A Bayesian Network-Based Approach to Port State Control Ship Detention Risk Assessment

Dingheng Yu[1,2] , Bing Wu[2,3] , Pei Chen[4]

(1. School of Transportation and Logistics Engineering, Wuhan University of Technology, Wuhan, Hubei, 430063; 2. Intelligent Transport Systems Research Centre, Wuhan University of Technology, Wuhan, Hubei, 430063; 3. National Engineering Research Center for Water Transport Safety (WTSC),Wuhan, Hubei, 430063; 4. Dong jiakou Maritime Safety Administration, Qingdao, Shandong, 266002)

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Abstract

Building a ship detention risk model can help Port State Control Official (PSCO) to accurately select ships with higher detention risk and improve the efficiency of port state supervision. This paper uses data from a total of 1893 ship inspection reports in the Data Paris MoU database to construct a model using Bayesian Network (BN), and uses sensitivity methods to analyze the relationship between the influence of inherent ship attributes, PSC inspection items, the number of ship defects and ship detention. The results show that pollution prevention, navigation safety equipment and the number of defects are the key inspection items affecting ship detention, and when the ship has the above defects, the ship detention rate increases to 12.85%, 11.07% and 22.19% respectively. Therefore, the key inspection items can be prioritized to determine the ship condition, quantitatively analyze the ship detention risk and provide suggestions for port state authorities to make ship detention decisions.

1. Introduction

The port state supervision system gives port state authorities the right to order defective ships to rectify and implement ship detention[1,2,6] , but due to the numerous items and cumbersome processes of port state supervision inspection, which may delay the progress of the ship or even cause unnecessary economic losses[3,4,7] . How to quickly select ships with defects and high risk of detention is a key concern for maritime authorities[8,9] . The main purpose of port state supervision is to ensure navigation safety and reduce marine pollution, therefore, this paper proposes a model for ship detention risk using Bayesian network modeling method[10,11,12] , which relies on historical data and expert judgment to calculate the probability distribution of events, and quantifies the ship detention risk from three aspects: inherent properties of the ship itself, number of defects, and PSC inspection items, and provides reference for port states to make detention decisions Recommendations.

2. Bayesian network model construction

2.1 Data sources

The data in this paper are mainly from the Paris Memorandum PSC data inspection database, with a total of 4409 defective ship port state supervision inspection data for three months from July 2021 to September 2021. The data contain ship type, flag, deadweight tonnage, inspection type, IMO number, number of defects, inspection report of PSC inspection items, inspection time and whether the ship was detained or not. Since this paper studies the relationship between ship defects and ship detention, only the data of 1893 ship inspections with defects are used.

2.2 Data processing

Based on the Paris Memorandum PSC inspection database, a total of 19 PSC inspection detention risk influencing factors were identified and two virtual nodes were created as well as the nodes for whether the ship was detained or not, represented in a Bayesian network with 22 nodes. The status of each factor is as

follows[13,14] .

(1) Age of the ship. The age of a ship is one of the inherent properties of the ship itself and one of the important factors affecting PSC inspection. In this paper, the ship age is divided into three states, which are 1-10 years, 11-20 years and more than 20 years.

(2)Type of ship. Different types of ships have different risks of detention and occurrence of various inspection defects. As there are many ship types, classifying all ship types one by one will lead to extremely complicated node types, but after data analysis, it is found that three types of ships occupy a great proportion, so the ships are divided into four types of ships, namely bulk carriers, general cargo ships, container ships and other types.

(3) Classification societies. The International Association of Classification Societies (IACS) is an international organization composed of classification societies from developed countries in maritime transport, which maintains close cooperation with the world maritime industry, and its members are American Bureau of Shipping Inspection (ABS), French Classification Society (BV), Korean Classification Society (KR), Lloyd's Register (LR), DNV GL, Japan Maritime Association (NK), Polish Register of Shipping (PRS), Italian Classification Society (RINA) and other 12 full members. Therefore, the certified classification societies are divided into two kinds: international classification society certification and non-international classification society certification.

(4) Type of inspection. The port state supervision prosecutor will make an overall judgment on the ship's appearance before the inspection on board, and if obvious defects such as the ship's condition or equipment does not match with the items contained in the actual certificate are found, a detailed inspection will be conducted, and an extended inspection will be conducted if necessary. Therefore, the inspection type variables are divided into 3 states, namely initial inspection, detailed inspection, and extended inspection.

