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An Integrated Risk Assessment Approach andApplication to Dynamic PositioningSystem

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ABSTRACT

Science many of ships accidents are the results of loss position, Dynamic Positioning (DP) system is fixed in different types of vessels to maintain its position.However there are potential hazards in DP system which need an effective risk assessment approach to deal with. In this endeavour integration two Multi Criteria Decision Making (MCDM) approaches, namely; qualitative and Fuzzy Analytic Hierarchy Process (FAHP), is proposed to overcome the shortcomings and maximize the advantages of each approach. The structure of this integrated approach is clarified then 15 potential hazard scenarios in DP system are selected as a case study where the proposed integration risk assessment approach is used to rank these scenarios in respect to eight criteria namely Frequency, Human safety, Environment, Finance and Cost, ship safety and technology, Reputation, Detectability and reduction measures. A huge amount of computer output are obtained but for space limitation only the final results are illustrated in different forms and thoroughly analysis is carried out and the rank levels forall scenarios are obtained.

Index Terms- Qualitative, FAHP, Risk assessment, Consequences, Dynamic Positioning.

I. INTRODUCTION

History of accidents which lead to total losses of vessels in a period from 2000 to 2013 showed that the number of total losses reached to 1673 from different types of vessels such as supply/Offshore, barges, containers and passengers. The reasons behind these total losses is shown in Fig. 1 refers to many causes ranging from collision, submerged, contact with harbour wall, machinery failure and hull damage [1]. The rout cause for some of these accidents as collision, contact with harbour wall and sinking refer to that the vessel loss it's ability to maintain its position which show the necessity to have DP system on different types of vessels.

DP is a system which enable a vessel to maintain its position and heading automatically without anchors or mooring lines as it control three of six degree of vessel freedom, namely; Sway, Yaw and Surge. The DP system as shown in Block diagram in Fig. 2 includes a control cabinet as there are separate closed loop control system, one for each of Sway, Yaw and Surge. As the feedback signal for each of these degree of freedom is fed to the computer and the error signal is initiated to the controller which send a control signal to actuator (Thruster) to maintain the position as set value.

Dynamic positioning started in the 1960 for offshore drilling. With drilling moving into ever deeper waters, in 1961 it was possible to keep the ship in position above the well at a depth of 948 meters, as the drillship was kept in position manually. Later in the same year the drilling ship had a control system interfaced with a taut wire was lunched making the first true DP ship and since then fast improvements have been made.

The DP system is used in different types of vessels such as: Drilling, shuttle tanker operations, Underwater operations, diving/ROV, Pipe lay operations, Pipeline trenching, Rock dumping operations, Crane barge operations, Cable lay/repair, Dredging, Anchor handling tug/supply vessel operations, Passenger/cargo/heavy-lift vessels and Military vessels.

The risk assessment approaches are ranging from qualitative, quantitative and fuzzy and each one has its advantages and limitations. In this present paper the integration of both qualitative and Fuzzy Analytic Hierarchy Process (FAHP) is proposed. The structure of the integrated approach is outlined and then it is applied on DP system as a case study.

II. PREVIOUS WORK

Risk assessment approaches have been widely applied in marine industry. IMO [2] proposed guidelines for formal safety assessment to be used in the IMO rulemaking process. United Nation [3] issued a framework for risk assessment in maritime

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industry. DNV [4] surveyed the different approaches for marine risk assessment. Brandsaeter A. [5] study the risk assessment in the offshore industry in relation to people safety, environment and property. ABS [6] presented different approaches of risk assessment in marine and offshore oil and gas industries. HSE [7] proposed risk assessment approaches for managing collision risk. Balmat, et al [8] proposed a fuzzy approach for the maritime risk assessment applied to safety at sea.

Qualitative approaches such as Failure Mode and Effect Analysis (FMEA), Event Tree analysis (ETA), Fault Tree Analysis (FTA) and Hazards and Operability study (HAZOP) have been used in different application where data are not sufficient or in linguistic variables, i.e. the risk level is low. As the qualitative approaches mainly depend on human evaluation so any change in the nature of the evaluation team will consequently affect the results obtained consequently extending the use of qualitative approaches over the hazards identification will cause uncertainties in the results.

