Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(7):1619-1627

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Safety monitoring and safety index of inland water shipping based on Bayesian network with *GeNIe*

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ABSTRACT

Taking the inland water navigation safety as the research object, analyze the factors influencing the shipping safety state with the viewpoint of systems engineering from the four aspects: crew, vessel, environment and management. Then, establish the Bayesian network model with the factors as the node to evaluate shipping safety state. Finally, Construct the Bayesian network model with the date of the marine accident and risk on Yangtze River for evidence reasoning by software GeNIe, which can measure the action mechanism of the factors in causing risk and also reflect the navigation safety status. The safety index system includes comprehensive index and subindex. Comprehensive index reflect the navigation safety trend with its change scope, and the sub-index represent the main risk factors in shipping safety. Safety index system can quantify the inland water shipping safety state continuously and dynamically, which could makes the safety monitoring more accurate.

Key words*:* Safety index, Bayesian Network, GeNIe, System engineering theory, Crew-vessel-environment-management

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INTRODUCTION

Although there are many achievements in the research for water navigation safety in China, but it's still weak in the study of monitoring inland shipping safety state. If the monitoring system can be established and the navigation safety state monitored can be released to the public with the form of "safety index", it will be helpfulfor personnel related to shipping productionrealize the current and recent shipping safety state in detail. The safety indexcouldconduct shipping enterprises to organize safety production and play aguiding role of conducting safety management for administrative departments of shipping. What's more, it has practical significance to improve the level of shipping safety management in the Yangtze River and to promote the economic development along the Yangtze River.

"Shipping safety index system" describes the current safety state of shipping system, reflects the possible accident type and the changing trend, measure the probability of accidents and the loss degree that could happen over a period of time. The comprehensive safety index, which belongs to the safety index system, can reflect the overall change in direction and degree of shipping safety state directly. The comprehensive safetyindex can also provide the basis for shipping administrative departments and shipping enterprise to make working plans reasonable. In addition, the subindexof the system can point out the factors that cause the accidents and serious consequences, making it more targeted to take measures.

Previous research setup the classification standard to evaluation the shipping safety state.The research for safety index can quantize the shipping safety state continuouslyand dynamically. It also specifies the changing developing trend, with which the safety monitoring is more effective.

ANALYSIS OF INLAND WATER SHIPPING SAFETY INFLUENCE FACTORS BASED ON SYSTEM ENGINEERING

The Systems Engineering is a composite frontier science. It proposes system science theory and systems engineering method to give a study in the mutual relations and rules among the man, machine and environment belong to the same system. So the inland water shipping safety could be regarded as a complex system, and it is necessary to study the factors influencing safety from the perspective of the System Engineering.

The water traffic safety system is a complex system composed of "crew-vessel-environment-management". When one or more of the elements are under unsafe condition, owing to the action of one element or the interaction of several elements, it will induce accident potential and then cause the traffic accidents on inland waterway. With the theory of systems engineering to analyzethe respective characters and interaction among Crew-vessel-environment-management,it is easier to explore the efficiency that the action of various factors influence the water navigation safety and cause accidents.

In the Crew-vessel-environment-management" system, crew has strong capacity to control or regulate. Crew is not only the principle of shipping operation, but also the main cause of shipping accident and risk.Crews in different ages are in different condition, which is age structure reflects the whole level of crew health in the process of shipping. The operation against rules reflects the normalizationof mariner's operating, which is the key to navigation safety. The manning of shipreflects whether the number and qualificationsof the crew are equal to the ship manning standard.The working years on board reflects the technicalproficiency of crew.Generally speaking, the longer the working yearsare,the familiar with operating the crew are. Fatigue status reflects the crew's working condition. Mariner may make more mistakes in operating when they feel tired and be slower to response in case of emergencies.Education reflects the overall working ability in shipping. The crew with higher education generallyhas higher working quality and ability. The crew trainingreflects their understanding of operating rules and safety regulations to a certain extent.