(5) Flags. In the annual report of the Paris Memorandum, flags are classified as blacklisted, whitelisted and greylisted according to the performance assessment and detention history of each flag state[5] . Only flags that have participated in more than 30 PSC inspections in the last three years will be included in the list, otherwise the flag status will not be listed. In this paper, the inspection records that do not list the status of the flag are removed and the flag variable status is set to white, gray and black.

(6) Number of defects. Ships may have multiple defects when they are inspected by PSC. Through data analysis, it is found that the probability of a ship being stranded is significantly increased when the number of defects is more than 3 defects and 6 defects. Therefore, the number of ship defects is divided into three states, which are: 1-3 defects, 4-6 defects and more than 6 defects.

(7) Deficiency status. After the PSC inspection of a ship, a report list is made to record the details of the inspection items. In this paper, the inspection results are transformed into two states of 0 and 1, where 0 means no defects are found in such inspection items of the ship and 1 means defects are found in such inspection items of the ship, which may affect the safety of ship navigation or will cause marine pollution and need to be rectified.

(8) Virtual nodes. Since there are many ship inspection items, connecting all of them to the same node will lead to complicated Bayesian network model nodes and difficult CPT calculation. In order to solve the above problems, two virtual nodes "ship inherent property" and "ship appearance" are introduced, and the states of the nodes are 0 and 1 respectively. In the node of "ship inherent properties", the state 0 means the ship has 10% probability to be detained, and the state 1 means the ship has 90% probability not to be detained; in the node of "ship appearance", the state 0 means the ship has no obvious defects in structural condition and wind and rain protection condition, and the state 1 means the ship has at least one obvious defect in structural condition and wind and rain protection condition. The variables and states of each network node are shown in Table 1

Table 1 Network node variables and node states

Variables	Node Status
Ship Age	1-10/11-20/over 20
Ship Type	Bulk Carrier / General Cargo / Container Ship / Others
Classification Society	IACS Certification / Non-IACS Certification
Type of Inspection	Initial inspection, more detailed inspection, extended inspection
Flag Type	White/Gray/Black
Certificate and Documentation	No defect / defective
Structural Conditions	No defect / defective
Water/Weathertight Conditions	No defect / defective
Emergence Systems	No defect / defective
Radio Communications	No defect / defective
Fire Safety	No defect / defective
Alarms	No defect / defective
Ballast Water	No defect / defective
Safety of Navigation	No defect / defective
Life-saving Appliances	No defect / defective
Propulsion and Auxiliary Machinery	No defect / defective
Pollution Prevention	No defect / defective
ISM	No defect / defective
Other	No defect / defective
Inherent Properties of Ships	No defect / defective
Vessel Appearance	No defect / defective
Number of Deficiencies	1-3/4-6/超过 6
Detention	Yes/no

2.3 Model construction

After analysis, the factors influencing ship detention were categorized into four major categories, namely: inherent ship attribute information, navigational safety, pollution prevention, and number of defects. The ship's inherent property information includes: ship's age, ship type, certified classification society, and flag; navigation safety check items include: main power and auxiliary equipment, fire safety equipment, life-saving equipment, radio system, emergency system, international safety management regulations, and alarm system; pollution prevention check items include: certificates and documents, ballast water system, and international safety management regulations; number of defects check items include: structural condition, Water and weatherproof condition, inspection type, and virtual node ship appearance. The Bayesian network model shown in Figure 1 is obtained by Bayesian network learning.

