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The Regulation of Ship-to-Ship Crude Oil Transfer at Sea: Is There A Need for an Intelligent Monitoring System?

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Abstract: Ship-To-Ship (STS) crude oil transfer at sea is an operation where crude oil is transferred between seagoing ships moored alongside each other. Due to the complex sea conditions and the poorer lightering facilities compared with the port operations, the risk of the operations is higher. Even though the frequency of incidents involving lager oil tankers has been reduced during recent decades, the consequences of such incidents can be very serious. In order to enhance regulation of STS operation and reduce risk of oil spill accidents, the study examined the existing regulation system and proposed an enhanced intelligent regulation system supported by modern Internet of Things technology. The framework of the intelligent regulation system was described in detail which included several intelligent monitoring means and a decision support system based on risk assessment.

Key words: STS crude oil transfer at sea, internet of things, intelligent monitoring, risk assessment, decision support system, fuzzy comprehensive evaluation method

INTRODUCTION

In recent years, a ship-to-ship transfer operation of crude oil is increasing and has become a common practice in the offshore marine industry. With the rapid development of Chinese economic, crude oil demand substantial increases. At present, the main way of crude oil transportation is in use of VLCC or ULCC from the Middle East or Africa (Gao, 2005; Chen, 2010) but Chinese deep water oil terminals are serious shortage, in this case, STS crude oil transfer operations are increasing rapidly. As a result, the risk of marine pollution is higher.

In order to ensure the safety of lightering operations, monitoring during the operation is essential. At present, in China the monitoring means are mainly the review of static information for the ships, equipment, personnel and so on before the transfer operation, so it lacks on-site remote monitoring means and cannot ensure the safety of the whole operation. Currently, the rapid development of some information technology, such as the internet of things technologies (Sun and Liu, 2010; Ning and Liu, 2012; Li and Chen, 2011) and successful application in other safety supervision areas provides a reference to the monitoring of STS crude oil transfer. STS transfer operation is two ships at anchor, the risk occurred during the operation is difficult to express accurately. Obviously, the risk is uncertainty, not only randomness but also fuzziness. The risk assessment of an uncertainty and ambiguity of events can use fuzzy mathematics approach (Li and Hu, 2001). Fuzzy comprehensive evaluation method is a new mathematical method that is divided out from the multi-objective decision-making. When there are many factors affecting things strongly uncertainty and ambiguity, the use of this method for quantitative analysis has obvious advantages. Fuzzy comprehensive evaluation method has got a good application in other research areas (Dahiya *et al*., 2007; Li and Ren, 2010; Chen *et al*., 2008). In this study the intelligent monitoring system is given. Meanwhile the risk assessment of great. In the event of an accident, it can cause operation as a decision support system based on fuzzy comprehensive evaluation method is discussed. A example is given to verify its applicability and effectiveness.

The risk of STS crude oil transfer operation: Due to the special working environment and equipment, the risk during the operation is huge economic losses and marine environmental hazards. The risks of STS transfer operation are various which can be summarized as following: weather conditions, equipment, personnel and ships. The key monitoring points and potential risks are shown in Table 1.

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Table 1: The risks of STS crude oil transfer operation

Key monitoring points	Monitoring objects	Potential risks
Approval and regulation		
Weather conditions	The information of wind, wave, current,etc.during transfer operations	The risks of broken cable, dragging anchor, etc.
Equipment	The evidence of inspection, maintenance, etc. of equipment such as ropes, fenders, etc.	The risks of broken cable, burst pipes, collision, oil spill, etc.
Personnel	Transfer operation personnel qualification certificate and experiment, etc.	the risks caused by operational errors
Ships	Ships relevant certificates	Ships' risks
Transfer plans	Transfer operation process and schedule	Risks caused by improper operation
Emergency planning	Incident response, emergency supplies, personnel deployment, etc.	Accident if they cannot take timely measures, causing a greater risk
Operation process		
Weather conditions	The information of wind, wave, current,etc.during transfer operation	The risks of broken cable, dragging anchor, etc.
Equipment	The operating status of equipment	The risks of broken cable, oil spill, fire, etc.
Personnel	Duty situation	Risk cannot be found in time, leading to greater accident
Ships	Dragging anchors, collisions, etc.	Dragging anchors, collisions, etc.

