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An Approach on the Evaluation of LNG Tank Container Transportation Safety

Feiyu Meng[1], Li Ma[2] and Xuefeng Wang[3]
[1]Master, College of Transportation and Communication, Shanghai Maritime University, The People's Republic of CHINA
[2]Master, College of Transportation and Communication, Shanghai Maritime University, The People's Republic of CHINA
[3]Professor, College of Transportation and Communication, Shanghai Maritime University, The People's Republic of CHINA

[1]Corresponding Author: 1687941529@qq.com

ABSTRACT

As a clean energy source, liquefied natural gas (LNG) has been widely accepted all around the world. As a way to transport LNG, tank container transportation is becoming more and more popular. However, how to carry out safety management for the whole transportation process of tank container is a problem troubling the whole industry. Therefore, this paper proposes a model based on the Recurrent Neural Networks(RNN) to evaluate the safety performance. First, find the factors affecting the safety of LNG transport by sea and construct an index system. Next, design a questionnaire and get scores from supporting experts. Then, this paper utilize the trained RNN to judge the safety statue of LNG tank transportation. Through the comparison of training results and the final score got from experts, the result shows that the MAE is negligible and prove the effectiveness of the RNN. Finally, a case study was conducted. From the analysis of the training results, it is known that enterprise safety management plays an important role in transportation safety and a better safety management system will greatly reduce the probability of accidents and improve the transportation safety.

***Keywords*--** LNG Tank Container, Index System, RNN, Case Study, Safety

I. INTRODUCTION

1. 1 Background & Significance

In the past, oil and coal have been the major sources of energy consumption in China, but the utilization of them emits sulfur dioxide, soot and other atmospheric particles, leading to environmental pollution. As a clean energy, LNG complies with the requirements of international policies on energy consumption. Therefore, in order to protect the environment, China began to use gas instead of oil and coal. The utilization of LNG helps to improve China's energy structure and is of great significance to the development of China's economy. China's LNG demand will reach 25 million tons per year, nearly35 billion cubic meters by 2020 [1]. However, current production capacity of China does not match the market demand, so, the import of natural gas makes a lot of sense to China. The existing transport modes of naturagas include pipeline, road, railway and sea transport. Pipeline transport is merely suitable for the gas projects of domestic or importing from neighboring inland countries. And other transport modes have not been well integrated. In recent years, the mode of tank container transport has been developed, which has many great advantages, such as more economic, convenient, effective and safe.

The main transportation modes of LNG tank container are road transport, railway transport and sea transport. Road tank container transportation is a kind of short-distance transportation with a single tank and the transportation of which is basically the same as other tank transportation. This mode only be applied to inland transport and the haulage is very small, however, that is an indispensable part of the whole transportation since the accomplishment of transport depends on the "last mile" transport to the customer [2]. Compared with road transport, railway transport has numerous limitations, such as vast infrastructure and strict technical requirements on safety. However, the advantage of low costs make railway transport more suitable for long-distance inland transportation. LNG tanks, whose shipping mode is consistent with the regular container, are shipped by sea in the form of containers. But it should not be ignored that LNG tank containers must be loaded in the cabin area, far away from the living place, and on the top layer, meeting the requirements for stowage of movable tanks and class 2.1 dangerous goods in IMDG code and Rules for the carriage of dangerous goods by water [3].

In addition, the transportation of LNG tank container primarily follows several supporting rules ,including the rules for the transport of dangerous goods, for mobile containers and others international conventions [4] [5].At present, the construction of laws and regulations related to LNG transportation has been generally mature in United States and some European countries, but the international laws and regulations are mostly based on the standards of Europe and America, that not suit China's

situation. If the policies of LNG transportation are perfect in China, it will tremendously promote the development of LNG tank container transportation industry.

It is still at the early stage about Tank container transportation in china, there is no a standard transportation safety evaluation system. Through the study of this paper, all the manager can get a reference to understand the key factors affecting the safety of transportation, know their own weakness and improve the safety performance in future transportation.

