Health Status Assessment Method of Oil Tanker Cargo Handling System

1st Chun-ping WANG
School of Energy and Power Engineering
Wuhan University of Technology
Wuhan, China
wchp1989@whut.edu.cn

2nd Shi-dong FAN
School of Energy and Power Engineering
Wuhan University of Technology
Wuhan, China
sdfan@whut.edu.cn

3rd Yu-nan YAO
School of Energy and Power Engineering
Wuhan University of Technology
Wuhan, China
ynyao@whut.edu.cn

***Abstract*—The cargo handling system is the second largest system of oil tanker, which directly operates on the cargo oil. By assessing its health status, it can grasp the deterioration trend of the system equipment, and then early warn the fault to take corresponding measures to ensure the timely and safe completion of cargo handling task. By analyzing the factors affecting the health status of the oil tanker handling system in operation, this paper constructs an evaluation index system from cargo tank, cargo oil pipeline, cargo oil pump, cargo pump cabin and steam turbine. Matching the corresponding deterioration degree calculation to obtain the relative deterioration degree, and then applying the variable weight theory to adjust the index constant weight. Introducing a normal cloud model with ambiguity and randomness to replace the traditional membership function, transforming the deterioration degree of the evaluation index into the health evaluation level membership degree, and combining with the fuzzy comprehensive evaluation method to establish health state assessment model for the oil tanker handling system in operation. Taking a 49,000 tons crude oil tanker as an example, the monitoring data of the cargo handling system at three times is selected, and the above-mentioned model is used to calculate the evaluation results to determine the health status. By analyzing the relative deterioration degree to determine the cause of the result, and comparing with the operation and maintenance records, the results show that the method can reflect the health status of the cargo handling system and provide a basis for adjusting the loading and unloading tasks, which helps to prevent serious failures occurred.**

Keywords- oil tanker cargo handling system；degradation degree；normal cloud model；fuzzy comprehensive evaluation；health status assessment

I. INTRODUCTION

The oil tanker cargo handle system is a system for direct operation of cargo oil. In the process of handling operation, due to equipment deterioration or improper operation, the system is malfunctioning. If operators cannot find and take measures in time, it may lead to serious accident, which will pose a great threat to the safety of oil tankers and oil ports. Arslan constructed a hierarchy of precautions for liquid chemical tankers from berthing, decking equipment, handling equipment, loading and unloading operations [1]. Håvold et al. analyzed the safety management and safety culture of tankers from four aspects: safety management attitude, safety knowledge, fatalism, work content and pressure [2]. Martins et al. used Bayesian belief network to analyze the impact of human reliability on collision accidents in tanker operations [3]. Akyuz et al. used CREAM (Cognitive reliability and error analysis method), a basic version and an extended version of cognitive reliability and error analysis methods to evaluate the reliability of people in the process of loading LPG tankers [4]. Therefore, a method of the Decision Making Trial and Evaluation Laboratory (DEMATEL) is proposed to evaluate the key operational risks in the gas drainage process for the gas release process of crude oil tankers [5]. Valdor et al., taking the port of Tarragona in Spain as an example, assessed the environmental risks brought by oil spills from port oil handling equipment in different situations [6]. Based on the determination of the risk factors of tanker safety, Hsu et al. proposed a risk matrix correction method based on fuzzy analytic hierarchy process [7]. Cui et al. introduced a fuzzy Bow-tie model in risk quantitative analysis to analyze the risk of oil spill accidents in tanker loading and unloading operations [8]. Furthermore, the safety risk factors of tanker loading and unloading operations are analyzed, and the Interpretation Structure Model (ISM) is constructed to analyze the hierarchical relationship among various factors, clarify the risk generation mechanism, and propose to improve the safety management level of tanker loading and unloading operations counter measures [9].