In the crew-vessel-environment-management system, vessel iscontrolled by the mariner. It's not so reliable to reduce and control the accident simply relying on the human behavior, but it'seasierto do this with the help of technology.Since marine equipment are manufactured according to regulation for operation and behavior of mariner, which is stable and reliable. Vessels with different tonnage don't have the same probability in causing accidents even under the same navigation environment, so it can be assumed that the vessel's tonnage reflects the shipping safety state. The ship's maintenance and repairing reflect not only the daily maintenance level but also the technology and safety condition of the marine equipment. Old vessel's equipment is worse than the others, which is easier to causeaccidents.Therefore ship's aging rate reflects the overall technology condition of navigating vessel. The more serious the vessel overload, the easier the accidents happen. Overload rate describes as the proportion of overload cargo tonnage accounting for the deadweight Tonnage of Ship, which reflects the overload degree and the shipping safety risk.

In the crew-vessel-environment-management system, environment is the specific working conditions for both crew and vessel. It influences the mental status of the crew on board. The reliability of human being behavior will decline under a bad environment, which indirectly affect the safety and stability of navigation.It is certainly that environment is thedirect acting factorfor shipping safety. Environmentis comprised ofnatural environment and traffic environment. Natural environment contains window,flow,wave and so on. Traffic environment contains channel conditionand vessel traffic flow condition.Wind, snow, rain, fog are the weather condition obviously influencingsailing on inland river.The widths, flow of channel and aid to navigation have impacts on ship operating. Concentration of vessel reflects the actual traffic on river. It's of great significance to know a specific concentration of vessel, whichcould help manage the traffic effectively on river.

In the crew-vessel-environment-management system, management in shipping system is an important part composed of people management, ship control and shipping supervisionunder various environmental conditions. Both of the levelof supervision equipment and the frequency of training reflect the safe management level and personnel management level.It could be evaluated by the number of inland mariners taking part in the competency theory examination terminally.Safety check is an important part of safety management, which is the guarantee of navigation security.

CONSTRUCTION BAYESIAN NETWORK MODEL STRUCTURE OF INLAND WATER SHIPPING SAFETY INDEX SYSTEM

Inland water navigation safety index consists of total index and subindex. The Bayesian network model has double layers, which is made up of total goal node, partial goal node and evidence node. The shipping safety influencefactors work together causing the traffic accidents or riskthat is uncertain. According to the basis of water traffic accidents on Yangtze River, the correlation analysisis used for analyzing the shipping safety influence factors and interactions among them. Then the topological structure of Bayesian network for inland water navigation safety evaluation could be established.

3.1*Selection and range of the node*

Through analysis, from the perspective of data acquisition and statistical analysis, the “inland water shipping safety state” is chosen as goal node, “crew”, “ship”, “environment” and “management” are as partial node, which are connected by their own evidence node. According to above analysis of the safety influence factors and expertise, it is suggested that that partial node “crew” has 7 evidence nodes, as following: age-Z_1,operating reliability-Z_2,manning-Z_3,adaptability-Z_4,fatigue status-Z_5, literacy-Z_6 and safetyawareness-Z_7.The partial node “ship” has 4 evidence nodes, as following:tonnage-Z_8, maintenance-Z_9, hullstructure-$Z_{10}$and stability-Z_{11}. The partial node “environment” has 8 evidences, as following: wind-Z_{12}, rain-Z_{13}, snow -Z_{14}, fog-Z_{15}, depth of channel-Z_{16}, flow-Z_{17}, navigation mark-$Z_{18}$and vessel density-Z_{19}. The partial node “management” has 3 evidence nodes, as following: information management-Z_{20}, safe education-Z_{21}, safety check-Z_{22}.

Owing to the universality of nodes, it’s necessary to set a detailed range of nodes to investigate the shipping safety status more comprehensively and accurately. The node range is an integer from 0, and 0 indicates good condition. The smaller number indicates the better condition of the node. In the crew factors, age is evaluated by the score of age structure-A; operational reliability is evaluated by deduction of mariner-B; ship manning is evaluated by insufficient manning rate-C; adaptability is evaluated by the proportion of new crew-D; fatigue status is evaluated by continuous working hours-E; education level is evaluated by education scores-F; safety awareness is evaluated by the training times-G. In the vessel factors, ship tonnage is evaluated by actual deadweight tonnage-H; maintenance is evaluated by security check retention rate-I; hull structure is evaluated by ship’s aging rate-J; stability is evaluated by overload rate-K. In the environment factors, wind is evaluated by the wind scale-L; rain is evaluated by rainfall-M; snow is evaluated by snowfall-N; fog is evaluated by visibility-O; channel depth is evaluated by additional depth-P; channel flow is evaluated by flow velocity-Q; navigation mark is evaluated by improvement rate-R; traffic flow density is evaluated by channel saturation-S. In the management factors, information management is evaluated by whether it equips with information-based system; company safety education is evaluated by the number-T of people who are organized to take part in the competency theory exam; safety inspection situation is evaluated by annual security checking ships U.