The remainder of the article is organized as follows. Section 2 reviews the related literature. Section 3 studies how to establish the safety index system for the transportation of LNG in tank container and use the RNN to calculate the factors that affects the safety of tank container transportation, and get the weight of them. Section 4 conducted the case study of Sinochem International Corporation. The summary and review of deficiencies in Section 5.

II. LITERATURE REVIEW

LNG's transportation follows the mode of dangerous goods transportation management. Lalit[6] quantitatively analyzes the risks of crude oil transportation, and expounds the possible safety problems in crude oil transportation through the simulation model. Constantine[7] illuminates the significance of safety in crude oil transportation and the security problems existing in the port. Then, emphasized the safety management in port plays an important role in the chain of crude oil transportation. Qian[8] builta multi-level safety evaluation index system based on the relevant regulations and current situations of the road transportation enterprise of dangerous goods.

Due to the nature of LNG explosion and liquefaction, the main research on LNG safety transportation focuses on the design of LNG carrier and LNG tank. Sergeichev[9], through the safety research of corrosive chemicals and petrochemical products under multi-modal transport, put forward some measures to optimize the design and manufacture of tank container. He also built a three-dimensional finite element model to analyze the strength of tank container and get the result that the strength meets regulatory requirements. Edward[10] analyzes the heat insulation capabilities of LNG tank containers and carry out heat insulation simulation for different designed tank containers with FEM model. The results shows that the tank containers with simple internal structure has better effect than those with complex. However, the study on the safety performance of LNG from the whole transportation process is still lacking.

In recent years, neural networks have made great achievements in many fields. For example, safety assessment, risk assessment etc., Goldarag[11] created a fire risk prediction model based on neural network, The result shows that neural network model is more accurate in fire point classification than others model. Peng and Sun[12] apply BP neural network to establish risk assessment model and use MATLAB to process the learning. The result shows that the method provides an effective method for e-commerce risk assessment, and has broad application prospects. Qiao and Lin[13] construct a financial credit risk evaluation index system of small and medium-sized enterprise based on supply chain, then use the BP neural network model to analyze credit risk of small and medium-sized enterprise and predict their financing credit level in order to provide the basis for Commercial Banks for credit. But in a evaluation system, all factors affecting security have interaction with others, while RRN has the advantage to handle that of inputs. Yao and Li[14], aim at the problem of congestion prediction in urban traffic network based on improved RNN algorithm. Through many simulation experiments, the results show that the prediction accuracy of traffic congestion period is the highest to 88%.Hu[15] propose a method to predict network security situation based on RNN and verify the feasibility and accuracy of model through simulation experiments.

III. METHODOLOGY

3.1 Index System

3.1.1 Design Logic

The construction of index system is a core part of evaluation system and key factor to influence the reliability of the result of a evaluation. In order to identify all the factors which have a great impact on the transport of LNG, three representative methods are utilized in this paper, which are survey study method, target decomposition method and multivariate statistics method[16].

3.1.2 Selection

The transportation process of LNG tank container in the sea was divided into three parts, the load of LNG, the transportation and the unload. And the nature of LNG, tank, supporting facility, management, environment, and the operator will make a big difference in the whole process[17]. Any problem happened will influence the transport safety greatly. After the comprehensive understanding of all the factors above, this paper get some points that have some effects on the safety of LNG transportation from each factor in detail. Finally, 20 points are got and All of them be showed in the under sheet.