Monitoring status of STS crude oil lightering: To ensure safety operation, the major monitoring means are administrative examination and approval, VTS monitoring and monitoring of field staff.

The existing monitoring means can basically ensure safe operation but there are still shortcomings as following. Information degree of administrative examination and approval is low. Remote information supervision means are deficiencies. Learning the accident information lag, Graded supervision model Lack. In order to solve above shortcomings, based on the rapid development of information technology and the successful application of internet of things in other regulatory areas, this study proposes the intelligent monitoring of STS crude oil transfer at sea.

Intelligent monitoring of STS crude oil transfer: Key technologies of internet of things includes sensors and radio frequency identification technology (RFID) as the core of collecting information technology, the communication machine between man and machine (Machine/Man to Machine, M2M) as the core of nearly-remote data network communication technology, cloud computing and information fusion system as the main technology of information intelligent analysis and control technology. From these key technologies, it has been successfully developed intelligent transportation (Xu, 2012; Zhou and Chao, 2011), intelligent logistics (Liu, 2012; Shi, 2011), intelligent medical (Varshney, 2007) and other systems. The intelligent supervision of STS crude oil transfer at sea can be studied drawing lessons from the existing mature technology.

General structures: With the wider application of information technology in various fields, STS crude oil transfer at sea can apply to a variety of information technology means to achieve information administrative examination and approval before transfer operations and intelligent monitoring during the process of oil lightering operation. Information administrative examination and approval before lightering operation use RFID technology to complete information transmission, achieving studyless approval. During the process of operation, it can use international and domestic most advanced technology, such as sensors monitoring, oil spill UV monitoring, on-site video surveillance, RFID, Vector Zone Electronic Chart, network monitoring cutting-edge technology etc, to built a comprehensive monitoring system that covers the entire transfer process in time and covers the full affected area in space. Through a variety of sensors and equipment, it can get a variety of dynamic and static information. Through the internet of things technology, the information can be transmitted to the monitoring center. The monitoring center can use the information with PSC data to do risk assessment based on fuzzy comprehensive evaluation method, with the result of the risk assessment and the level of the risk, it can choose the appropriate monitoring means. It can realize intelligent supervision. According to Table 1, the general structure of STS intelligent monitoring is shown in Fig. 1.

Risk assessment: Depending on the risk during transfer operation, we establish risk evaluation system. In this system, it includes four first indexes, namely equipment subsystem, ships subsystem, marine environment subsystem, personnel subsystem and thirteen secondary indexes, corresponding to first indexes, as shown in Table 2. In this table, A= $[a_1\ a_2\ a_3\ a_4]$ is the weight vector of first indexes:

$$a_i \left(0 \le a_i \le 1\right), \sum_{i=1}^{4} a_i = 1$$

$A_i = [a_{ij}]$ (i = 1, 2, 3, 4; j = 1, 2, 3…n) is the secondary indexes:

$$a_{ij} = \left(0 \le a_{ij} \le 1\right), \sum_{j=1}^{n} a_{ij} = 1$$

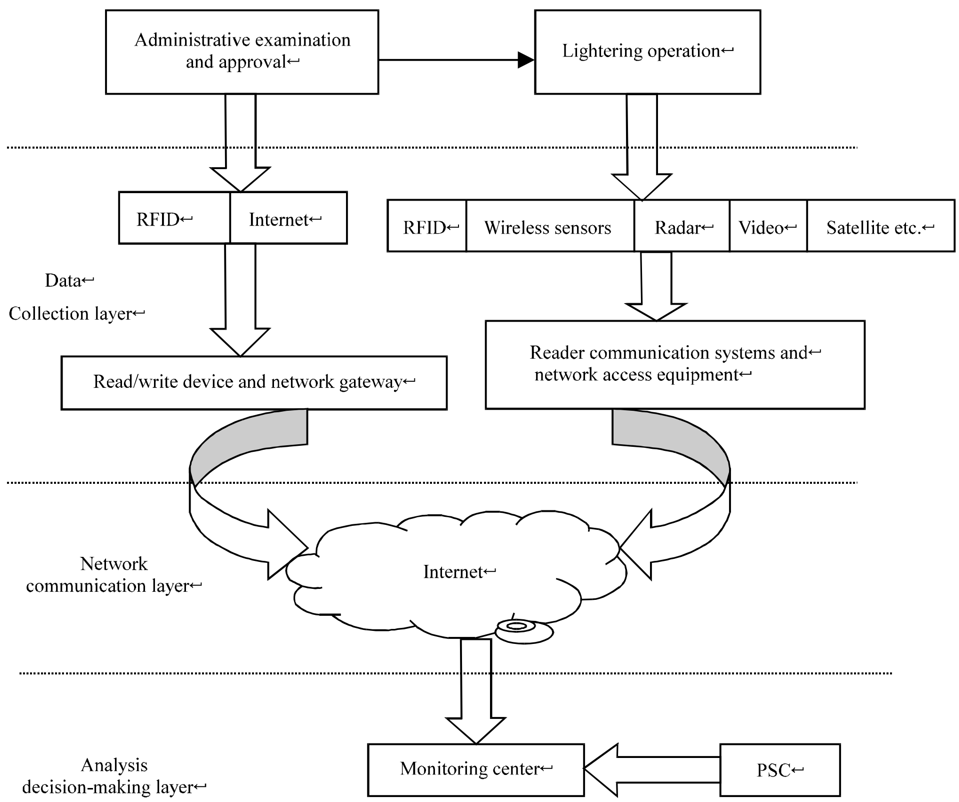

Fig. 1: the framework of the intelligent monitoring of STS crude oil transfer at sea

Table 2: Evaluation indexes of STS crude oil transfer at sea

Label	First indexes	Secondary indexes	Connotation
1	equipment subsystem a_1	equipment inspection report a_{11}	Inspection report of facilities and equipment before lightering operation
		Information technology monitoring equipment a_{12}	Remote monitoring equipment, such as sensors, video, RFID, etc.
		Status of the use of facilities and equipment during the operation a_{13}	The work status of facilities and equipment, such as fenders,hoses,etc.
2	Ships subsystem a_2	Ships age a_{21}	Ships age under 20
		Ships structure a_{22}	Single shell or double shell, tonnage, etc.
		Ship certificates, Captain qualification a_{23}	Ships relevant certificates, masters certificates
		Ship inspection report a_{24}	Inert gas equipment, deck gas concentration, etc.
3	Marine environment subsystem a_3	Marine sensitive resources a_{31}	The level of marine environmentally sensitive resources
		Weather condition a_{32}	Current, wind, wave, etc.
		anchorage conditions a_{33}	Sediment, water depth, navigation conditions
4	Personnel subsystem a_4	Transfer operating personnel qualification a_{41}	Qualifications of transfer operating personnel, operating history, etc.
		Historical experience of lightering staff a_{42}	Lightering personal qualifications and experience, lightering history, etc.
		personnel on duty a_{43}	The record of being on duty and changing shift during transfer operation, etc.

The evaluation system includes five evaluation sets that is v = {higher, high, moderate, low, lower}.

Risk assessment of STS crude oil transfer at sea adopt two level evaluation of fuzzy comprehensive evaluation method, in the evaluation process, it is important to determine the weight vectors, directly affecting the results of the evaluation. In this study, we use statistical methods to obtain the weight vectors of the first and the secondary indexes. The approach is to select experienced experts to give weight values of each indexes and then decide the weight of taking arithmetic average value and the normalized processing, eventually get the weight vectors as shown in Table 3.

Every lightering operation, according to static: and dynamic information obtained during transfer operation, by 10 experts scoring, it can get the secondary evaluation fuzzy relation matrix: R1, R2, R3, R4. Based on the secondary evaluation fuzzy relation matrix and the respective weight vector, we can get the first fuzzy relation matrix R. Do calculation using the Eq. 1:

Table 3: Weight values of every evaluation index

Label	Weight value of first indexes	Weight value of secondary indexes
1	$a_1(0.240)$	$a_{11}(0.315)$, $a_{12}(0.240)$, $a_{13}(0.445)$
2	$a_2(0.230)$	$a_{21}(0.250)$, $a_{22}(0.210)$, $a_{23}(0.260)$, $a_{24}(0.280)$
3	$a_3(0.245)$	$a_{31}(0.260)$, $a_{32}(0.385)$, $a_{33}(0.355)$
4	$a_4(0.285)$	$a_{41}(0.325)$, $a_{42}(0.355)$, $a_{43}(0.320)$

$$B = AR = \{b1\ b2\ b3\ \ldots\ bn\} \tag{1}$$

In the above formula, B is output fuzzy vector. We can get the risk level in this lightering operation.