Analytic Hierarchy Process (AHP) is established on constructing the hierarchy of the problem in which the goal (Risk Ranking), criteria and potential hazard scenarios are clearly recognized, and pair-wise comparisons among the criteria in respect to the goal are carried out to obtain individual weight for each criterion. Then the pair-wise comparisons among hazard scenarios in respect to each criterion are carried out to obtain risk weight for each scenario and accordingly rank them.

AHP is used indifferent applications. Moustafa M. and Jamel F. [9], Jiang H. and Ruan J. [10] used AHP to solve problems of investments risk assessment on high-tech industry projects. Lee M. [11] used AHP approach for information security risk analysis, Zayed. et al. [12] assessed the risk and uncertainty inherent in Chinese highway project using AHP approach. Bureika G. et al [13] applied AHP approach to assess traffic safety risk of railway infrastructure.

FAHP approach is widely used in different applications. Jeng H. and Hsuan L. [14] used FAHP in risk assessment and management of runway construction of military airport. Naghadehi et.al [15] proposed FAHP for selection the optimum underground mining method, lumaksono H. [16] integrated both FAHP and SWOT approaches for selection shipyard development strategy. Al Aziz A. [17] proposed a comparative study between AHP and FAHP for consistent and inconsistent data. Zejli K. et al. [18] proposed FAHP to build a framework for modelling the problem selection of locating logistics platforms in emergency affected area, Lashgari Z. and Safari K. [19] used FAHP approach to determine the factors affecting the selection of both the volume and type of invested securities. Wang M. and Hwang K. [20] used FAHP approach to analyse the key factors involved in evaluating and screening industry managers. Wang J. and Li Y. [21] proposed FAHP for evaluation index system of the Energy Performance Contracting (EPC) project risk from the different stokeholders, Novei et al [22] used FAHP approach to assess the most important risk factors to predict outcomes. Tang Y. and Beynon M.[23] used FAHP for the selection of the type of fleet car to be adopted by a small rental company.

III. FUZZY LOGIC

While the traditional logic deals with crisp and fixed values e.g. (1 or 0) or (yes or No) the fuzzy logic which is first introduced by Zadeh [24] deals with rough values and incomplete data in which the value ranges between completely right (1) and completely false (0), it also deals with the linguistic variables such as (very high, low, increasing, …etc.). As these incomplete data and linguistic variables represent the real data available in most cases of multi criteria decision making (MCDM) problems and the traditional logic find difficulties to deal with while the fuzzy logic can provide solution for these problems.

As the fuzzy logic deals with a partial degree of membership so the truth of any value becomes a matter of degree as a membership function is a curve which defines the transition from zero to one. There are different types of membership functions, such as triangular, generalized bell-shaped, s-shaped, and z-shaped sigmoidal, product of two sigmoidal. For simplicity the triangular membership function will be used in this paper. A triangular function $\mu(x)$ is defined by a lower limit l, an upper limit u, and a value in between m, (l, m, u) where $l<m<u$.

IV. MODLEING

The proposed integrated approach which is combination of both qualitative and FAHP approaches is applied to DP system as a case study according to the following steps:

Step 1: Identify the potential hazards

This step is carried out by a qualitative approach as the different potential hazard scenarios (Sc1 - Sc15) in various different operation modes of DP Vessel are identified by a group of experts (5 herein) in DP vessels as chief engineers, captains and technical managers. Every expert surveyed the DP system and put a list of hazard scenarios that which might occurr and these lists are collected then only 15 hazard scenarios are selected as a case study.