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Table1Safety Index Evaluation System

Aim	First class indexes	Second class factors
The factors affecting the safety of LNG tank container transportation U	The LNG physical and chemical properties U_1	Harm to human U_{11}
		harm to equipment U_{12}
		Other harm U_{13}
	The related factors of tank U_2	Tank design U_{21}
		Material of tank U_{22}
		Secure attachment U_{23}
		Thermal insulation layer U_{24}
		Filling quantity U_{25}
	The factors of others supporting equipment U_3	Equipment design U_{31}
		Working life U_{32}
		Routine maintenance U_{33}
	The factors of people U_4	Professional knowledge U_{41}
		Working years U_{42}
		The comprehensive quality U_{43}
	The factors of safety management U_5	Safety precautions U_{51}
		Emergency response U_{52}
		Information management system U_{53}
		The training and assessment of worker U_{54}
	Geography or environmental factors U_6	Geological conditions U_{61}
		Weather U_{62}

3.2 Safety evaluation

3.2.1 RNN

Among the comprehensive evaluation methods for complex systems, the common ones include Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE), BP Neural Network Method, Data Envelopment Analysis (DEA), etc., which have some flaw of subjectivity, randomness and information loss. The

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purpose of this paper is to scientifically evaluate the safety status of LNG sea transport, where the factors listed above have interactions with each other. In order to describe the correlation of those indexes, we choose the Artificial Neural Network (ANN) to deal with this problem. Artificial Neural Network (ANN) is one of the more popular technologies in the field of deep learning in recent years, which has shown great promise in machine translation, speech recognition and image recognition [18]. In traditional neural networks, neurons in each layer are fully connected with those in the next layer. While those neurons in the same layer have no connections, which means that all input and output layers are independent of each other. But in the reality, the factors always have some relations with others and sequence information need to be processed in some tasks. RNN, through adding the connection of neurons in same layer, has a abilities to deal with correlation between those inputs. The working principle of RNN is that RNN will reserve the information input before and apply that into current calculation of output, which refers to the input of hidden layer not contain the output of the input layer, but the output of the hidden layer last moment. The essence of it is the ability to remember like a person [19]. RNN, used to handle sequence information, can easily achieve the purpose of model construction and has a higher performance of the accuracy.

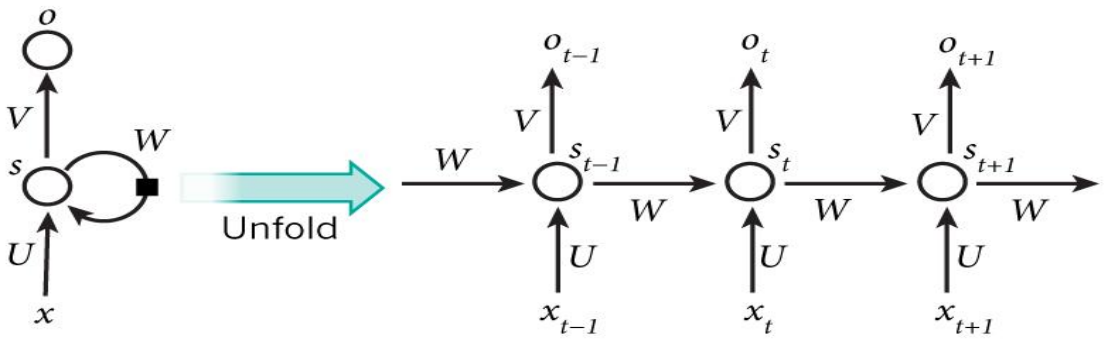

Fig.1: The RNN model schematic

The formulas that govern the computation happening in a RNN are as follows [20]:

x_t is the input at time step t.

s_t is the hidden state at time step t. It's the "memory" of the network. s_t is calculated based on the previous hidden state and the input at the current step: $s_t = f(U_{x_t} + W_{S_{t-1}})$. The function f usually is a non-linearity such as Tanh or ReLU. S_{t-1}, which is required to calculate the first hidden state, is typically initialized to zero. W is the self-connecting matrix of hidden layer neurons, U is the connection weight matrix from the input layer to the hidden layer, V is the connection weight matrix from the hidden layer to the output layer, O_t is the output at time step t.

There is something we need to focus: Unlike a traditional deep neural network, which uses different parameters at each layer, a RNN shares the same parameters (U, V, W above) across all steps. This reflects the fact that we are performing the same task at each step, just with different inputs. This greatly reduces the total number of parameters we need to learn.