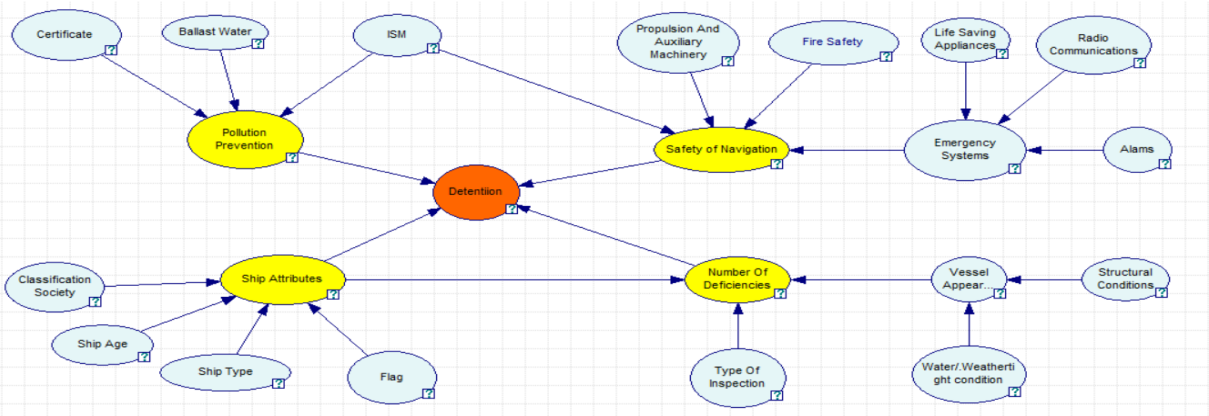

Fig. 1 Bayesian network model of s hip detention

2.4 Node parameter conditional probability table calculation

2.4.1 Calculation of the prior probability of the PSC check term node

According to the Paris memo data, the distribution of the probabilities of the PSC check term nodes can be obtained by combining the Bayesian network model, as shown in Table 2.

Table 2 Calculation results of the probability of PSC

Node Variables	Node probability (without defects)	Node probability (defective)
Certificates and Documents	0.601	0.399
Ballast water	0.936	0.064
ISM	0.790	0.210
Main power and auxiliary equipment	0.844	0.156
Fire Safety	0.619	0.381
Life-saving equipment	0.769	0.231
Radio System	0.922	0.078
Alarm system	0.958	0.042
Structural conditions	0.801	0.199
Waterproof and weatherproof condition	0.854	0.146

2.4.2 Calculation of the a priori probability of the nodes of inherent properties of the ship

Each ship has different state nodes for inherent attributes such as age, flag, classification society, and ship type, and the calculation results of CPT for each node are shown in Table 3.

Table 3 Calculation results of the probability of inherent properties of ships

Node Variables	Node Classification	Node prior probability
Classification Societies	International Classification Society Certification	0.910
	Non-International Classification Society Certification	0.090
Ship Type	Bulk Carrier	0.246
	Miscellaneous Cargo Ships	0.313
	Container ship	0.098
	Other	0.343
Flag	White	0.909
	Grey	0.036
	Black	0.055
Ship age	0~10	0.247
	11~20	0.136
	More than 20	0.317

2.4.3 Calculation of the conditional probabilities of the remaining nodes

By using the node relationships of the Bayesian network model and the calculated values of the prior probabilities of the above nodes, the posterior probability values of the remaining nodes can be calculated based on the Paris Memo database. Table 4 shows the results of the posterior probability calculation for the navigation safety nodes, and the remaining nodes can be calculated according to the same method.

Table 4 Calculation results of the probability of navigational safety node conditions

Fire Safety	No defects							
Emergency System	No defects				Defective			
Pollution Prevention	No defects		Defective		No defects		Defective	
ISM	No defects	Defective	No defects	Defective	No defects	Defective	No defects	Defective
No defects	0.759	0.581	0.786	0.636	0.731	0.410	0.867	0.444
Defective	0.241	0.419	0.214	0.364	0.269	0.590	0.133	0.556

Continued Table 4 Posterior probability calculation results of navigation safety nodes

Fire Safety	Defective							
Emergency System	No defects				Defective			
Pollution Prevention	No defects		Defective		No defects		Defective	
ISM	No defects	Defective	No defects	Defective	No defects	Defective	No defects	Defective
No defects	0.801	0.727	0.792	0.500	0.695	0.394	0.692	0.356
Defective	0.199	0.273	0.208	0.500	0.305	0.606	0.308	0.644

3 Analysis of results and discussion

3.1 Model accuracy analysis

According to the inspection reports of 1893 Paris memoranda used in this paper, 126 ships were found to be detained through data analysis, and the inspection detention rate of defective ships was 6.656%. Figure 2 shows the results of ship detention analysis based on Bayesian network model, and the probability of ship detention model in this paper is 6.705% through Bayesian network parameter learning, which indicates that the Bayesian network model is consistent with the actual detention rate results.