Domestic and foreign scholars mainly through analyzing the multiple factors affecting the operation of oil tanker, adopt different methods to evaluate the possible risk consequences and give safety management suggestions. In order to adapt to the development of ship cargo handling control system, and in order to improve the efficiency of cargo handling, ease the fatigue of personnel during loading and unloading, increase the safety of ships and personnel, shorten the time of ship staying in port, and ultimately achieve the fundamental purpose of improving economic efficiency, the "Guidelines for the Inspection of Ships (Oil Tankers) Intelligent Cargo Management" prepared by China Classification Society came into effect in 2018, which puts forward requirements for the cargo oil loading and unloading monitoring alarm and auxiliary decision-making system. On this basis, because the cargo handling system of oil tanker has multiple subsystems such as cargo pumps, and its composition of equipment and structure are complex, so it is necessary to consider the influence of

Ministry of Industry and Information Technology of the People's Republic of China，Intelligent Ship 1.0 ([2016]544)

978-1-7281-0860-5/19/$31.00 ©2019 IEEE

multi-level and multi-factors when evaluating its health status. Therefore, this paper chooses a fuzzy comprehensive evaluation method based on fuzzy linear transformation and membership degree. In order to meet the need of unified evaluation of different indexes, the relative deterioration degree is used to describe the degree of deviation from the normal state of the evaluation indexes, and as the input of the normal cloud model to obtain the membership degree. Using the variable weight theory to calculate weight, and combining the fuzzy comprehensive evaluation method, the health state evaluation model of the oil tanker cargo handling system in operation is established.

II. CARGO HANDLING SYSTEM OPERATION HEALTH ASSESSMENT SYSTEM

A. *Selecting evaluation index*

The loading and unloading operation of the oil tanker is accomplished by the cargo handling system. By using the cargo pumps on shore/tanker, the oil tanker's interface is connected with the loading arms of the wharf, so that the cargo oil tank of oil tanker and the oil tanker on shore form a closed system. Centrifugal pumps driven by steam turbines are generally installed on modern large tanker as main cargo pumps. Centrifugal pump uses centrifugal force when impeller rotates to suck liquid to increase liquid pressure to obtain pressure head, and connects with the steam turbine through the pump shaft through the bulkhead sealed by the packing box. Common problems include cavitation and leakage of cargo pumps, over speed and low pressure of steam turbines, negative pressure, overpressure and overflow of cargo tanks, and leakage caused by rust perforation of flanges, valve and other accessories.

Through the monitoring and control system, the cargo control room ensures that the cargo handli0ng system in operation can detect and stop the operation as soon as it reaches the alarm value, and then the crew can quickly find and solve the problem to avoid major accidents. Therefore, this paper establishes a hierarchical health status assessment index system from five subsystems of cargo tank, cargo pipeline, cargo pump, cargo pump tank and steam turbine, including target layer, project layer and index layer, as shown in Fig 1. The health status of cargo oil handling system in target layer can be divided into five evaluation items $G=\{G_1, G_2, G_3, G_4, G_5\}$ in project layer, and then important health status parameters are selected as evaluation indexes under each project layer. For example, the cargo tank reflects its health status through the tank level, average temperature and gas pressure, $G_1= \{G_{11}, G_{12}, G_{13}\}$. The health status indexes of the index layer of the cargo handling system have different physical meanings and value ranges, and can be compared after processing.