Because of the advantage of RNN and the nature of factors, the RNN is utilized to evaluate the safety of LNG marine transport. The model can reasonably reflects the connection between the factors and gives a better result.

3.2.2 model construction.

(1) the quantification of indexes

The input to RNN are vectors, not strings. So we set up a mapping between number and factors. All evaluation factors were quantified to the closed interval [0,1] in this paper. Because when using the integer activation function, if all figures are positive, there would be no situation where negative gradient need to be calculated. The quantified data would be easier to train in process of forward propagation and that is conducive to the network convergence.

(2) input layer

Through the analysis of the factors that affect the safety of LNG container in sea transportation, this paper confirm six first level indexes and twenty second level factors, which means that the input layer has 20 neurons. And this paper simplifies them to one to easily show in the fig 3-3 below.

(3) hidden layer

The hidden layer consists of two layers, the first layer contains four LSTM neurons, the second layer include

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ten neurons. Each neuron receives only one data at a time. Due to the different initialized weights, the data will carry out different linear mapping in first layer. Then, the hidden information of each data is preserved and used in the next time. Next, the input layer continues to receive data and repeat the process above until all 20 factors are input completely. Finally, connecting with the second layer, the output of first layer will do linear mapping again.

(4) output layer

The purpose of this paper is to determine the safety status of LNG transportation. The final output result of the model is the comprehensive safety value, therefore, the number of neuron in output layer is one.

(5) Finally, the Jacobian matrix composed of the weights of each neurons is obtained by BPTT algorithm. Then, use it to update the current weight and train RNN model. The training iteration is taken as 5000.

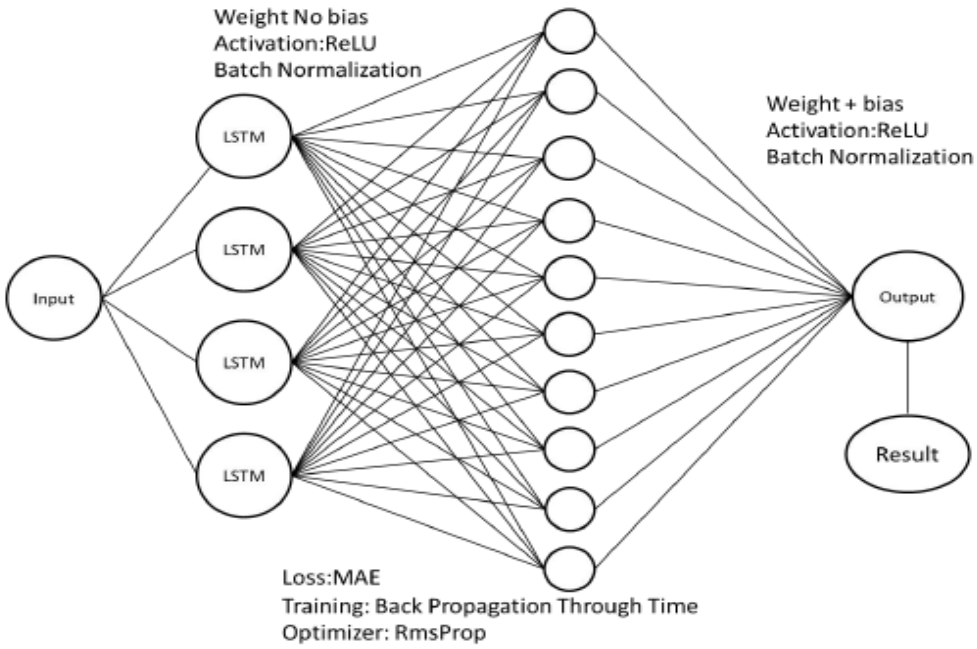

Fig. 2: the structure of RNN used in this paper

Figure 3-3 is the structure of the RNN, the design of each layer is given below:

Layer 1: LSTM (4neurons) without bias.

Layer 2: Full connected layer (10neurons), use bias and the activation functions ReLU

Layer 3: Output layer (1neurons), without bias, get the final score, loss value: Mean Absolute Error (MAE).