Step 2: Identify the criteria

The same group of experts identified the different criteria which could affect the ranking level of each potential hazard scenario identified in step 1. These criteria include frequency of occurrence (F) and consequences (S) which could be affected in case the potential hazard is occurred such as human safety (H), Environment (E), finance and cost (C), Vessel technology and safety (T), reputation (R), detectability (D) and reduction measures (M), where (P, H, E, C, T, R) are considered as positive criteria which means that the increase in any of these criteria will consequently increase the risk value, while D and M are considered negative criteria, which affect the risk value in an opposite way.

Step 3: Evaluation of the frequency and consequences

In this step every one of experts evaluate the frequency of occurrence (F) and the consequences of each hazard scenario.The process is carried out according to risk index [25] as shown in Table 1.

Table 1 Risk Index [25]

PI*	Probability	Consequence/Severity				
		1	2	3	4	5
		Minor	Significant	Severe	Catastrophic	Disastrous
8	Very frequent	9	10	11	12	13
7	Frequent	8	9	10	11	12
6	Probable	7	8	9	10	11
5	Reasonably probable	6	7	8	9	10
4	Little probable	5	6	7	8	9
3	Remote	4	5	6	7	8
2	Very remote	3	4	5	6	7
1	Extremely remote	2	3	4	5	6

* PI: Probability Index

The risk index of the ith scenario is obtained by the jth expert according to the following equation [26].

$$RI_{ji} = F_{ji} + C_{ji} = F_{ji} + \frac{1}{z}\left(H_{ji} + E_{ji} + C_{ji} + T_{ji} + R_{ji} - D_{ji} - M_{ji}\right)$$

Where RI_{ji}, F_{ji}, and C_{ji} are respectively the risk index, probability and consequence of the ith scenario according to the jth expert, with j ranging between 1 and 5 and i between 1 and 15. On the other hand, H_{ji} , E_{ji} , C_{ji} , T_{ji} ,R_{ji} , D_{ji} , and M_{ji} are the corresponding human Safety (H), Environmental (E), Cost and finance (C), Vessel safety and Technology (T), Reputation (R), Detectability (D) and reduction Measures (M) and z is the number of the consequences, seven in this case. It should be mentioned herein that these results obtained from the previous steps which are based on qualitative approach are used as input data for the FAHP model as in the following steps with aid of MATLAB software.

Step 4: Construct the hierarchy

The hierarchy structure for the problem is built in as ranking the risk comes on top of the structure as a goal. Then, the criteria C1, C2, … Cj, …, C8 come second while the all hazard scenarios Sc_1, Sc_2, …, Sc_{15} come as third alternatives.

Step 5: Construct the decision matrix

The pair-wise comparisons for all objects are carried out by using Saaty's 1 - 9 scale (Wanderer, et al 2013) by the decision makers and the decision matrix is obtained in the form:

$$D_p = \begin{bmatrix} b_{11p} & b_{12p} & \cdots & b_{1mp} \\ b_{21p} & b_{22p} & \cdots & b_{2mp} \\ \cdots & \cdots & \cdots & \cdot\cdot \\ b_{m1p} & b_{m2p} & \cdots & b_{mmp} \end{bmatrix},$$

where p = 1, 2… 5, is the number of experts. The number of Pair-wise comparison are carried out in this process is according to the following equation:

$$NPWC = \frac{n\,(n-1)}{2}$$

Where n is the number of criteria or scenarios. Herein the NPWC for criteria in respect to the goal are 28 and for scenarios in respect to 8 criteria are 680 so the total NPWC are 708. 5 decision matrices are obtained from this step but for space limitation only one is listed in Table 2.