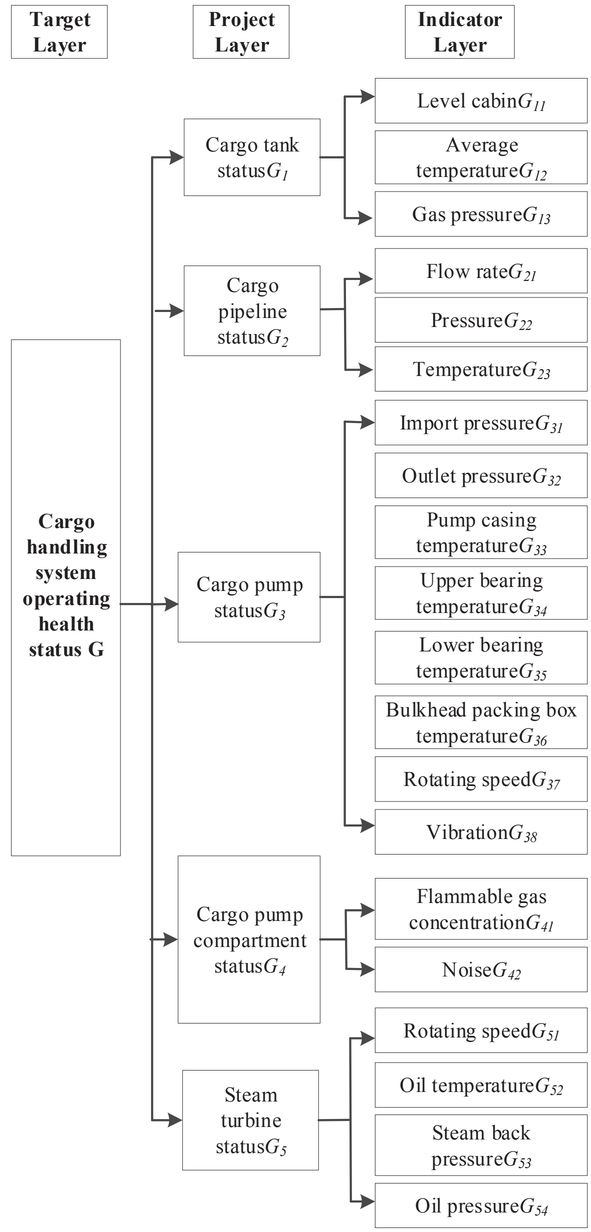

Figure.1 Cargo Handling System Health Status Assessment Index System

B. *Calculation of Relative Deterioration*

The health state of oil tanker cargo handling system is characterized by a series of state characteristic parameters. Deterioration degree can be defined as the degree of deviation of equipment state from good state to limit technical state. Therefore, when measuring the degree of deterioration, the deviation degree of measured parameters from good value (quantity value in good state) and the approaching degree of limit value should be examined at the same time. The relative deterioration degree is calculated differently for different index types. For example, the flammable gas concentration G_{41}, upper bearing temperature G_{54}, and pump casing temperature G_{55} and other evaluation indexes belong to the smaller the better type, and the formula for calculating the relative deterioration degree is formula (1).

$$l(x)=\begin{cases}0 & x<x_{\min}\\ \dfrac{x-x_{\min}}{x_{\max}-x_{\min}} & x_{\min}<x<x_{\max}\\ 1 & x>x_{\max}\end{cases} \tag{1}$$

Note that x is the actual parameter value of the evaluation index; x_{max} and x_{min} are the thresholds for evaluating the critical interval of the operation parameter of the index.

The average temperature G_{12}, flow rate G_{21} and so on are intermediate indexes, and the relative deterioration degree is calculated as formula (2).

$$l(x)=\begin{cases}1 & x<x_{\min}\\ \dfrac{x-x_{\min}}{x_a-x_{\min}} & x_{\min}\le x<x_a\\ 0 & x_a\le x\le x_b\\ \dfrac{x-x_b}{x_{\max}-x_b} & x_b<x\le x_{\max}\\ 1 & x>x_{\max}\end{cases} \tag{2}$$

Note that x_a and x_b are the boundary values of the optimal operating parameter interval for the evaluation indexes.

C. *Determining the Weight of the Evaluation Index*

Weight is the impact of evaluation index on the health of tanker cargo handling system, so the accuracy of weight directly affects the final evaluation results. Firstly, the constant weight is determined by analytic hierarchy process (AHP). Then, when some state parameters deviate from the normal value seriously, it often represents a sharp decline in the performance of some part of the cargo oil handling system and an increase in the risk in the process of cargo oil loading and unloading. At this time, it is necessary to strengthen observation and pay attention to maintenance. However, in the constant weight evaluation model, it may be due to factors with relatively small weight, the comprehensive evaluation results given can maintain the system operation status, which cannot truly reflect the health status of the cargo oil handling system in operation, so variable weight theory is introduced.

$$w_{ij}{}'=\frac{w_{ij}(1-l_{ij})^{\alpha-1}}{\sum_{k=1}^{n}w_{ik}(1-l_{ik})^{\alpha-1}} \tag{3}$$

Note that w_{ij}’ is the variable weight value of the j-th index of the i-th project, is the constant weight value of the j-th index of the i-th project, n is the number of evaluation indexes under the i-th project, l_{ij} is the relative deterioration degree of the j-th index of the i-th item, α is the variable weight factor, and this paper takes -1.

III. Normal Cloud Model and Cloud Membership Degree

The cloud model, firstly proposed by Chinese scholar Professor Li Deyi in 1995, is a qualitative and quantitative conversion model. Cloud model can be divided into triangular cloud, symmetrical cloud, trapezoidal cloud and normal cloud, among which normal cloud is the most widely used because of its unique mathematical properties. The three basic digital features of a normal cloud are Ex (Expected Value), En (Entropy) and He (Hyper Entropy). Normal cloud model is usually represented by (Ex, En, He). Ex is the center of gravity of cloud, which can best represent the value of qualitative concepts. En is an uncertainty measure of attribute concepts. The larger the entropy value, the more fuzzy the qualitative concepts are. He is the entropy of entropy, which reflects the uncertainty of entropy. The greater the hyper-entropy, the higher the uncertainty of entropy.