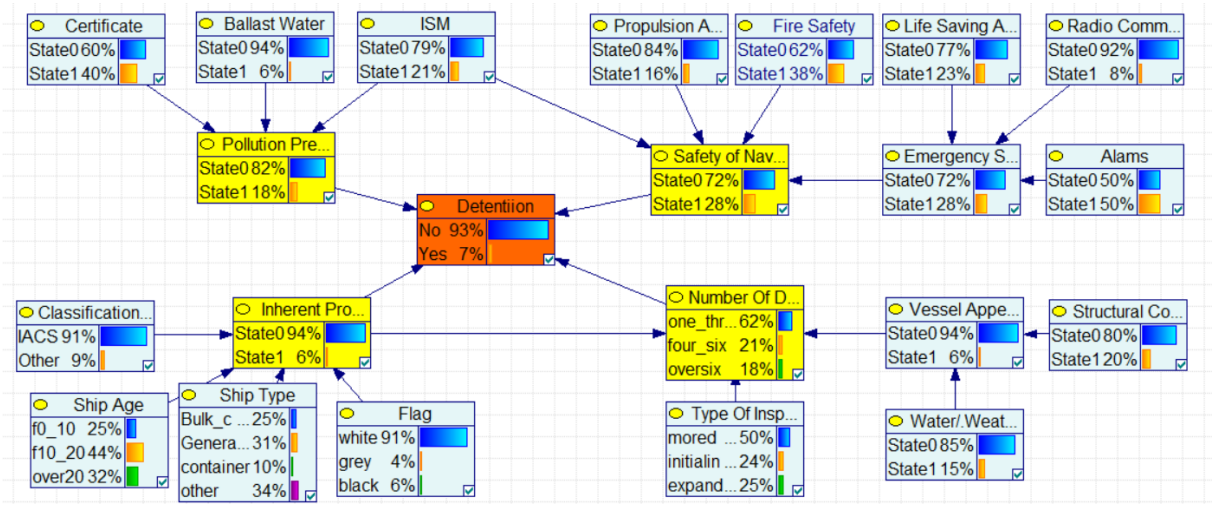

Figure 2 Vessel Detention Results

Two axioms are often used to validate the developed model：

1. Axiom 1. A slight increase/decrease in the prior probabilities of each parent node should certainly result in a relative increase/decrease of the posterior probabilities of the child node.

2. Axiom 2. The total influence magnitudes of the combination of the probability variations from x attributes (evidence) on the values should always be greater than that from the set of $x - y(y \in x)$ attributes (sub-evidence).

1. Test of axiom 1. Taking ship detention as an example, the number of defects is divided into three levels. When the number of defects is 1-3, the probability of ship detention is 1.57%, and when the number of defects becomes 4-6 and more than 6, the probability of ship detention becomes 8.90% and 22.29%, respectively. Other nodes can also be verified by following Axiom 1.

2. Test of axiom 2. The probability of ship detention is 13.00%, 11.08% and 14.44% when the three cases of defective pollution prevention, defective navigation safety equipment and ship inherent property detention rate exceeds 90%, respectively, and 24.93% when the situation is set to the state where these three cases are defective at the same time. The remaining nodes are similarly verified and the results reflect that follow Axiom 2.

3.2 Ship detention sensitivity analysis

Using the sensitivity method, after setting the top-level event ship detention probability, the factors influencing ship detention are analyzed. Figure 3 shows the results of the sensitivity analysis.

