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Emergency Management of Maritime Accidents in the Yangtze River: Problems, Practice and Prospects

X.P. Yan, B. Wu, D. Zhang & J.F. Zhang
Wuhan University of Technology, Wuhan, China

ABSTRACT: Maritime accidents have received considerable attentions due to the enormous property damage, casualties and serious environmental pollution. This paper first makes statistical analysis of the different types of maritime accidents in the period of 2012 to 2014 in the Yangtze River. Second, the problems of emergency management of maritime accidents are also proposed from the analysis of the major accident “Eastern Star”.. Afterwards, four practice cases, including decision support for maritime accidents, emergency resource allocation, emergency simulation system and effectiveness of emergency management, are introduced to present the insights gained from these practices. Last, in order to address these problems, this paper proposes that an artificial societies, Computational experiments, and Parallel execution (ACP) approach should be introduced to establish an improved management system for maritime accidents in the future, and an ACP based maritime accident emergency management framework is proposed.

1 INTRODUCTION

Maritime accidents have attracted considerable attention in the past decades owing to the enormous property damage, casualties and serious environmental pollution. In the recent years, major accidents have been occurred worldwide, Table 1 shows the major maritime accidents in the recent years, it can be seen that serious consequences have been caused by these maritime accidents.

Table 1 major maritime accident in recent years

Ship name	Fatalities	Ship type	Accident type
Eastern Star	442	passenger	foundering
Pinak-6	48	ferry	foundering
Sewol	294	passenger	flooding
Costa Concordia	17	cruise	stranding
Xinmingfa 17	8 lost	container	foundering
Jinyouyuan	9 15	oil tanker	collision

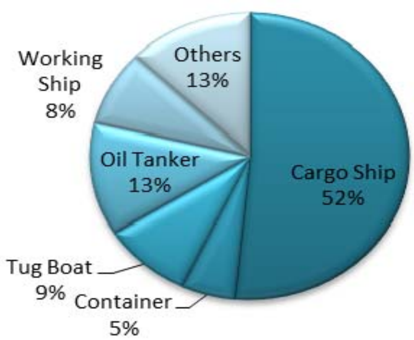

Figure 1. Different types of ships involved in maritime accidents

While in the Yangtze River, a statistic analysis of the maritime accidents is carried out in the period of 2009 to 2012. Among all the maritime accidents, different types of ships are involved. Specifically, the cargo ship accounts for 52%, and oil tanker ranks second, which accounts for 13%, while container ranks the last, it accounts for only 5%. It can be seen that the container ship has a better safety situation than other ships though the throughputs of container are also high in Yangtze River.

Moreover, the distribution of different types of maritime accidents can also be obtained. The collision accidents, which are also the most frequently-occurring accidents, rank first with a proportion of 49%. Not under control ships, though haven't caused accidents after well handled, it's also taken consideration, which accounts for 35%. Moreover, the grounding accidents account for 10%.

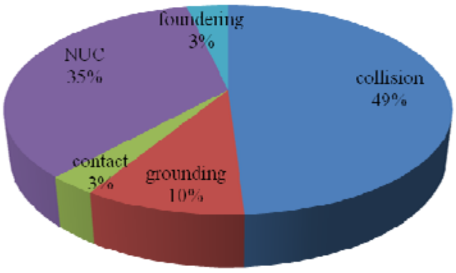

Figure 2. Different types of maritime accidents

Although many accidents have occurred together with different types of accidents and different types of ships are involved, there are only a few major accidents occurred. In fact, only the "Eastern Star" caused more than 10 casualties in the Yangtze River in the recent years, and less than five accidents caused more than 3 casualties. This can be seemed that the emergency management in Yangtze River is good. However, as the major accident occurred, some problems may also exist. Therefore, this paper manages to make a thorough review on the practices of emergency management in Yangtze River, and then intends to discover the problems from this major accident. The remainder of this paper is organized as follows. Section 2 presents the practices of maritime accident management, Section 3 proposes the problems of emergency management learned from the "Eastern Star". The future work of developing a parallel control and management system that used to enhance the emergency management is discussed in Section 4. Conclusions are drawn in Section 5.

2 PROBELEMS OF MARITIME ACCIDENTS MANAGEMENT

A major accident, which caused 442 casualties, has been occurred in June 1, 2015. After organized more than 200 interviews, the Chinese government has issued the accident investigation report. From the analysis, the key causation factors can be ranked as wind, ship and human error. Moreover, two projects have also been funded in the last 2 years. One project is to identify the major hazards in the Yangtze River, including the human factors, ship condition, navigational environment, and also safety management. Another project is to develop a novel safety system for the inland waterway transportation especially in the Yangtze River. From these two projects, insights have been gained and many problems have been addressed to promote the safety level in the Yangtze River.

However, as this paper focuses on the emergency management of maritime accidents, only the problems related to the emergency management will be introduced in this paper. From the analysis of "Eastern Star" accidents and previous works, the significant problems that should be addressed can be summarized as follows.