Table 2 Expert pair-wise comparisons

$$D_3 = \begin{array}{cccccccc} P & S & E & C & T & R & D & M \\ 1.0000 & 0.3333 & 1.0000 & 0.3333 & 0.2000 & 0.3333 & 3.0000 & 0.3333 \\ 3.0000 & 1.0000 & 3.0000 & 1.0000 & 0.3333 & 1.0000 & 5.0000 & 1.0000 \\ 1.0000 & 0.3333 & 1.0000 & 0.3333 & 0.2000 & 0.3333 & 3.0000 & 0.3333 \\ 3.0000 & 1.0000 & 3.0000 & 1.0000 & 0.3333 & 1.0000 & 5.0000 & 1.0000 \\ 5.0000 & 3.0000 & 5.0000 & 3.0000 & 1.0000 & 3.0000 & 7.0000 & 3.0000 \\ 3.0000 & 1.0000 & 3.0000 & 1.0000 & 0.3333 & 1.0000 & 5.0000 & 1.0000 \\ 0.3333 & 0.2000 & 0.3333 & 0.2000 & 0.1429 & 0.2000 & 1.0000 & 0.2000 \\ 3.0000 & 1.0000 & 3.0000 & 1.0000 & 0.3333 & 1.0000 & 5.0000 & 1.0000 \end{array}$$

Step 6: Consistency check

The consistency check is carried out for all data according to the following [12]:

(a) Calculate the Eigenvalue as:

$$ʎ = \sum b_{ji} \times w_j$$

where ʎ is the maximal eigenvalue and w_j is the eigenvalue corresponding to the j^th^ object.

(b) Calculate the Consistency Index:

$$\text{CI} = \frac{ʎ - \text{n}}{n-1}$$

where CI is the consistency index and n is the number of comparisons.

(c) Calculate the Consistency Ratio

$$\text{CR} = \frac{\text{CI}}{RI}$$

Where CR is the consistency ratio, CI is consistency index and RI is the random consistency index obtained from Table 3.

Table 3 Saaty's Random consistency Index (RI) (Jandova and Talasova, 2013)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If:

CR ≤ 10% is accepted consistency and the data able to be used, or

CR > 10% means inconsistency and the data cannot be used.

In this paper the consistency check assured that the data collected from the 5 experts are able to be used.

Step 7: Integrate the decision makers' matrixes

In this step, all decision matrices are integrated in a triangular fuzzy number (TFN) matrix as follows:

$$l_{je} = \min(b_{jep}), \quad u_{je} = \max(b_{jep}), \quad m_{je} = \frac{\sum_{p=1}^{t} \text{bjep}}{t}$$

where p =1, 2,.., 5 and j =1, 2, …, 8. The results obtained from this step are presented in Fig. 3

Step 8: Calculate the fuzzy synthetic value S_i as follows:

$$S_i = \sum_{j=1}^{m} \text{M}_{g_i}^{\text{j}} \varnothing \left[\sum_{i=1`}^{n} \sum_{j=1}^{m} \text{M}_{g_i}^{\text{j}}\right]^{-1}$$

$$\sum_{j=1}^{m} \text{M}_{g_i}^{\text{j}} = \left(\sum_{j=1}^{m} l_{j,} \sum_{j=1}^{m} m_{j,} \sum_{j=1}^{m} u_j\right)$$

$$\sum_{i=1`}^{n} \sum_{j=1}^{m} \text{M}_{g_i}^{\text{j}} = \left(\sum_{i=1}^{n} l_{j,} \sum_{i=1}^{n} m_{j,} \sum_{i=1}^{n} u_j\right)$$

$$\left[\sum_{i=1`}^{n} \sum_{j=1}^{m} \text{M}_{g_i}^{\text{j}}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right)$$

where S_i is the fuzzy synthetic extent value with respect to the i^th^ criterion and $\text{M}_{g_i}^{\text{j}}$ is the extent analysis value given in triangular fuzzy numbers (TFN).

Step 9: Compare between every two criteria (pair-wise comparison)

$$V(M_2 \geq M_1) = \begin{cases} 1, & if\ m_2 \geq m_1, \\ 0, & if\ l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise, \end{cases}$$

Where $M_1 = (l_1, m_1, u_1)$, $M_2 = (l_2, m_2, u_2)$

Step 10: Calculate the degree of possibility for each criterion using the equation:
$\bar{d}$ (M_i) = min V($M_i \geq M_k$),
$\overline{W}$ = ($\bar{d}$(M_1), $\bar{d}$(M_2), … $\bar{d}$(M_n)).
where$\bar{d}$(M_i) is the degree of possibility, i = 1, 2… m and k$\neq i$ and $\overline{W}$ is the weight vector in non-fuzzy numbers . The following results were obtained:$\overline{W}$ = (0.8180, 0.7650, 0.9614, 0.8950, 0.9806, 0.9176, 0.8026, 0.9421).