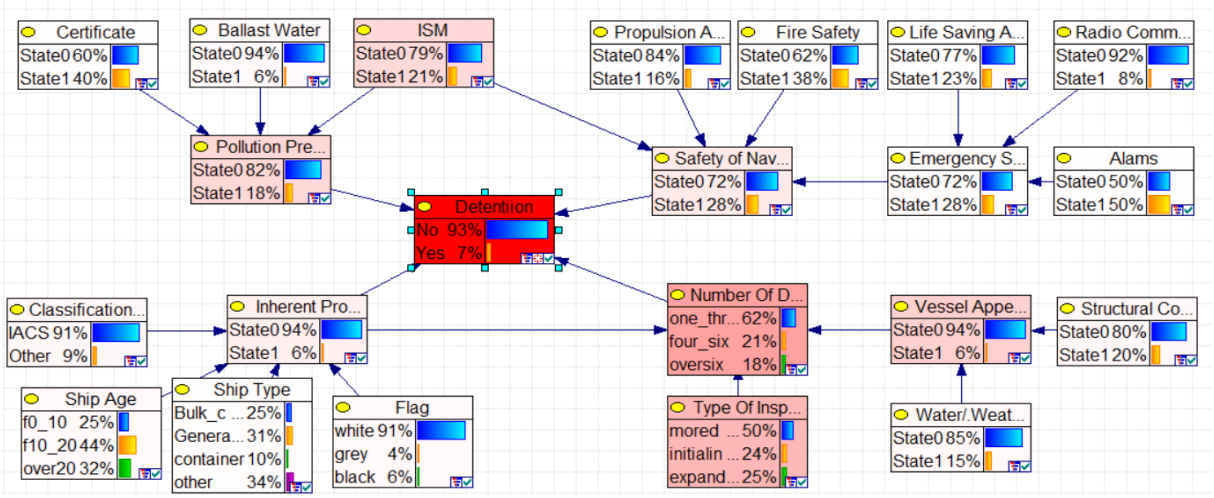

Figure 3 Results of ship detention sensitivity analysis

Figure 3 shows that the node sensitivity can be divided into four levels. The first level is the number of defects, the second level is pollution prevention, inspection type, ship's appearance condition, ISM, and the third level is navigation safety equipment, ship's inherent properties. The fourth level includes certificate documents, ballast water, main power class auxiliary equipment, classification society, ship age, ship type, ship flag, fire safety, life-saving equipment, radio system, alarm system, emergency system, structural condition, and waterproof and weatherproof condition equipment. Sensitivity analysis shows that the number of defects is the most important influencing factor affecting the ship's detention. Among the various defects, ISM and pollution prevention, navigation safety equipment are the most important PSC inspection items.

3.3 Ship inherent property analysis

The ship inherent attributes are divided into the following four points: ship age, ship type, flag, and classification society. When the node state of ship inherent property changes to 1, the ship detention rate changes from 6.71% to 14.44%, and the ship detention rate increases by 115%, which indicates that the ship inherent property has an important influence on the ship detention, and the detention rate and the probability change of each node of ship inherent property are shown in Figure 4.

The range of variation of each state of ship age is: the probability distribution of 1-10 years decreases from 24.67% to 11.36%, the probability distribution of 11-20 increases from 43.63% to 48.85%, and the probability distribution of more than 20 years increases from 31.70% to 39.79%. It proves that the longer the age of the ship, the higher the rate of ship detention under the same PSC inspection defects; the range of change of each state of ship types is: the probability distribution of bulk carriers increases from 24.56% to 27.54%, that of general cargo ships increases from 31.27% to 36.06%, that of container ships decreases from 9.78% to 9.49%, that of other types of ships decreases from 34.39% to 26.91% for other types of vessels. The detention rate of bulk carriers increased significantly, the detention probability of container ships did not change significantly, and the detention rate of general cargo ships and other types of ships decreased significantly. The range of change of each state of the flag is: white list decreased from 90.86% to 85.23%, gray list increased from 3.59% to 6.12%, black list increased from 5.55% to 8.65%; it proved that the detention rate of ships flying the flags of gray list and black list flag states increased significantly, and the detention rate of ships flying the flags of white list flag states was significantly lower than that of ships flying the flags of gray list and black list. The change range of each status of classification societies is: the probability distribution of international classification societies

decreases from 91.02% to 84.38%; the probability distribution of non-international classification societies increases from 8.98% to 15.62%; it proves that the probability of detention of ships certified by international classification societies is significantly lower than that of non-international classification societies.

The change of ship inherent property nodes leads to the probability distribution of each state of the number of defects as follows: the probability of the number of ship defects 1-3 decreases from 61.74% to 41.31%, the probability of the number of ship defects 4-6 increases from 20.53% to 33.11%, and the probability of the number of ship defects more than 6 increases from 17.73% to 25.58%. The results indicate that if the inherent properties of a ship have more than 90% probability of lingering, the number of defects of the ship also has a high probability of increasing.