3.2 *Network topology*

It’s clear that factors work together to cause a traffic accident or a risk. Correlation test is used for analyzing the interaction mechanism among each factor causing accidents on the basis of historical shipping safety accidents data and factors summarized on Yangtze River. The topology is confirmed by all of the factors and the interaction relationship between correlation factors. So in order to confirm the correct Bayesian network topology, the first step is to realize associations between nodes through the correlation analysis. On the basis of confirmed index system, make correlation analysis on factors of crew, vessel, environment and management respectively.

In order to ensurethe scientific rationality of Bayesian network topology of inland water shipping safety evaluation, a total of 1092 accidents in the recently 4 years on Yangtze Riverare selected and analyzed. The status level of each factor above was analyzed and recorded when an accident happened. PMCC and T test is adopted to confirm the significance level of the correlation. PMCC is calculated and t-test is performed with software SPSS17.0.

Data analysis shows that negative correlation exists between “age structure” and “fatigue status” at level of 0.05, but the correlation coefficient R is 0.235, $|R|<0.5$, so “age structure” is not significant correlated with “fatigue status”. Negative correlation exists between “operating reliability” and “literacy” at level of 0.05, but the correlation coefficient R is 0.204,so “operating reliability” is not significant correlated with “literacy”. Negative correlation exists between “operating reliability” and “adaptability” at level of 0.01, the correlation coefficient R is 0.585, the bilateral probability in t-test is less than 0.01, so “operating reliability” is significant correlated with “adaptability”. There is a significant correlation only between “operatingreliability” and “adaptability”. Although there is certain correlation among othernodes but it’s non-significant, the other nodes can be seen as independent events.

Negative correlation exists between “maintenance” and“hull structure” at level of 0.01, the correlation coefficient R is 0.663, $|R|>0.5$, the bilateral probability in t-test is less than 0.01, so “maintenance” is significantcorrelated with “hullstructure”. Positive correlation exists between “hull structure” and “stability” at level of 0.05, but correlation coefficient R is 0.408, $|R|<0.5$, so“hull structure” is not significantcorrelated with “stability”. In the 4 nodes of vessel factor, there is only a significant correlation between “maintenance” and “hull structure”. There isno significant correlation among other nodes, so the other nodes can be seen as independent events.

Positive correlation exists between "depth of channel"and "flow" at level of 0.05, but the correlation coefficient is 0.122, |R|<0.5, so "depth of channel" is not significantcorrelated with "flow". Positive correlation also exists between "depthof channel" and "rain" at level of 0.05, but the correlation coefficient R is 0.069, so "depth of channel" is not significantcorrelated with "rain". Positive correlation exists between "flow" and "fog" at level of 0.05, but the correlation coefficient is 0.199, so "flow" is not significantcorrelated with "fog".Negative correlation exists between "depthof channel" and"vessel density" at level of 0.05, the correlation coefficient R is 0.552, the bilateral probability in t-test is less than 0.01, so "depth of channel" is significant correlated with "vessel density". The final result shows there is a significant correlation between "depth of channel" and "vessel density" at level of 0.05; and thereis also a significant correlation between "fog" and "vessel density"at level of 0.05. The other 6 nodes of environment have some interaction relationship not significant, so the other 6nodes can be seen as independent events.

Positive correlation exists between "safety check" and "information management" at level of 0.05, but the correlation coefficient R is 0.170, |R|<0.5, so "safety check" is not significantcorrelated with "information management". The final result shows that there is some interaction relationship between each nodeof management factors but not significant, so these 3 nodes can be seen as independent events.

From the above analysis, the Bayesian network topology of shipping safety evaluation is shown as Figure 1.

