \ i = 1,2,3,\ldots,m \quad (10)$$

If the indicator is negative:

$$\bar{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \quad j = 1,2,3,\ldots,ni = 1,2,3,\ldots,m \quad (11)$$

2-Gain the matrix of normal weight Weighted sum model (WSM)

$$Q^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j \qquad j = 1,2,3,\ldots,ni = 1,2,3,\ldots,m \quad (12)$$

Wj is the respective indicator weight Multiplication weight model (WPM)

$$Q^{(2)} = \prod_{j=1}^{n} \bar{x}_{ij}{}^{w_j} \qquad j = 1,2,3,\ldots,ni = 1,2,3,\ldots,m \quad (13)$$

Wj is the respective indicator weight.
3-Ranking and total computation
Total ranking from the combination of sum weighted model (WSM) and the weight multiplication model is obtained according to the following equation.

$$Q_i = \lambda Q^{(1)} + (1 - \lambda) Q^{(2)} \ \lambda = 0,\ldots,1 \quad (14)$$

RESEARCH METHODOLOGY

The research is a kind of descriptive and contains a set of methods for describing the condition or studied phenomena. Descriptive research can be divide into

Table 3. matrix compare of couple risk factors based on lingual Variations

detection	Occurrence	severity	Couple compare matrix
SS,SS,SS	SS,VS,FS	E,E,E	severity
SS,SS,E	E,E,E	_	Occurrence
E,E,E	_	_	detection

Table 4. lingual words for variations ranking

Fuzzy scores	Linguistic words
(0,0,1)	Very poor(VP)
(0,1,3)	Poor(P)
(1,3,5)	Medium poor (MP)
(3,5,7)	Fair (F)
(5,7,9)	Medium good (MG)
(7,9,10)	Good (G)
(9,10,10)	Very good (VG)

Table 5. 18 impairment modes regarding three risk factors

D			S			O			Team decision making matrix	
DM3	DM2	DM1	DM3	DM2	DM1	DM3	DM2	DM1		
VP	MP	P	MP	MG	F	F	G	MG	FM1	Impairment modes
VP	MP	P	VP	MP	P	P	F	MP	FM2	
P	F	MP	P	F	MP	F	G	MG	FM3	
VP	MP	P	VP	MP	P	F	G	MG	FM4	
VP	P	VP	VP	P	VP	P	F	MP	FM5	
VP	MP	P	VP	P	VP	MP	MG	F	FM6	
VP	MP	P	VP	P	VP	P	F	MP	FM7	
VP	MP	P	VP	P	VP	P	F	MP	FM8	
VP	MP	P	P	F	MP	MP	MG	F	FM9	
VP	P	VP	VP	P	P	MP	MG	F	FM10	
VP	MP	P	P	MP	MP	MP	MG	F	FM11	
P	F	MP	VP	MP	P	MP	MP	F	FM12	
P	F	MP	VP	MP	P	VP	MP	P	FM13	
VP	MP	P	VP	MP	P	P	F	MP	FM14	
P	F	MP	MP	MG	F	MP	MG	F	FM15	
VP	MP	P	MP	MG	F	MP	MG	F	FM16	
VP	MP	P	VP	MP	P	VP	MP	P	FM17	
VP	MP	P	VP	P	VP	VP	MP	P	FM18	

survey, case study, content analysis and ethnography categories.

The required data are collected in library way in theoretical section and fieldwork in practical section and through the FMEA worksheet. By observing and experts opinions in the stockroom of oil company their years of experience have been used.

Today, the fuzzy method is used instead of certain decision making methods to define and making meaningful the vague concepts and uncertainties (Wang et al., 2009). In this study, risk factors and the level of their relative importance in the form of verbal variables are taken into consideration and the linear triangular membership function which will be used in this study will be sufficient to deal with the ambiguities of verbal assessment. In this section the a systematic approach will be used in fuzzy environment for applying the WASPAS and AHP methods in order to determine the

Table 6. lingual phrases of fuzzy score

Fuzzy score	Linguistic terms
(2,5/2,3)	Absolutely strong (AS)
(3/2,2,5/2)	Very strong (VS)
(1,3/2,2)	Fairly strong (FS)
(1,1,3/2)	Slightly strong (SS)
(1,1,1)	Equal (E)
(2/3,1,1)	Slightly weak (SW)
(1/2,2/3,1)	Fairly weak (FW)
(2/5,1/2,2/3)	Very weak (VW)
(1/3,2/5,1/2)	Absolutely weak (AW)

Table 7:WSM values:

FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM1 0	FM1 1	FM1 2	FM1 3	FM1 4	FM1 5	FM1 6	FM1 7	FM1 8
0.86 2	0.3 32	0.62 3	0.72 5	0.36 4	0.37 8	0.36 7	0.36 7	0.61 7	0.51 2	0.58 8	0.48 2	0.33 1	0.40 2	0.73 4	0.7	0.29 7	0.26 3

Table 8:WPM values:

FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM1 0	FM1 1	FM1 2	FM1 3	FM1 4	FM1 5	FM1 6	FM1 7	FM1 8
0.7 82	0.3 18	0.5 88	0.6 31	0.3 47	0.3 49	0.3 51	0.3 51	0.5 83	0.42 9	0.55 3	0.47 8	0.32 4	0.39 5	0.71 2	0.64 7	0.29 4	0.26 2

Table 9: The final ranking of the combination of weighted sum model (WSM) and weighted multiplication model (WSM) is obtained according to equation 3

Option	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM 10	FM 11	FM 12	FM 13	FM1 4	FM 15	FM 16	FM 17	FM 18
Q	0.8 22	0.32 5	0.60 5	0.67 8	0.35 6	0.36 4	0.35 9	0.3 59	0. 6	0.47 1	0.5 7	0.48	0.32 7	0.39 8	0.7 23	0.67 4	0.29 6	0.26 2

weights of risk factors and ranking the crashes modes.