Step 11: Calculate the normalized weight vector as:

W = (d (M_1), d (M_2), … d (M_n)),
where W is a normalized weight vector. The following results were obtained as W = (0.1155, 0.1080, 0.1357, 0.1264, 0.1385, 0.1296, 0.1133, 0.1330)
Then Steps 5 to 11 are repeated for the hazard scenarios to calculate the weight of each scenario and rank them according to these weights and the results obtained are illustrated in Table 4 and Fig. 4.

Table 4 Weights and Ranks of DP System Hazard Scenarios

Scenario	Description	Weight	Rank
Sc_1	Failure of the affected Workstation	0.0712	2
Sc_2	Failure of Workstation 24V DC PSU	0.0656	12
Sc_3	Failure of joystick or turning moment control	0.0679	4
Sc_4	Failure of Failure of 24V DC Power Supply Unit of one PSU	0.0676	5
Sc_5	Failure of the DP Controller	0.0719	1
Sc_6	Incorrect feedback value of Analogue input card	0.0644	13
Sc_7	Loss of mains input or charger fault of UPS	0.0613	14
Sc_8	Open circuit of UPS Battery isolator	0.0666	9
Sc_9	Short circuit or cable breakof Ethernet network.	0.0669	7
Sc_{10}	Failure of Ethernet switch.	0.0667	8
Sc_{11}	Incorrect output from DGPS.	0.0707	3
Sc_{12}	Gyro compass heading output drifting or frozen.	0.0662	10
Sc_{13}	Anemometer Wind speed or direction failure	0.0596	15
Sc_{14}	Pitch output of Vertical reference unit (VRU) failure to zero, frozen or drifting	0.0675	6
Sc_{15}	Cable break of Generator kW Signal	0.0661	11

V. RESULTS and DISCUSION

The results obtained listed in Table 4 and presented in Fig. 4, show that scenario DP_5, i.e. Failure of the DP Controller is the worst scenario with risk weight 0.0719 and scenario DP_{13}, i.e. Anemometer wind speed or direction failure is the lowest scenario. On the other hand each one of the rest scenarios is assigned on its own risk level with a total number of the 15 risk levels.

The advantages of integrated qualitative and FAHP approaches in one approach include:

- The FAHP solves the problem of qualitative approach which is grouping of scenarios resulted in reducing the total number of rank levels less than the number of scenarios.
- The FAHP solve the problem of qualitative approach which is the weight of individual criterion is not taken into consideration or considered equal weights while in FAHP each criterion is assigning its own weight.

The FAHP has its difficulties such as:

- The sum of the risk weight for all scenarios should equal to one so increasing the number of scenarios will decrease the risk weight for each scenario so accordingly the difference among them will reduce. For instance scenario DP_{15} has a risk weight 0.0661 in risk level 11 while scenario DP_{12} has a risk weight 0.0662 in risk level 10 with a difference of 0.0001. So this problem is considered one of the limitations of FAHP.
- Increasing the number of scenarios will increase the number of pair-wise comparisons which could exhaust the experts and accordingly cause inconsistency in the data.

Finaly it is recommended for further study to propose an integration approach between two or more models to solve the difficulties found in this study.