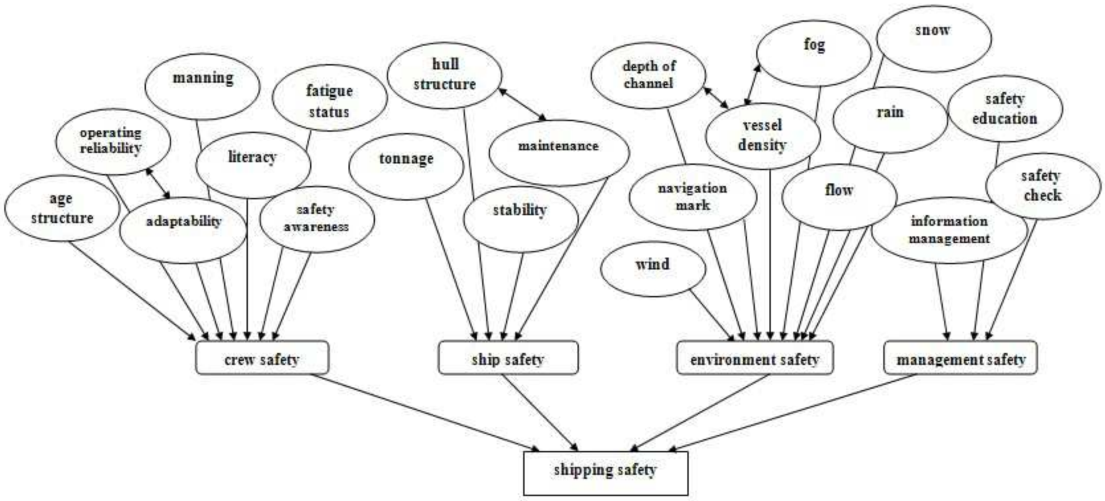

Figure 1.Bayesian Network Topology of Shipping Safety Evaluation Model

BAYESIAN NETWORK ALGORITHM OF INLAND WATER SHIPPING SAFETY EVALUATION

An accident occurs accidentally and randomly, but many accidents indicate the inevitability and law. With the understandingof the dialectical relationship between chance and necessity, stochastic property and regularity, it is a proper way that to calculate the probability distribution table according to the statistical sample.

4.1 ***Probability table of Bayesian network***

Bayesian network model is composed of network topology structure and model parameters.The previous section has constructed Bayesian network topological structure. It is necessary to calculate the probability of each evidence node and the conditional probability to each partial node to get the probability distribution table. According to the statistics of accident and risk data which conclude a sum of 1465, probability distribution table could represent the contribution of the factors under different state to the accident or risk.

It is more difficult to calculate the joint probability distribution of the partial node and the target node. It is suggested to calculate the probability distribution of nodes with the maximum a posteriori. In statistics, maximum a posteriori estimation refers to observe point estimation of unavailable variable according to empirical data, which can bring the Prior Distribution of estimator into Maximum a posteriori. So the maximum a posteriori estimation can be regarded as a rule.

It is supposed that the population parameters θ not observed should be estimated according to observation data$x$. Define$f$ as the sampling distribution of x, then $f(x|\theta)$is the probability of x when the population parameter is θ . The function $\widehat{\theta} \rightarrow f(x|\theta)$ is likelihood function, and its estimation- $\hat{\theta}_{ML}(x) = \arg\max_{\theta} f(x|\theta)$ is the maximum likelihood estimation of *x*.

Suppose that there is a prior distribution *g*, and regardθas random variables in the Bayesian statistics, then the posterior distribution of$\theta$is shown as Formula1:

$$\theta \mapsto \frac{f(x|\theta)g(\theta)}{\int_{\Theta} \int (x|\theta')g(\theta')d\theta'} \quad (1)$$

θ is the domain of g. Maximum a posteriori estimation of target function will be shown as Formula2:

$$\hat{\theta}_{MAP}(x) = \arg\max_{\theta} \frac{f(x|\theta)g(\theta)}{\int_{\Theta} f(x|\hat{\theta})g(\theta')d\theta'} = \arg\max_{\theta} f(x|\theta)g(\theta) \quad (2)$$