The programming language used in this paper is Python3.6. The source code and interpreter of Python follow the GPL(General Public License) protocol. Python can call various extended libraries with abundant functions, and this paper uses klearn, Scipy, Numpy, Keras, etc..

3.2.3 Model Evaluation

The index system contains both qualitative index and quantitative index. As to quantitative index, we can get the accurate data through looking up some related material. To the qualitative index, this paper gets a score via expert scoring method. The scores are divided into five grades: excellent, good, fair, poor and worst, which are shown in table 2.

Table 2: Rating scale

Safety condition	excellent	good	fair	poor	worse
Score interval	0.8-1.0	0.6-0.8	0.4-0.6	0.2-0.4	0-0.2

After the end of aforesaid tasks, this paper consult 10 transportation cases of LNG tank container that come respectively from The Sinochem International (holding)co., LTD., Zhenhua Logistics Group co., LTD., Tianjin Store New Energy Development co., LTD. etc. Then, twenty questionnaires well designed were sent to experts with

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supporting experience in the transport of dangerous goods. The experts include ocean shipping company personnel, middle managers in energy companies, ship company managers, and university professors who conduct research on related subjects.

Finally, thirteen questionnaires were received, and ten were actually valid. All the details are as follow.

Table 3: The Data of Learning Sample

Factor	1	2	3	4	5	6	7	8	9	10
U_{11}	0.9	0.8	0.9	0.5	0.7	0.9	0.6	0.7	0.7	0.7
U_{12}	0.4	0.3	0.5	0.3	0.3	0.4	0.4	0.3	0.4	0.3
U_{13}	0.3	0.4	0.2	0.2	0.4	0.4	0.3	0.2	0.3	0.4
U_{21}	0.4	0.5	0.5	0.6	0.6	0.4	0.6	0.4	0.6	0.4
U_{22}	0.2	0.4	0.3	0.2	0.4	0.6	0.2	0.5	0.4	0.5
U_{23}	0.8	0.5	0.6	0.8	0.6	0.8	0.6	0.5	0.7	0.8
U_{24}	0.1	0.3	0.3	0.2	0.2	0.2	0.1	0.3	0.1	0.3
U_{25}	0.6	0.8	0.6	0.5	0.7	0.5	0.5	0.7	0.5	0.7
U_{31}	0.7	0.8	0.8	0.7	0.8	1	0.9	0.8	0.7	0.7
U_{32}	0.8	0.9	1	0.8	0.7	0.8	0.9	1	0.6	0.8
U_{33}	0.3	0.2	0.4	0.5	0.4	0.3	0.4	0.3	0.3	0.4
U_{42}	0.7	0.6	0.5	0.6	0.7	0.5	0.5	0.6	0.7	0.6
U_{43}	0.4	0.5	0.4	0.4	0.3	0.6	0.6	0.4	0.5	0.4
U_{51}	0.4	0.3	0.4	0.2	0.5	0.4	0.5	0.2	0.4	0.5
U_{52}	0.5	0.6	0.4	0.7	0.5	0.6	0.4	0.6	0.5	0.5
U_{53}	0.8	0.9	0.9	1	0.8	0.8	0.6	0.9	0.8	0.7
U_{54}	0.2	0.1	0.3	0.4	0.2	0.4	0.3	0.2	0.2	0.3
U_{61}	0.2	0.2	0.2	0.2	0.3	0.3	0.1	0.2	0.3	0.2
U_{62}	0.7	0.9	0.8	0.5	0.7	0.8	0.5	0.7	0.7	0.5

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Final Score	0.58	0.62	0.61	0.49	0.55	0.69	0.68	0.47	0.62	0.66

According to the feature of safety evaluation of LNG tank container transportation, this paper optimize the RNN model through some programs. First, call Keras serialization model, Second, add structure of each layer through Model.add（）. Third, the Model. Compile（）is used for compilation, the MAE is regarded as the loss value. Final, the RMSprop is used to optimize gradient training. Only in this way, will the error of final result be as low as possible.