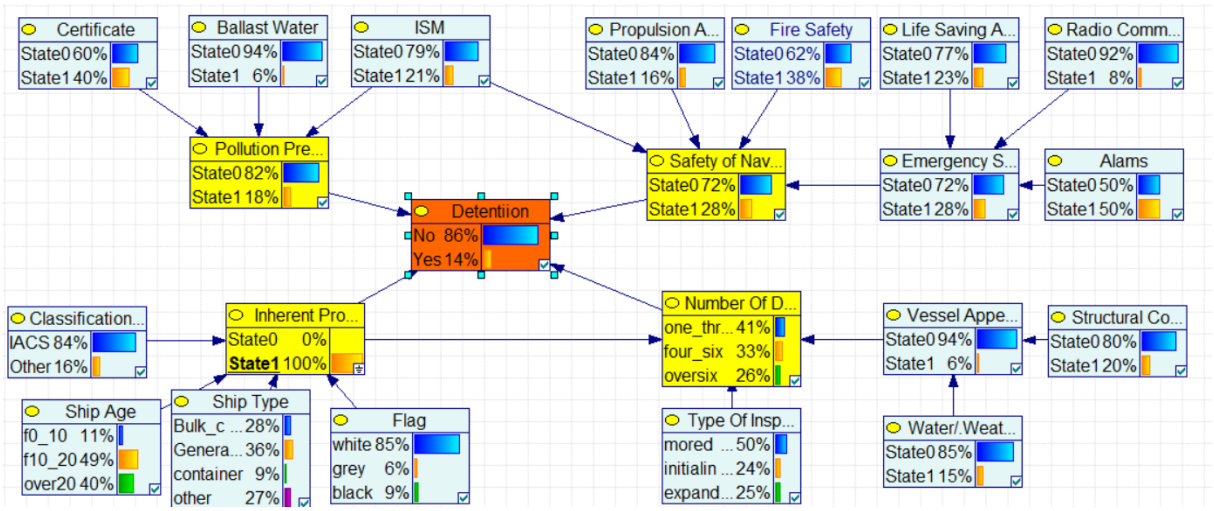

Fig. 4 Results of ship inherent property analysis

3.4 Ship PSC inspection item detention analysis

Through data analysis, 11 of these PSC inspection items are divided into two major categories, one for ship pollution prevention and one for navigation safety equipment. When the probability of having defective node states of ship pollution prevention and navigation safety equipment is adjusted to 1 respectively, the changes of their associated node states are shown in Figure 5 and Figure 6.