Software GeNIe is developed by the laboratory of the University of Pittsburgh system decision, which provides a theoretical model of decision graphical development environment. GeNIehas visualization window, which is the biggest characteristic.The static and dynamic model could be established with capacity of GeNIe for accurate and approximate inference, parameter and structure learning.Statistical data could not be directly used for calculation. The statistical results should be converted to the data accepted by the model, under the node domain partition rules.
Input the processed sample data into GeNIe software. Calculate the marginal probabilitiesofall nodes with the maximum a posteriori. Then , the contingent probability of the partial node -"crew safety", “vessel safety ”, “environment safety” and the “management safety” should be worked out, too. Partial nodes are divided into two levels: safety -0,accident -1 . The target node is divided into 3 levels: safety (no accident)-0 ,accident without casualty -1 , accidents with casualty -2.

4.2 *Inland water navigation safety evaluation model based on Bayesian network*
With Network topology structureand conditional probability of nodes,the inland water navigation safety evaluation model based on Bayesian network has been established. Use the GeNIe software to simulate the navigation safety state of the route segment which is researched in this paper. At first, construct inference network model in GeNIe. Input the statistical data into GeNIefor evidence reasoning in Bayesian network.After network training, network parameter and network model simulation results comes out, as shown in Figure 2. According to the sample data obtained, it is show that in 3 yearsthe shipping safety status of the segment isin good condition. The result is as following: probability of non-accident is 0.93, the probability of accidents without injuries is 0.06, and the probability of accidents with injuries was 0.01. At the same time, this model can reflect the contribution rate of influence factors to inland watershipping safety state.

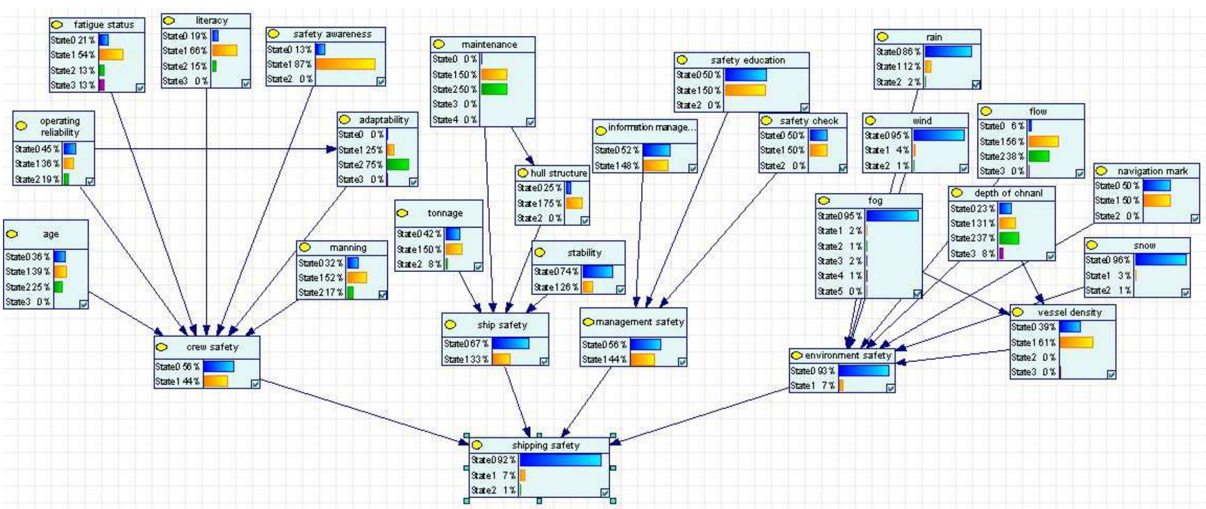

Figure 2.Safety evaluation model of Bayesian Network based on *GeNIe*

ESTABLISHMENT OF INLAND WATER NAVIGATION SAFETY INDEX SYSTEM AND ALGORITHM MODEL

The previous chapter make a detailed introduces of the modeling process of inland water shipping safety evaluation of Bayesian network model. Use the model to evaluate the shipping safety condition of a route segment of the river this paper researched. According to the monitoring of the 22 nodes, bring the data monitored into the evaluation model, then the probability of the accident and risk of navigation could be obtained together with each state of crew, ship, environment and management .The reason and essence is that, the Bayesian network reasoning to the posterior probability.