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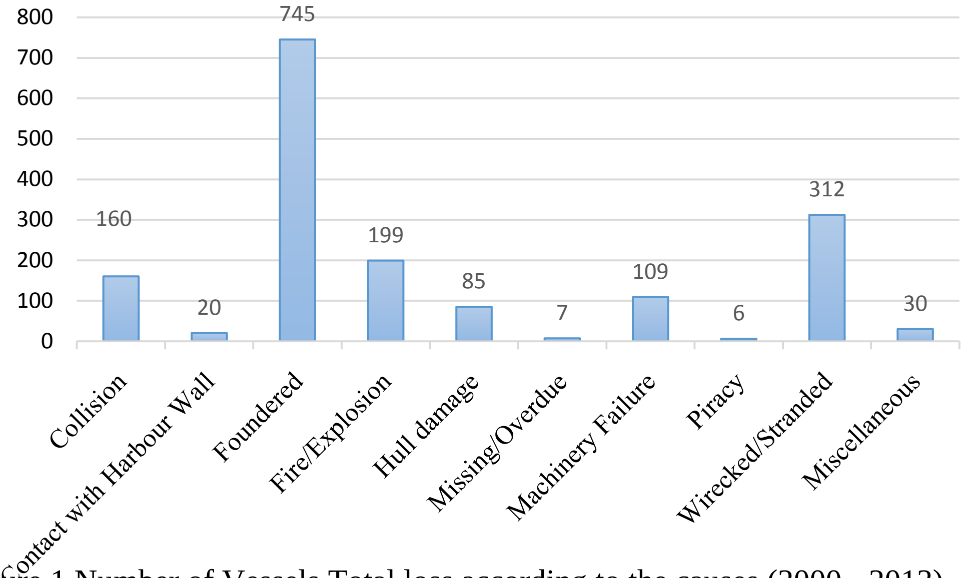

Figure 1 Number of Vessels Total loss according to the causes (2000 - 2013)
Source: Lioyds List Intelligence Casuality Statistics Analysis (AGCS)