FINDINGS

The proposed model was applied for Chabahar oil company. The initial interviews was done the experts who were years experienced in the stockroom of oil company, and the 18 potential risk modes extracted from Chabahar oil company in stockroom environment which is pointed in the following:

Evaluating the choices base on the criteria according to fuzzy numbers and table statements, we gained opinions in the form of average fuzzy numbers and made the choices defuzzy according to the center of the region method and continued the WASPAS method in the following.

After determination of impairments, the importance of risk factors were extracted by lingual variations and couple decision making matrix in the form of phase hierarchical method:

For example, in the compare of risk factors, the response of three experts are Slightly strong, Very strong and Fairly strong.to extract the weights of risk factors with the method of phase hierarchical analysis, it is noteworthy that changing lingual variations to trilingual numbers the following table is used:

Then, the experts analyzed ranking of 18 impairment modes with lingual variations.

Linguistic evaluation are shown in Table above and the following triangular fuzzy numbers are converted according to the table:

Defuzzification is dine in the form of the region center method:

$$\mathrm{C(A)}\,\frac{(a3-a1)+(a2-a1)}{3}+a1 \qquad (15)$$

Table 10: Ranking

FM 1	FM 15	FM 4	FM 16	FM 3	FM 9	FM 11	FM 12	FM 10	FM1 4	FM6	FM7	FM8	FM5	FM1 3	FM2	FM1 7	FM1 8
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

View ranking WASPAS:

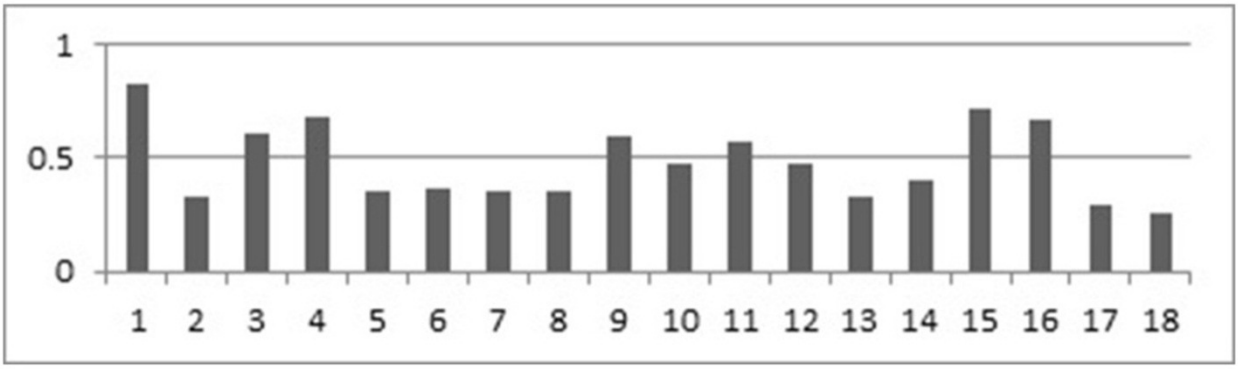

Fig. 2. View ranking WASPAS

View ranking WASPAS

The WASPAS method has proposed the options1,15,4,16,3 up to the end, respectively, which is shown above as the major potential risks. As it can be seen, the WASPAS is considered as an efficient method to obtain the most major potential risks.

THE RESULTS ANALYSIS

Base on the analysis of the results of potential risks modes, showed that the modes of risks which takes to itself the highest amounts of risk priority are considered as the most major potential risk but this action is different in various ways. Initially, defuzzification the amount of risk priority for every modes of risk using verbal terms by experts. In order to prevent of deficiencies of certain risk priority we used fuzzy theory in this study and as it stated, the method of modes analysis and its effects for factors of severity, occurrence, and detection considers an identical value while it is possible that their importance is not identical, therefore, in this study by using the hierarchical fuzzy method, different weights was computed by using Chang method for every one of the severity, occurrence and detection factors.

After comparing the results of modes analysis and its effects base on the fuzzy logic the weighting of fuzzy hierarchical analysis turned clear by using WASPAS, that the ranking of risk priority is different from WASPAS method. Base on the same results of the reform and preventive measures mentioned in order to reform the modes before resulting the risk.

DISCUSSION AND CONCLUSION

In this study, a new approach is obtained to get the risk priority by using the WASPAS based on fuzzy AHP. In this study, the fuzzy approach was used in order to weighting to risk factors and priorities the crashes modes. To do this, a combined model from WASPAS and FAHP was proposed in fuzzy environment. Then this model was used in order to evaluation and ranking the risks modes of the stockroom of Chabahar Oil Company. Base on the results, the risks mode of FM3, FM16, FM4, FM 15, FM1, are the most major mode of risks which include " careless and lack of attention of workers in the correct way of doing the work", " lack of CCTV cameras in the tanks to prevent the accidents", "lack of painting and restoration loading platforms and tanks", " the accidents result from involving with different machinery and tools (tear, rupture, crush) and " the lack of automatic fire control pills in tanks", respectively.

For more research the results of this article can e compared with other multi-norms techniques of DEA, PROMETHEE.

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