A. *Dividing Evaluation Level*

With the development of equipment technology and maintenance theory, it is difficult to meet the actual needs by using the "fault" and "normal" binary functions to describe the technical status of the equipment. According to relevant regulations and field experience, the relationship between relative deterioration degree and health status of cargo oil handling system is summarized, as shown in Table I.

TABLE I. Relative Deterioration Degree and Health Status Description

Level	**Relative Deterioration**	**Health Status**	**Describe**
1	0.0~0.2	good	No obvious deterioration trend.
2	0.2~0.4	general	An inconspicuous deterioration trend.
3	0.4~0.7	attention	A clear deterioration trend. Strengthen the attention and inspection
4	0.7~1.0	fault	Failure state. Stop operation and Carry out maintenance

According to the on-site operation and maintenance experience of the oil tanker loading and unloading system, when assessing the health status of the cargo handling system, the evaluation level is divided by V=（V_1, V_2, V_3, V_4）=(good, general, attention, fault). Four normal clouds C=（C_1, C_2, C_3, C_4）, and the numerical characteristics are calculated as shown in Table 2. In the table, a, b and c are the limits of the relative deterioration interval. The corresponding interval between the relative deterioration degree and the evaluation level is determined as V_1 [0, 0.2), V_2 [0.2, 0.4), V_3 [0.4, 0.7）, V_4 [0.7, 1.0), then in the table: a = 0.2, b = 0.4, c = 0.7. Refer to the relevant literature and calculation formula to determine q=0.005. Using the numerical feature calculation method of Table II, the digital feature values of each evaluation level can be obtained, and the results are shown in Table III.

TABLE II. Digital Feature Calculation Method

V_m	C_m	Ex_m	En_m	He_m
V_1	C_1	$Ex_1 = 0$	$En_1 = (Ex_2 - Ex_1)/3$	q
V_2	C_2	$Ex_2 = (a+b)/2$	$En_2 = (Ex_2 - Ex_1)/3$	q
V_3	C_3	$Ex_3 = (b+c)/2$	$En_3 = (Ex_3 - Ex_2)/3$	q
V_4	C_4	$Ex_4 = 1.0$	$En_4 = (Ex_4 - Ex_3)/3$	q

TABLE III. Digital Eigenvalues for Each Evaluation Level

V_m	C_m	Ex_m	En_m	He_m
V_1	C_1	0.000	0.100	0.005
V_2	C_2	0.300	0.100	0.005
V_3	C_3	0.550	0.083	0.005
V_4	C_4	1.000	0.150	0.005

B. *Determining Cloud Membership*

X-Conditional Normal Cloud Model Generator brings the deterioration degree of evaluation index into the normal cloud model with known digital characteristics（Ex, En, He）, and obtains the cloud membership degree of each evaluation level. The algorithm steps are as follows:

- Generating the random number $En,i' = NORM\ (En,i, He,i)$ with En as the expected value and He as the variance.
- Calculating $r_{ij}' = \exp(-\frac{(l_{ij} - Ex_i)^2}{2En_i})$.
- l_{ij} with determinacy r_{ij}' becomes a cloud drop in the number field.
- Repeating steps until the required n cloud droplets are generated.
- Because the cloud membership degree obtained is a random number in a small range, but it has a stable tendency. The average value of all the results of 20 times, that is $r_{ij} = \sum_{i=1}^{20} r_{ij}' \big/ 20$, finally determines the cloud membership degree r_{ij}.

IV. Health Assessment Model of Oil Tanker Cargo Handling System Based on Normal Cloud

A. *Health Assessment Process of Oil Tanker Cargo Handling System based on Normal Cloud*

Taking the health status of cargo oil handling system as the evaluation object, the evaluation index system affecting the health status of cargo oil handling system was established by using the analytic hierarchy process, and the constant weights of each index were calculated. According to the normal cloud theory, the evaluation set is determined. If the degree of deterioration is less than 0.9, then the membership degree of each evaluation index is determined by normal membership cloud, and a fuzzy evaluation matrix is constructed to calculate the evaluation result. If the degree of deterioration exceeds 0.9, the evaluation result can be directly given as "fault". The flow chart is shown in Fig. 2.