Algorithm of inland water navigation safety index is proposed from two aspects, accident probability and consequences.Safety index could not make accurate evaluation fornavigation safety in of a Riverpreviously,but also can monitoring the navigation security situation.This index maypush through the limitation of the five indicators which only finished after accident and risk.

5.1 *weight in safety index algorithm*

Using the Bayesian network model can calculate the inland safety state and the safety probability of crew, vessel, environment and management. The probabilities are selected as samples to calculated safety index, including comprehensiveshipping safety index, crew safety index, vessel safety index, environment safety index and management safety index. Safety index is gained by both probability of accident and the consequence of accident. The probabilities of different type of accidents can be calculated by the Bayesian model in the Chapter IV, so it's essential to quantize the loss caused by the accidents and give the corresponding weight, which can realize the calculation of safety index.

According to the statistics analysis, most are risks and accidents are fewer. The safety situation is divided into 3 states on the basis of casualties. The first is no accidents and no casualties; the second is accidents with no casualties and the third is accidents with casualties. The report adopts AHP to give weight to the above 3 situations, specific steps are as follows:

(1) Establish comparative matrix

AHP compares the consequences caused by the 3 situations and get the relative severity of consequences. The assessment scale is divided into 5 grades that are equally serious, a bit serious, quite serious, extremely serious and absolutely serious. The 5 grades were given the corresponding 1, 3, 5, 7 and 9 scores. The other 4 items between the 5 basic grades were given 2, 4, 6, 8 scores respectively. The comparison matrix of consequence caused by 3 situations is shown as Table 1.

Table 1. Judgment matrix

case	Non-accident	Accident without injuries	Accident without injuries
Non-accident	1	1/7	1/9
Accident without injuries	7	1	1/3
Accident without injuries	9	3	1

(2) Calculate the weight of 3 consequences

At first, it's better to calculate and judge the product $M_i$of each line elements in the matrix.

$$M_{\mathrm{i}} = \prod_{j=1}^{n} a_{ij} \quad \mathrm{i}=1,2,\cdots,n \qquad (3)$$

Then to calculate the approximate value of weight vector in each consequence,

$$\overline{W_{\mathrm{i}}} = \sqrt[n]{M_i} \qquad (4)$$

Making the vector for normalization processing,

$$W_{\mathrm{i}} = \frac{\overline{W_i}}{\sum_{j=1}^{n}\overline{W_j}} \qquad (5)$$

So $W = [W_1, W_2, \cdots, W_n]^T$ is the weight vector.

With the method above, the weight vector of 3 consequences is W=[0.05，0.29，0.66]^T

(3) The consistency check of judgment matrix
As the knowledge structure and judgment standard of experts are different, the accident consequence assessments are different. In order to avoid this contradictory, it's necessary to have consistency check for the judgment matrix. In the AHP, brings in the minus average of other characteristic roots beyond the maximum characteristic root, and set the minus average as indicator to measure deviating consistency of judgment matrix, *CI* is :

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

The greater the *CI* is, the greater the degree of deviating complete consistency for judgment matrix is.The smaller the *CI* is (close to 0), the better the consistency is. Different judgment matrix has different conformity error and requirement of *CI*. The average random consistency indicator *RI* of judgment matrix is brought in to measure whether the judgment matrix of different order has satisfactory consistency. For judgment matrix of 1 to 9 order, the value of *RI* are shown as Table 2.

Table 2. Average random consistency index

1	2	3	4	5	6	7	8	9
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Taking consistency check for expert's judgment matrix, the *CI* is 0.0401, RI is 0.58, *CR* is 0.0692, and it's less than 0.1, so the judgment matrix has the satisfactory consistency. Therefore, the weight of accidents, accidents with no casualties and accidents with casualties are 0.05, 0.29, 0.66.

5.2 *Selection of base period*
Confirming reasonable base period is one of important parts in establishing index. In order to guarantee the comparability of index and to make it reflect changing tendency of shipping safety accurately, index should have a relatively fixed base period which should be stable and comparable.