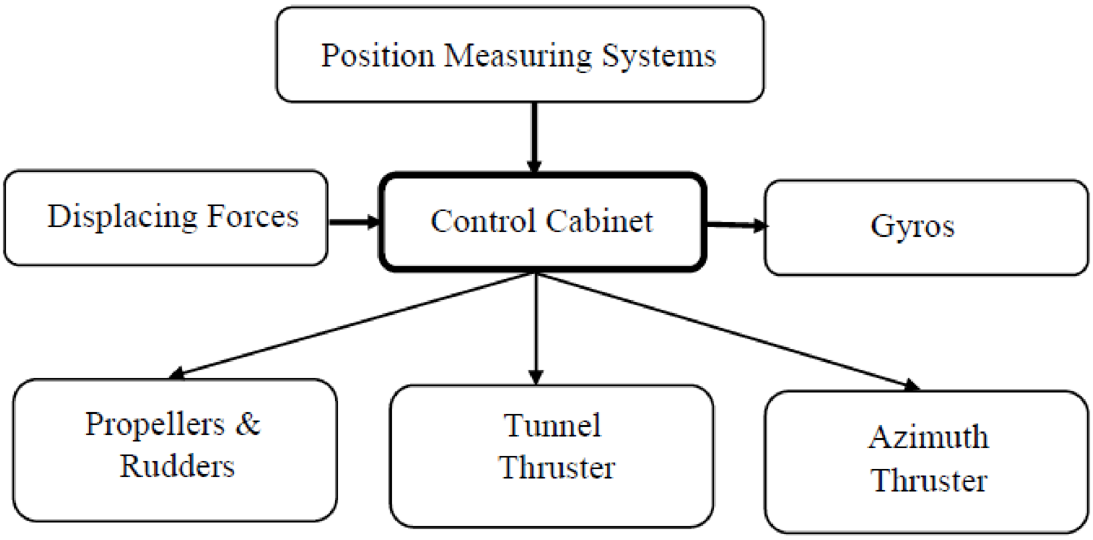

Figure 2 DP System Block Diagram

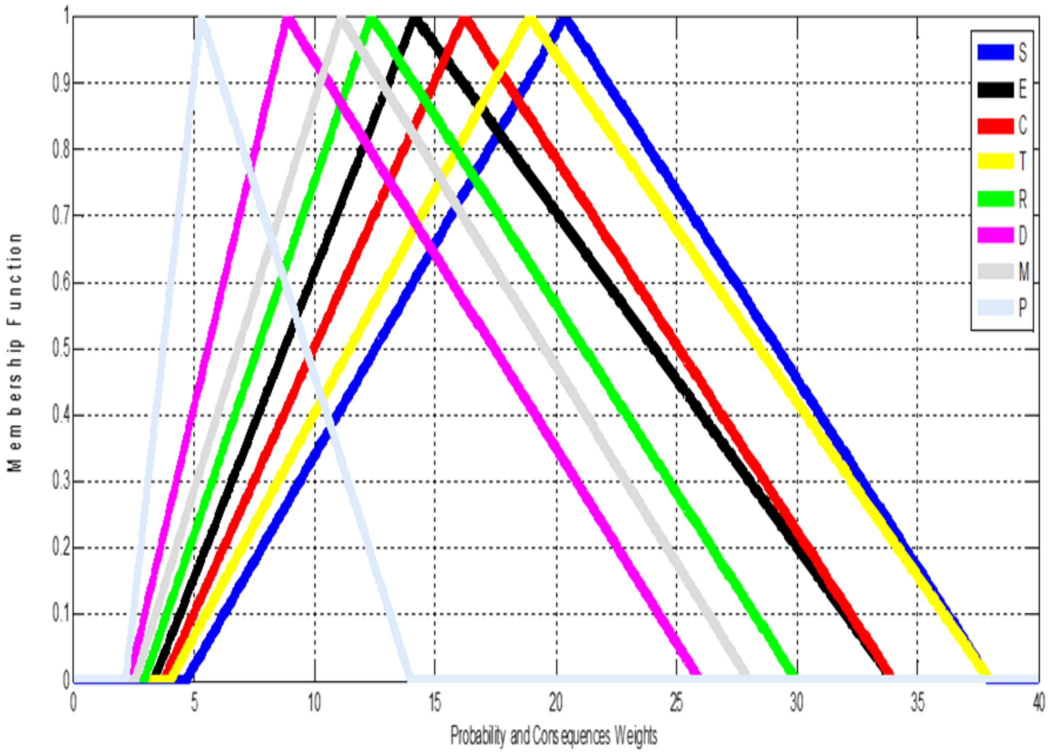

Figure 3 Membership function for the 8 criteria

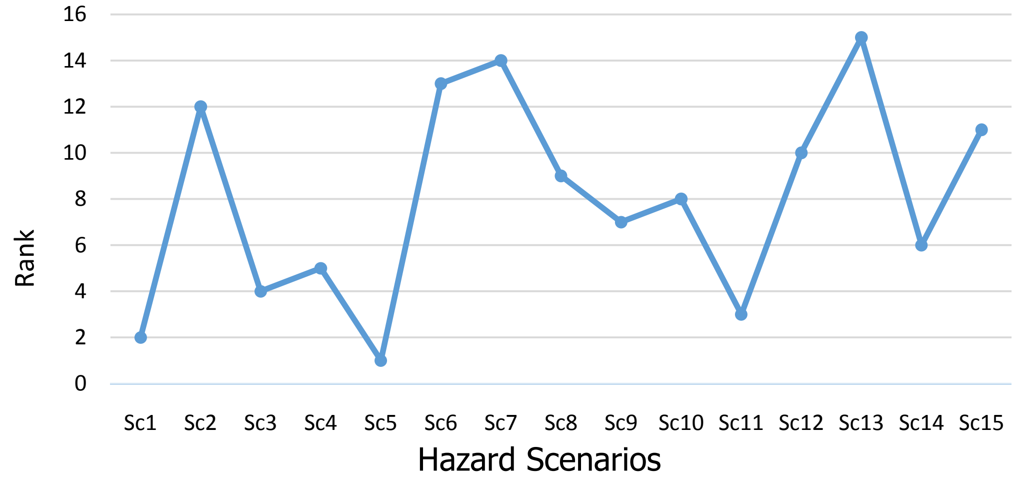

Figure 4 Ranking of DP System Hazard Scenarios