3.2.4 Training Results

Through training and 5000 times iterations, the MAE is 0.0052, this figure is negligible, which means that all of the output are fitting with the final score of ten case. The MAE is shown in figure 3.

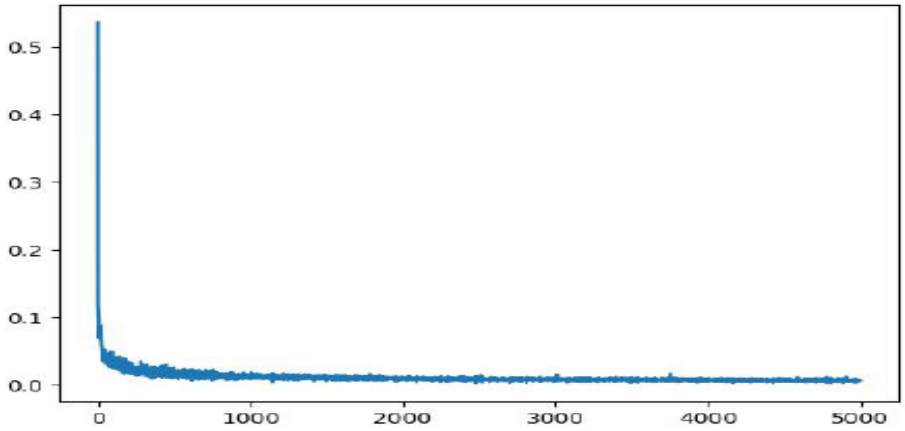

Fig.3: Training absolute average error

The weight and rank of every second class factors is listed:

Table 4: The weight and rank of each factors

Sequence	Sign	Name	Weight
1	U_{43}	The comprehensive quality	0.44833333
2	U_{51}	Safety precautions	0.17111111
3	U_{54}	The training and assessment of worker	0.12222222
4	U_{24}	Thermal insulation layer	0.11666667
5	U_{52}	Emergency response	0.03333333
6	U_{53}	Information management system	0.0277778
7	U_{23}	Secure attachment	0.01944444
8	U_{41}	Professional knowledge	0.01388889
9	U_{21}	Tank design	0.01388889
10	U_{22}	Material of tank	0.01388889
11	U_{33}	Routine maintenance	0.01111111
12	U_{25}	Filling quantity	0.00555556
13	U_{11}	Hazard to human	0.00277778

14	U_{12}	Hazard to equipment	0
15	U_{13}	Other hazards	0
16	U_{31}	Equipment design	0
17	U_{32}	Working life	0
18	U_{42}	Working years	0
19	U_{61}	Geological conditions	0
20	U_{62}	Weather	0

Given the information above, it can summarize that among the six first-class indexes, The factors of people U_4 has the biggest impact on the safety of transport, next are The factors of safety management U_5, The related factors of tank U_2, The factors of others relevant equipment U_3, LNG physical and chemical properties U_1 and Geography or environmental factors U_6.

Among the factors, most of those not only have a great impact on the process of transport, but also are affecting each other. This model utilizes the advantages of RNN to process this factors, making the training results more science. What's more, the rank of this factors will provides a reference to the companies about what should focus preferential in the management of LNG transportation. The manager learn the vulnerabilities of LNG tank transport and make targeted rules and corresponding management measures, so as to decrease the risk of accident and make transportation more safe.

The safety management of enterprises is essential to ensure the smooth completion of transportation. Without a good safety management system, the probability of the occurrence of dangerous accidents cannot be reduced and the safety cannot be guaranteed. While the factor of people determine directly the result of transportation. The enterprises should pay attention to safety management and personnel training and examination. Do a good job in security management is the defense of first line for transportation safety. Personnel training and examination will allow employees to have specialized knowledge and operation level that can not only improve the efficiency of transport, but also influence whether the front-line employee can finish the work tasks perfectly. In the analysis of historical accident case of LNG tank container transport, the case caused by human improper operation accounted for a third, while the training result of RNN also shows that the factors of people ranks high and the personnel training and examination have a great influence in the factors of people. If enterprise can carry out strict screening and control on personnel recruitment, training and assessment, transportation accidents will be reduced and safety performance will be improved.