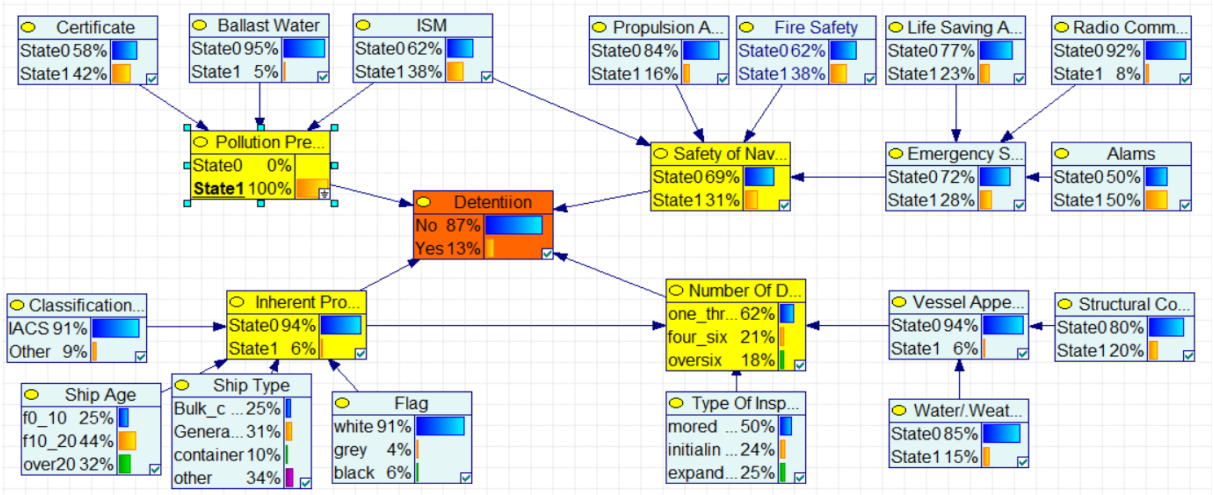

Figure 5 Pollution prevention analysis

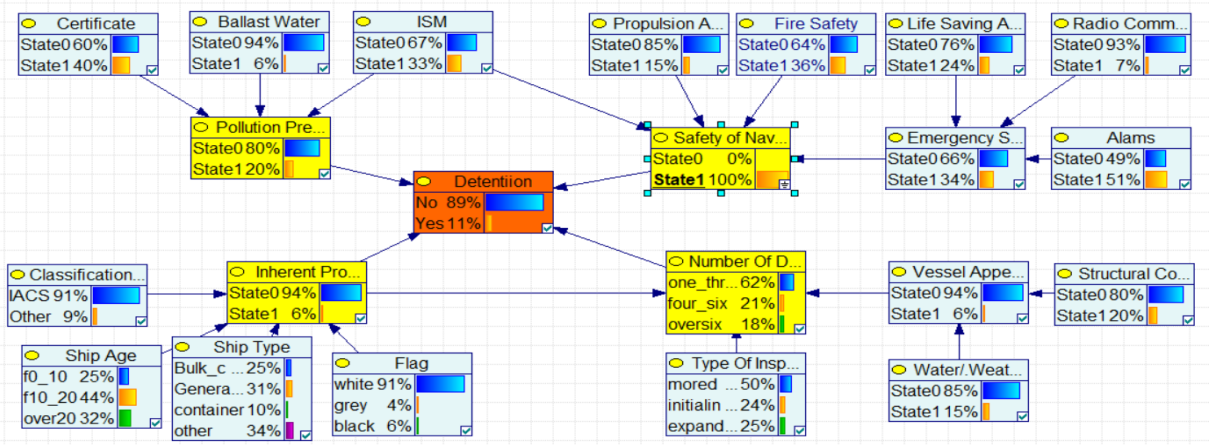

Figure 6 Analysis of navigational safety

From Fig. 5 and Fig. 6, it can be seen that the risk of ship detention increases from 6.71% to 12.85% and 11.07% respectively, and the model results indicate that pollution prevention and navigation safety equipment are the main influencing factors leading to ship detention in the PSC inspection items. The probability distributions of the remaining node states are shown in Table 5.

Table 5 Probability distribution of different nodes when pollution prevention and navigation safety status change

Node Parameters	Unadjusted defective probability	Adjusted with defect probability	Rate of change	Node Parameters	Unadjusted defective probability	Adjusted with defect probability	Rate of change
Pollution Prevention	17.61%	1	/	Safety of navigation	27.13%	1	/
Certificate Documents	39.94%	42.23%	5.73%	Life-saving equipment	23.14%	23.70%	2.42%
Ballast water	6.39%	4.90%	-23.31%	Emergency Response System	20.55%	25.89%	25.99%
ISM	20.97%	38.45%	83.36%	Main power and auxiliary equipment	15.58%	14.93%	-4.17%
Safety of navigation	27.13%	30.35%	11.87%	Fire Safety	38.09%	35.52%	-6.75%
				ISM	20.97%	32.24%	53.74%

After the sensitivity analysis of pollution prevention and navigation safety equipment use, it is known from Table 5 that ISM is the node variable with the most significant change rate in the probability change distribution of each node parameter, and the change rate is 83.36% and 53.74% respectively, which indicates that ISM is the most critical factor for pollution prevention and navigation safety, and also the influencing factor that affects the key of ship detention. Among the pollution prevention parent node variables, the probability of having defective ballast water decreases by 23.31%, which may be due to the fact that more attention is paid to ballast water treatment in daily inspection; among the navigation safety parent nodes, the probability of having defective main power and auxiliary equipment and fire safety also decreases, which may be due to the fact that these two inspections are stricter in daily inspection and will not appear defective easily.

3.5 Analysis of the impact of the number of defects on ship detention

The target of this paper is a ship with defects, so the influence of the number of ship defects on ship detention can be seen by comparing the two cases when the number of ship defects is 1-3 and more than 6. Figure 7 and Figure 8 show the probability of ship detention in the two cases of ship defects number 1-3 and over 6 respectively, from which it can be seen that the probability of ship detention increases from 2% to 22%,

and when the number of defects is 4-6, the probability of ship detention also increases to 9%. The results show that the higher the number of ship defects found by PSC inspection, the higher the risk of a ship being detained.

It can also be seen from Figures 8 and 9 that when the number of ship defects is small, the probability of selecting initial inspection and detailed inspection is 34.55% and 41.61%, respectively; when the number of ship defects is more than 6, the probability of selecting initial inspection and detailed inspection becomes 1.62% and 70.49%, respectively. It can be judged from this that when the port state prosecutor checks that the ship is equipped with correct certificate documents and the overall condition of the ship is good, the probability of stranding a ship that only needs initial inspection is much lower than that of a ship that needs detailed inspection.