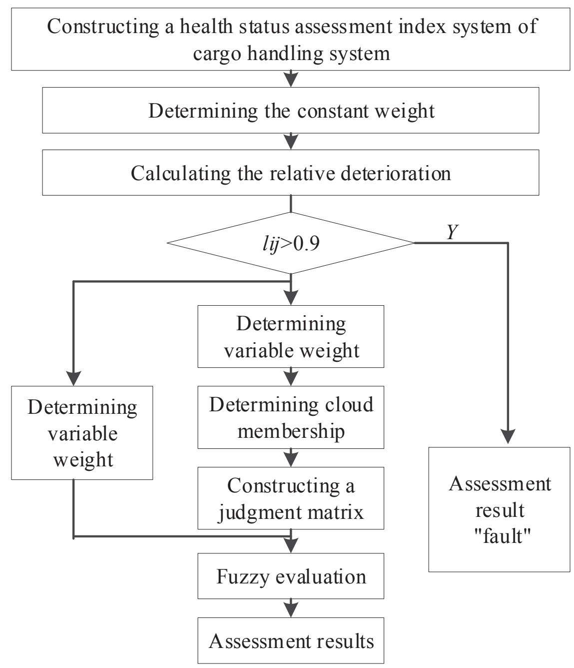

Figure.2 Oil Tanker Cargo Handling System Health Status Assessment Process

B. *Case Analysis*

Taking a 49000T tanker as an example, taking a cargo oil handling pipeline from a cabin to a pump as an example, the parameters of T_1, T_2 and T_3 are obtained through the cargo control room monitoring system. As shown in Table IV, the health status of cargo oil handling system running at three times is evaluated and the results are compared and analyzed.

TABLE IV. Data for a Tanker Cargo Handling Monitoring System

Indexes	**Oil Tanker Cargo Handling Monitoring System Data**		
	T_1	T_2	T_3
G_{11} (m)	7.05	10.03	16.52
G_{12} (℃)	29.2	28.7	26.8
G_{13} (MPa)	0.0091	0.008	0.0073
G_{21} (m)	2.61	2.5	2.3
G_{22} (MPa)	0.45	0.4	0.32
G_{23} (℃)	26.3	25.2	27.6
G_{31} (MPa)	0.30	0.30	0.8

G_{32}（MPa）	0.70	0.72	0.5
G_{33}（℃）	61.2	55.2	12.7
G_{34}（℃）	30.5	49.7	38.6
G_{35}（℃）	48.7	52.2	17.4
G_{36}（℃）	28.1	30.1	29.0
G_{37}（r/min）	1200	1200	1000
G_{38}（mm/s）	2.5	2.3	1.9
G_{41}（%LEL）	1.16	1.25	0.95
G_{42}（dB(A)）	81.2	78	62.7
G_{51}（r/min）	1245	1245	1145
G_{52}（℃）	40	34	33
G_{53}（MPa）	-0.05	-0.06	-0.05
G_{54}（MPa）	0.4	0.4	0.08

C. Cargo Handling System Health Assessment

1) Taking T_1 as an example, the deterioration degree of each evaluation index of the item layer G_i is calculated using formula (1) and (2) according to the technical parameters and safety requirements of the respective devices, and the calculation results are as follows.

$$(l_{11}, l_{12}, l_{13}) = (0, 0.070, 0.490)$$

$$(l_{21}, l_{22}, l_{23}) = (0.096, 0, 0.143)$$

$$(l_{31}, l_{32}, l_{33}, l_{34}, l_{35}, l_{36}, l_{37}, l_{38}) = (0.214, 0.530, 0.942, 0.436, 0.696, 0.375, 0.125, 0.259)$$

$$(l_{41}, l_{42}) = (0.280, 0.838)$$

$$(l_{51}, l_{52}, l_{53}, l_{54}) = (0.072, 0.8, 0, 0)$$

In the data at T_1, the relative deterioration degree l_{33} of the evaluation index G_{33} is >0.9, so the failure is directly judged.