According to the actual safety management condition of river, it's assumed that each node on a certain period is in the mostly occurringcondition, and set the assumed period as base period. When the index of report period is lower than the index of base period, it shows that navigation safety condition is better than base period, the navigation condition is good; when the index of report period is higher than the base period, it shows that the current condition is worse compared to the base period, the navigation condition is not good. Based on the advice of management department, the evidence node condition of base period is shown as Table3.

Leading the condition grade of base period node into the Bayesian network model, the probability distribution of goal node and partial node on base period can be obtained, which is shown as Figure 3.

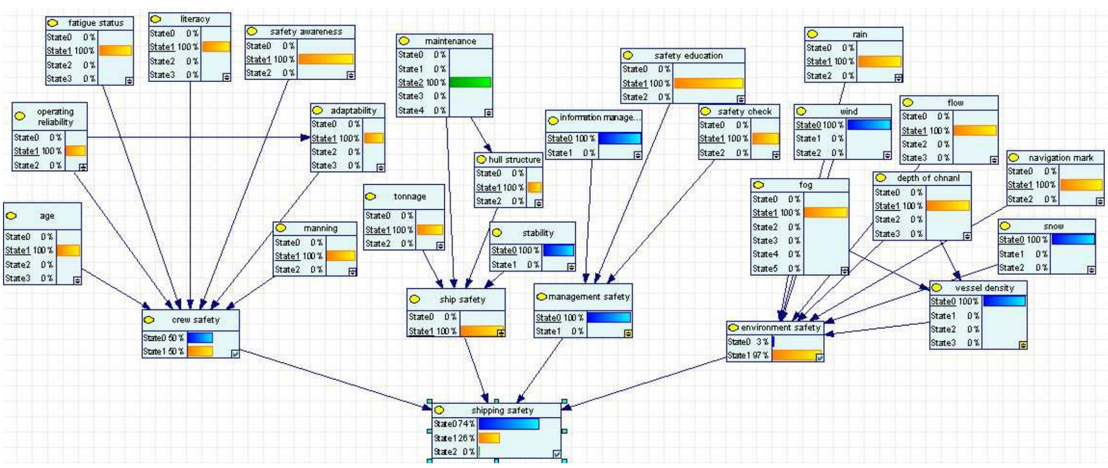

Figure 3.Probability distribution of node in base period

Table3. The state of evidence node in base period

Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
1	1	1	1	1	1	1	1	2	1	0
Z_{12}	Z_{13}	Z_{14}	Z_{15}	Z_{16}	Z_{17}	Z_{18}	Z_{19}	Z_{20}	Z_{21}	Z_{22}
0	1	0	1	1	1	1	0	0	1	1

5.3 ***Confirm the index of base period***

Leading the monitoring data into the Bayesian network model I, the probability *P* of 3 safety situation on the period can be calculated. Considering the influence of different safety condition, the comprehensive condition of inland water shipping safety can be calculated as Formula 7:

$$IS = \sum_{i=1}^{n} P_i * W_i \quad n = 1,2,3 \quad (7)$$

IS- the comprehensive condition of inland water shippingsafety;
P_i- the probability of situation *i*;
W_i -is the weight of situation *i*.

Based on the above formula, the comprehensive safety condition can be calculated, the report sets the safety index of this safety condition as 100, which is easy to understand because of the international practice. It can see the index change in percentage directly. For instance, when the safety index of base period is 124, it’s thought that the condition is 24% worse than the base period.

5.4 ***Calculate the index***

Inland water shipping safety index is the comprehensive dynamic index evaluating the shipping safety. The higher the index is, the more the risks are; otherwise it shows that the risk is less. In a similar way, if we establish the partial index for different river, when the risk index of one river is high, it shows that the risks are too much, vice versa.

It’s assumed that: $\theta$is the inland water shipping safety index. *P* is the probability considering all the factors.*w* is the weight under different condition.The subscript 0 is the value of base period.The subscript 1 is the value of report period. The subscript *i* is the grade of accident.