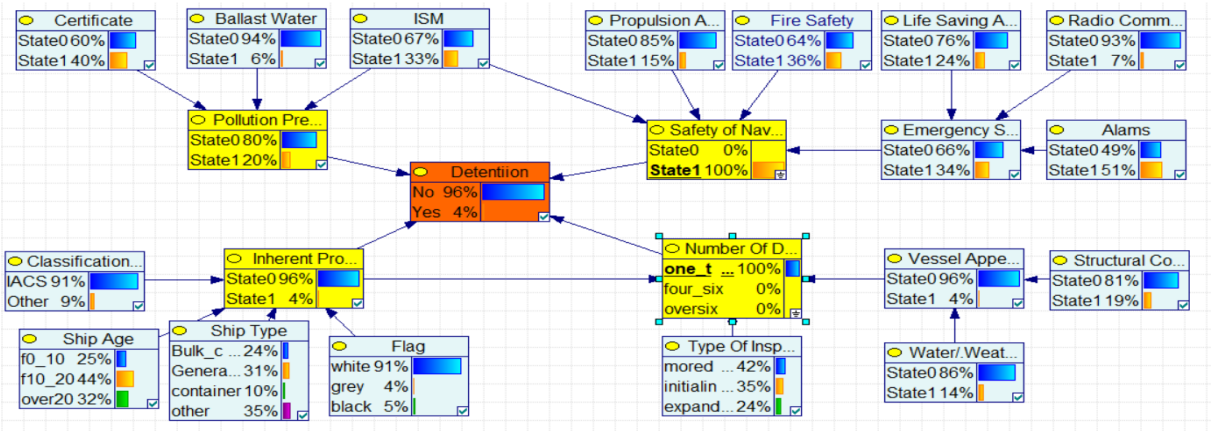

Figure 7 Probability of ship detention when the number of defects is 1-3

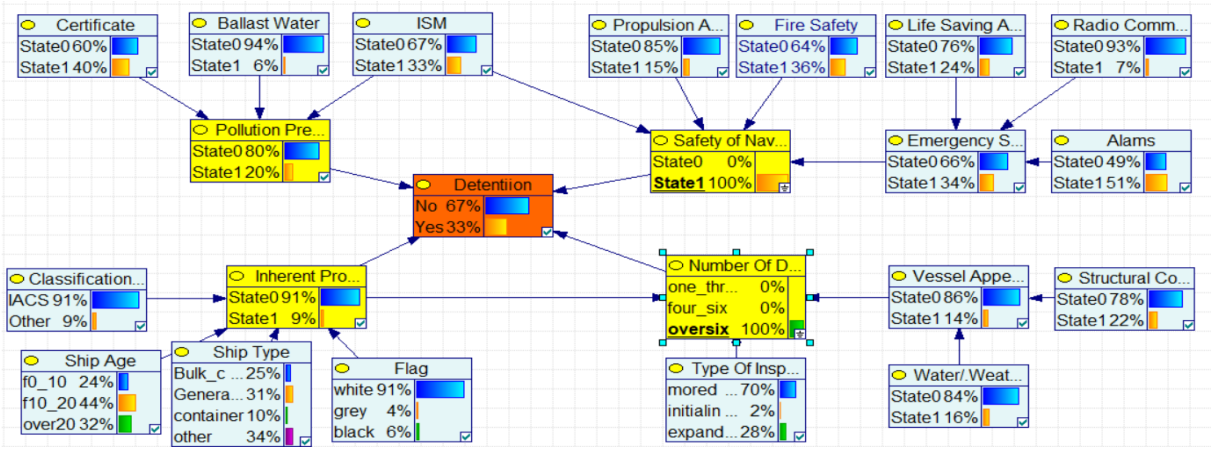

Figure 8 Probability of ship detention when the number of defects exceeds 6

4 Conclusion

This paper takes ships with defects as the research object, constructs a ship detention risk model by using Bayesian network, and analyzes the influencing factors of ship detention from four aspects of ship inherent attributes, pollution prevention, navigation safety and the number of defects by combining sensitivity analysis methods. The results show that among the nodes of inherent ship attributes, ship age, ship flag and classification society are the key node factors of ship detention. Among the PSC inspection items, they are divided into two main nodes, pollution prevention and navigational safety, among which ISM has a strong influence on both pollution prevention and navigational safety, and the remaining nodes also have a strong dependence on pollution prevention as well as navigational safety. Therefore, the port state authorities can first send someone to check the navigation safety equipment and ship pollution prevention status, and when there is no defect in these two items, they can consider less or no inspection of other defects. However, when these two key nodes are

defective, other inspection items that have strong correlation with the key inspection defect items must be considered. This can reduce the ship inspection time and improve the efficiency of port inspection.

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Author

Dingheng Yu: Male, Master's degree student of Wuhan University of Technology, School of Transportation and Logistics Engineering, research direction: traffic risk assessment and emergency response. E-mail: yudingheng@whut.edu.cn.

Bing Wu: Male, Intelligent Transport Systems Research Centre, National Engineering Research Center for Water Transport Safety，Wuhan University of Technology, Associate Researcher, PhD supervisor, research interests: intelligent ship navigation safety, emergency decision-making and simulation. E-mail: bing.wu@whut.edu.cn.

Pei Chen: Male, Director of Integrated Division, Dong jiakou Maritime Safety Administration. E-mail: 81821060@qq.com.