2) Taking T_2 as an example, according to Fig. 2, the operational health assessment of the cargo handling system is carried out.

a) Calculating the relative deterioration degree. The relative deterioration degree of each sub-item G_i is calculated by formula (1) and (2), and the calculation results are as follows.

$$(l_{11}, l_{12}, l_{13}) = (0, 0.083, 0.447)$$

$$(l_{21}, l_{22}, l_{23}) = (0.125, 0, 0.170)$$

$$(l_{31}, l_{32}, l_{33}, l_{34}, l_{35}, l_{36}, l_{37}, l_{38}) = (0.214, 0.653, 0.849, 0.710, 0.746, 0.401, 0.125, 0.185)$$

$$(l_{41}, l_{42}) = (0.302, 0.102)$$

$$(l_{51}, l_{52}, l_{53}, l_{54}) = (0.072, 0.56, 0, 0)$$

b) Determining weight. The deterioration degree of each evaluation index satisfies l_{ij} <0.9. Therefore, the weight of the project layer calculated by the AHP and the constant weight of the index layer are shown in Table V.

TABLE V. Oil Tanker Cargo Handling System Evaluation Index Weight

Project Layer	**Weight**	**Index layer**	**Constant Weight**
G_1	0.180	(G_{11}, G_{12}, G_{13})	(0.2, 0.6, 0.2)
G_2	0.267	(G_{21}, G_{22}, G_{23})	(0.261, 0.106, 0.633)
G_3	0.069	($G_{31}, G_{32}, \ldots, G_{38}$)	(0.067, 0.051, 0.123, 0.123, 0.123, 0.123, 0.099, 0.291)
G_4	0.408	(G_{41}, G_{42})	(0.167, 0.833)
G_5	0.076	($G_{51}, G_{52}, G_{53}, G_{54}$)	(0.088, 0.205, 0.182, 0.525)

Among them, it is determined that the item layer weight vector is:

$$W = [0.180 \quad 0.267 \quad 0.069 \quad 0.408 \quad 0.706]$$

According to the formula (3) of the variable weight theory, the variable weight vector distribution of each evaluation index is calculated as shown below.

$$W_1 = [0.129 \quad 0.460 \quad 0.411]$$

$$W_2 = [0.250 \quad 0.077 \quad 0.673]$$

$$W_3 = [0.011 \quad 0.042 \quad 0.527 \quad 0.143 \quad 0.187 \quad 0.034 \quad 0.013 \quad 0.043]$$

$$W_4 = [0.249 \quad 0.751]$$

$$W_5 = [0.055 \quad 0.567 \quad 0.097 \quad 0.281]$$

c) The cloud membership matrix is obtained. The cloud membership matrix of each project layer is obtained by inputting the above deterioration calculation results l_{ij} into the X-conditional normal cloud model, and the results are as follows.

$$R_1 = \begin{bmatrix} 1 & 0.011 & 0.803 & 0 \\ 0.709 & 0.095 & 0.853 & 0 \\ 0 & 0.375 & 0.991 & 0.001 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.468 & 0.216 & 0.877 & 0 \\ 1 & 0.011 & 0.803 & 0 \\ 0.236 & 0.430 & 0.900 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.101 & 0.691 & 0.921 & 0 \\ 0 & 0.002 & 0.992 & 0.069 \\ 0 & 0 & 0.937 & 0.603 \\ 0 & 0.001 & 0.982 & 0.154 \\ 0 & 0 & 0.972 & 0.238 \\ 0.001 & 0.601 & 0.984 & 0.001 \\ 0.458 & 0.216 & 0.877 & 0 \\ 0.181 & 0.516 & 0.908 & 0 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.011 & 1 & 0.956 & 0 \\ 0.594 & 0.141 & 0.864 & 0 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.772 & 0.074 & 0.847 & 0 \\ 0 & 0.034 & 1 & 0.014 \\ 1 & 0.011 & 0.803 & 0 \\ 1 & 0.011 & 0.803 & 0 \end{bmatrix}$$