DEMONSRATION

Take the state of a route segment on June6th, 2011 as research object to calculate the shipping safety index. The mariners deducted 42 points because of operation against rules.The number of registrationmariners having college degree or above is 2258.The per capita number of mariners taking part in training a year was 0.75.The proportion of new mariners whose working year on board below 2 years for crewis 21.9%. The insufficient ship manning rate on June is 25.3%. The average continuous working hours are 5.5 hours.The number of registration crew aging between 30 and 39 is 3089.The aging vessel has a proportion of 26.57%. The average overload rate on June is 9.6%.All ships on river equipped with VTS/AIS/GPS/CCTV. Little rain to cloudy, bias E is 2 to 3 grades; the water level is 5.17 meters. The vessel traffic flow is 461.

Bring the value node in the Bayesian network model, but different from the common node, the value node doesn’t reflect the probability distribution of different status grade, it only bases on the conditional probability table and single value of father node.This paper sets “shipping safety on Yangtze River” node as father node of value node-*IS*, based on the different weight of each accident and formula 7. The conditional probability table of node *IS*is shown as Table 4.

Table 4.Conditional probability table of *IS*

Case	Non-accident	Accident without injure	Accident wi injure
weight	0.05	0.29	0.66

Leading in the software GeNIe, the result is shown as Figure 4.Through the above calculation, it shows that the comprehensive safety index of this river on June 6th 2011 is 108.7, which explains the condition deteriorated by 8.7% compared with the base period. And the oil ship ran aground in the middle reach that day, so it shows that safety index can obviously reflect navigation safety condition in the Yangtze River

The crew safety index, vessel safety index, environment safety index and management safety index are 100, 123.1, 100 and 95.4, the vessel safety index is higher than the comprehensive index, which shows that the bad vessel condition is the main reason to cause accident, man and environment factor are basically same with the base period, it's a normal state. The management safety index is 95.4, which is the lowest in the 4 partial nodes. It shows that the shipping safety management condition is good.

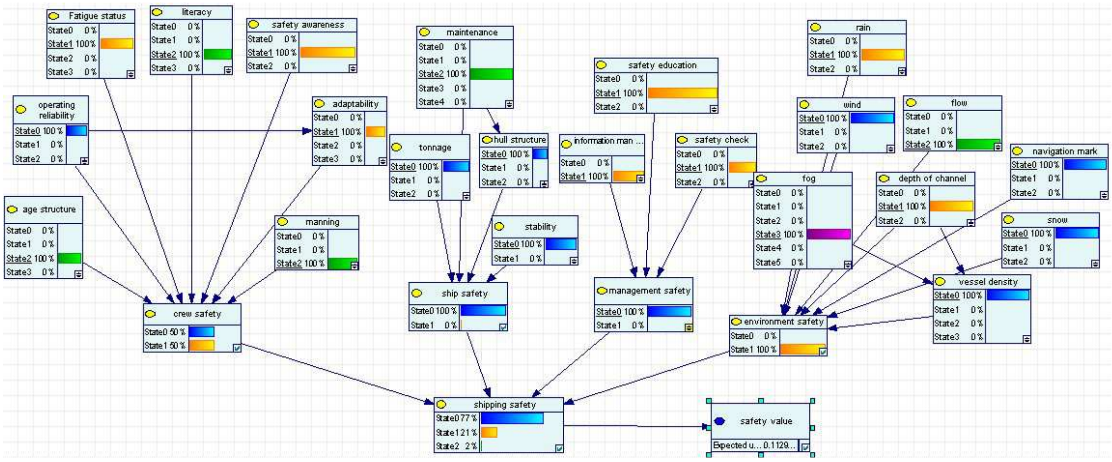

Figure 4. Probability distribution of node monitored in real-time

CONCLUSION

The perspective of systems engineering could help conduct a comprehensive conclusion and analysis for the shipping safety factors. Establish the Bayesian network model based on the mass data to obtain the contribution rate of shipping safety factors under safety condition through reasonable reasoning. The Bayesian network model can measure the actionmechanism of the factorsin causing risk and also reflect the navigation safety status. The comprehensive total index can reflect the change in direction and degree of total safety condition, and it can provide foundation for management department and shipping enterprises to make reasonable plans. The partial index can indicate the main factors causing the accidents, making the solutions more targeted. Besides, it has advantage of minimizing the loss. The safety index quantifies the inland water shipping safety state continuously and dynamically, which is beneficial to monitor inland shipping safety and guarantee safe management.

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