IV. CASE STUDY

4.1 Description

In order to promote the development of LNG in china, Sinochem International Corporation signed a contract with LNG terminal in Belgium. The implementation of that is divided into three stages:

This paper select one tank from the stage 2(Sinochem sent 6 clean empty tanks to Antwerp, which carry data collector to monitor medium) for the safety evaluation. All massage of medium is shown in Tab 5.

Table 5: Filling Goods Situation

LNG composition（Mol%）						
N_2	CH_4	C_2H_6	C_3H_8	i-C_4H_{10}	n-C_4H_{10}	n-C_5H_{12}
0.038	92.551	7.319	0.082	0.005	0.005	0.004
LNG temperature		-159℃	Filling volume			39.09m³
LNG density		440.6kg/m³	Filling weight			17220kg

Discharge: After more than 30 days transportation, the tank was delivered to the destination. Before discharging, the monitor displayed the pressure of in tank is 1.6 bar and the temperature of tanks is minus 148.8 ℃, both showed a good heat preservation and leakage-proof performance. There is no danger accident and no loss of the medium in whole course.

4.2 Result

Through the in-depth investigations to Sinochem combined with expert opinions and supporting internal data, This paper mark every indicator given in table 6. Then, the RNN was utilized to evaluate its safety performance.

Table 6: Index Scores

U_{11}	U_{12}	U_{13}	U_{21}	U_{22}	U_{23}	U_{24}	U_{25}	U_{31}	U_{32}	U_{33}
0.4	0.4	0.3	0.7	0.7	0.5	0.8	0.4	0.5	0.3	0.5
U_{41}	U_{42}	U_{43}	U_{51}	U_{52}	U_{53}	U_{54}	U_{61}	U_{62}		
0.7	0.5	0.8	0.9	0.8	0.5	0.9	0.2	0.3		

Through the calculation of the trained RNN, this paper get the result 0.6942078. According to table 3-3, we know the safety condition of this transportation is good.
The case above is selected from the representative one in China. The result shows the safety condition be accordance with reality. That indicates the application of RNN to evaluate the LNG tank container transportation safety is feasible and can make progress in the development of LNG containerized transport in China.

It is a new attempt to apply the RNN to evaluate the actual transportation process. This paper lists a series of factors that influence the safety of LNG tank container transportation for enterprise. That not can help manager concentrate on their own weaknesses easily ignored to make improvements and increase the safety performance, but provides a system that can be applied to evaluate the safety condition for the LNG transport companies to make some improvements.

V. CONCLUSION

This paper analyzes the current and future situation of LNG energy demand in China, the main mode of LNG tank transport, the supporting rules and drawback, the meaning of developing the safety evaluation system.

Through the comprehensive analysis of all aspects of LNG maritime transportation, this paper finds out the influencing factors affecting the safety of the whole process and constructs a index evaluation system. This paper applies the model of RNN trained by the case already finished to case study and proves the feasible and scientific of RNN. Combining the suggestions given, it can reduce losses and improve the safety of LNG maritime transport.

It is a new period for world energy consumption, LNG, as a clean and high-quality fossil energy, is playing an increasingly important role in the energy pattern. Making full use of LNG can make up for the shortage of petroleum resources in China and reduce the cost, optimize the energy structure and gradually improve China's environmental quality. It is of great practical significance for China to understand the world LNG trade, market demand and supply, resource reserves, transportation mode, price mechanism, contract terms to develop LNG industry.

Based on the theory research of the RNN, this paper constructs a safety evaluation model to understand the status of the tank transportation. It makes a lot of sense to LNG industry to reduce risk index, make up the defects and improve the management of LNG tank transport. It also provides certain theoretical guidance and reference for major LNG transportation companies.

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