An example: In order to verify the effectiveness and feasibility of this method, an example is given. October 12, 2012-October 13 2012 in Ningbo Beilun 9 # anchorage, a transfer operation will start. The discharge ship is ANTOMIS, length: 333.27M, breadth: 58M, draft: 19.50M, tonnage: 160100.00T, Nett tonnage: 109604.00T, DWT: 309371.00T; It plan to discharge 54000T oil. In the anchorage, Beaufort force is 5.7, current is small. According to the actual operation, by 10 experts scoring, it got the secondary evaluation fuzzy relation matrixes as following:

$$R1 = \begin{bmatrix} 0 & 0 & 0.5 & 0.5 & 0 \\ 0.5 & 0.3 & 0.2 & 0 & 0 \\ 0 & 0 & 0.6 & 0.3 & 0.1 \end{bmatrix}$$

$$R2 = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0. & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0.3 & 0.3 & 0.4 & 0 \end{bmatrix}$$

$$R3 = \begin{bmatrix} 0 & 0.5 & 0.3 & 0.2 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5 & 0.5 \end{bmatrix}$$

$$R4 = \begin{bmatrix} 0 & 0 & 0 & 0.3 & 0.7 \\ 0 & 0 & 0 & 0.1 & 0.9 \\ 0 & 0 & 0 & 0.2 & 0.8 \end{bmatrix}$$

According to the weight vector of the secondary indexes and evaluation fuzzy relation matrix, we can also get the first evaluation fuzzy relation matrix as following:

$$R = \begin{bmatrix} 0.12 & 0.072 & 0.315 & 0.291 & 0.202 \\ 0.23 & 0.314 & 0.084 & 0.112 & 0.26 \\ 0.231 & 0.284 & 0.078 & 0.2295 & 0.1775 \\ 0 & 0 & 0 & 0.197 & 0.803 \end{bmatrix}$$

According to the Eq. 1, B = AR = {b1 b2 b3 … bn}, the result is shown as the following:

$$B = AR = \begin{bmatrix} 0.240 & 0.230 & 0.245 & 0.285 \end{bmatrix} \begin{bmatrix} 0.12 & 0.072 & 0.315 & 0.291 & 0.202 \\ 0.23 & 0.314 & 0.084 & 0.112 & 0.26 \\ 0.231 & 0.284 & 0.078 & 0.2295 & 0.1775 \\ 0 & 0 & 0 & 0.197 & 0.803 \end{bmatrix} = \begin{bmatrix} 0.138295 & 0.15908 & 0.11403 & 0.2079725 & 0.3806225 \end{bmatrix}$$

The above calculation result is corresponding to the membership degree of evaluation set, namely the membership of higher-risk is 0.138295, the membership of high-risk is 0.15908, the membership of moderate risk is 0.11403, the membership of low-risk is 0.2079725 and the membership of lower-risk is 0.3806225. According to the principle of maximum membership degree, this risk level of this lightering operation is low risk. After verification with the actual situation, the evaluation results and the theoretical results fit well with the actual level of risk, verify the reliability of this method.

CONLUTION

STS crude oil transfer at sea is associated with China rapid economic development and a gradual increase in demand for crude oil. Due to the complex sea conditions and the poor lightering equipment, the risk of the operations is higher. As the rapid development of information technologies, especially the internet of things technologies in the sensor monitoring, data transmission, the existing monitoring tools can achieve transparent monitoring for crude oil transfer operations. From a long-term technology development trend, lightering ships equipped with information technologies to strengthen monitoring. Accurate and efficient monitoring means can real-time access to operation information and find signs of an accident. Based on the establishment of information supervision networks, maritime supervision authorities use fuzzy comprehensive evaluation method to establish risk assessment mode and develop intelligent monitoring decision support system. According to different operation risk grade adopts hierarchical intelligent monitoring schemes to save manpower and improve efficiency. It also makes limited manpower and material resources focus on high-risk operations monitoring, enhancing the overall security of STS crude oil transfer operations.

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