According to the formula 1, using the weights of the above evaluation indexes and the cloud membership matrix, the evaluation result vector of each item layer can be calculated, and thus the integrated cloud membership matrix B is constructed, and the results are as follows:

$$B = \begin{bmatrix} 0.455 & 0.199 & 0.903 & 0 \\ 0.353 & 0.344 & 0.887 & 0 \\ 0.015 & 0.053 & 0.952 & 0.387 \\ 0.449 & 0.355 & 0.887 & 0 \\ 0.421 & 0.028 & 0.917 & 0.008 \end{bmatrix}$$

d) Evaluating the health status of cargo oil handling system. From the weight of the project layer W and the comprehensive cloud membership matrix B, the evaluation result vector of the operational health status of the cargo handling system is:

$$E = W \times B = [0.392 \quad 0.278 \quad 0.897 \quad 0.027]$$

3) Taking T_3 as an example, according to the above process, the health status evaluation result is:

$$E = W \times B = [0.234 \quad 0.160 \quad 0.493 \quad 0.025]$$

D. Result Analysis

The decision of the result of fuzzy comprehensive evaluation usually adopts the strategy of taking the maximum subordinate degree. At T_1, the relative deterioration degree of G_{33} is more than 0.9. According to the health evaluation process of the cargo oil handling system established, the evaluation result is directly determined to be the fault state, indicating that the temperature of the cargo oil pump shell exceeds the set limit value and there is a fault. At T_2, the cargo handling system is in a fault condition. By analyzing the relative deterioration degree of each index, it is found that the deterioration degree of G_{33}, G_{34} and G_{35} is large, especially G_{33} has reached 0.8 even more, indicating that the operating temperature of the pump casing and upper and lower bearings of the cargo pump exceeds the attention value, close to the set limit value, thus causing the health status assessment result of the entire cargo handling system to be a fault condition. At T_3, the evaluation result of the health status of the cargo handling system is the state of attention, and there is a significant deterioration trend at the beginning, which requires intensive attention.

V. Conclusion

The purpose of this paper is to discuss the health status of oil tanker loading and unloading system in operation, establish a health status assessment index system for cargo handling system, calculate the degree of deterioration through operational parameters, apply the theory of variable weight to ensure the balance between indexes, and introduce a normal cloud. The model replaces the traditional membership function and establishes a health assessment model for the cargo handling system based on the degradation degree and cloud model.

Based on the monitoring data of a tanker cargo handling system, the health status was evaluated and compared with the actual loading and unloading records. The results show that the health assessment index system of the cargo handling system established in this paper is reasonable. The evaluation results obtained by the evaluation model are consistent with the actual health status, which can provide technical support for optimizing the loading and unloading tasks and maintenance strategies.

Under the background of research and development of sensing technology and multi-source sensing data fusion technology, the intelligent sensing system for data acquisition and data fusion of oil tanker cargo handling system is under development and promotion, which will be able to obtain more reflections on cargo handling during operation. The parameters of the system health status are enriched by the evaluation index system, and the accuracy of the obtained monitoring data is also greatly improved. Finally, the health condition evaluation results of the tanker cargo handling system are more practical and meaningful.

References

[1] G Arslan O, "Quantitative evaluation of precautions on chemical tanker operations," Process Safety and Environmental Protection, vol 87, pp. 113-120, 2009.

[2] Jon Ivar Håvold, "Safety culture and safety management aboard tankers," Reliability Engineering & System Safety, vol 95, pp 511-519, 2010.

[3] Martins M R , Maturana M C, "Application of Bayesian Belief networks to the human reliability analysis of an oil tanker operation focusing on collision accidents," Reliability Engineering & System Safety, vol 110, pp. 89-109, 2013.

[4] Akyuz E , Celik M, "Application of CREAM human reliability model to cargo loading process of LPG tankers," Journal of Loss Prevention in the Process Industries, vol 34, pp. 39-48, 2015.

[5] Akyuz E , Celik E, "A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers," Journal of Loss Prevention in the Process Industries, vol 38, pp. 243-253, 2015.

[6] Valdor P F , Gómez, Aina G, Puente A, "Environmental risk analysis of oil handling facilities in port areas. Application to Tarragona harbor (NE Spain)," Marine Pollution Bulletin, vol 90, pp. 78-87, 2015.

[7] Hsu W K , Lian S J , Huang S H, "Risk Assessment of Operational Safety for Oil Tankers - A Revised Risk Matrix," Journal of Navigation, pp. 1-14, 2017.

[8] CUI Wengang, FAN Houming, YAO Xi, YANG Yu, MA Mengzhi, "Risk analysis on oil spill in berthing and handling operation of oil tanker based on fuzzy Bow-tie model," Journal of Safety Science and Technology, 2016.

[9] . CUI Wengang, FAN Houming, YAO Xi, YANG Yu, MA Mengzhi, "Safety risk analysis on oil tanker berthing and handling operation based on interpretive structural model," Journal of Shanghai Maritime University, 2016.