The first problem is the time limitation. Time is the most important factor for life salvage. When predicting the trajectory of ship, uncertainties will increase when the time passes (Zhang et al., 2016). Moreover, according to the investigation of many ship flooding accidents, only the people take actions quickly can be saved (Jasionowski 2011), for example, MV Estonia and MV Rocknes. In this "Eastern Star" accident, although 12 people have been saved, but only 2 people were saved after the ship foundering. That means all the other 10 people have take early actions before the ship foundering.

The second problem is the resource constraint. The allocation of resources is a trade-off between economic and safety. There are a few oil spill sites in China, see (Xiong et al., 2015). Moreover, even in the Nansha Islands, the search and rescue ability is also restricted (Shi et al., 2014). In the Yangtze River, the emergency resources are also constraint, from the regulation of local administration, in the port area, the tug should arrive at the accidental scene in 15 min, while in the other waterway area, and the tug should arrive at 30 min. In this "Eastern Star" accident, the large-sized floating crane is far from the accidental scenes which makes the search and rescue a little delay.

The third problem is the cooperation among involved multiple organizations. As the emergency response to maritime accidents are very complex and experts from different organizations should be involved in this process, in this "Eastern Star" accident, more than 10 organizations are invited to give opinions, such as the army, the MSA, the Salvage Bureau.

The last problem is the dynamic feature of the maritime accidents. The maritime accident may cause second tier accident if it is not well handled (Ulusçu et al., 2009). Moreover, the accident will also develop into different stage if the response actions are different (Mazaheri et al., 2014). Fig. 10 presents a framework for the accidents development, which incorporates both the risk scenario and safety barrier (Wu et al., 2017), while Fig. 11 presents the safety barriers in the maritime accident development. It can also be interpreted that this framework can consider the accident development by using different response actions. In order to address this problem, an information system should be flexible to define the navigational environment including the traffic flow, critical structures, etc., otherwise, the simulation system will be much different from reality. Then, the calculations and experiments can be carried out in this platform. However, in reality, it is very hard to model the behavior of the traffic flow.

3 PRACTICES OF MARITIME ACCIDENTS MANAGEMENT

3.1 *Decision support for maritime accidents*

Decision support is to use the historical data and expert experience to select the best option among multiple alternatives for accident damage control. This is the most important tool for maritime accidents management in practice and much attention has focused on this research field (Calabrese et al., 2012; Jasionowski 2011; Wu et al., 2015a; Krohling et al., 2011). For instance, the knowledge-based system, proposed by Calabrese (et al. 2012), can assist to handle the dangerous events and accidents effectively. Jasionowski (2011) presented a decision support system to help the crew members in making decisions for ship flooding crisis management. Krohling & Campanharo (2011) proposed a Fuzzy TOPSIS method decision support for oil spill management. Ölçer & Majumder (2006) presented a case-based decision support system for flooding crises onboard ships.

Regarding the decision support for maritime accidents, a very important step is to discover the multiple alternatives. In the Yangtze River, for the not under control ships, there are four alternatives, which are tug assistance operation; beaching or anchoring in the outer limit of the fairway; anchoring in nearby anchorage; immediate anchoring in fairway, respectively (Wu et al., 2016). While for the grounded ships, the options are self-refloating, waiting for high water, run aground at full speed, and tug assistance, and physical/mechanical, chemical, biological technologies are widely used for oil spill accidents (Li et al., 2016). For the collision ships, the options are pushing with dead slow speed, run aground, immediately anchoring (Ma & Shen 2008; Xue, 2013).

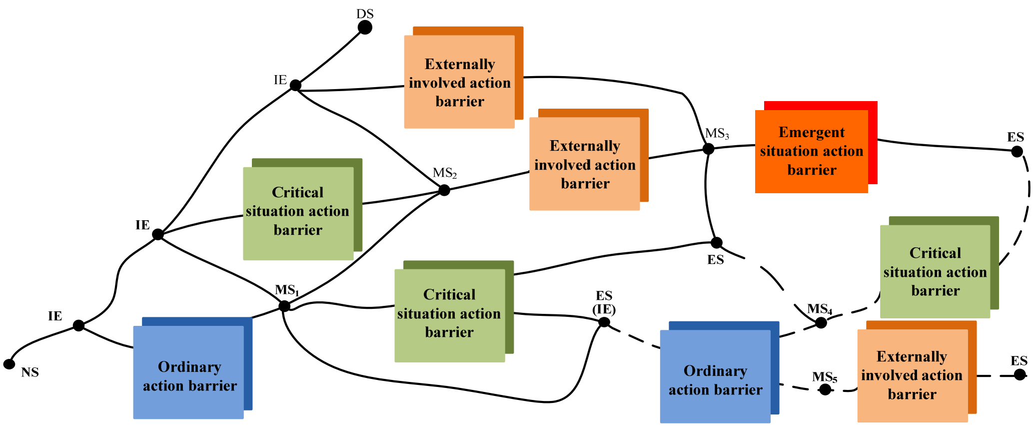

Figure 10. Framework of accident development

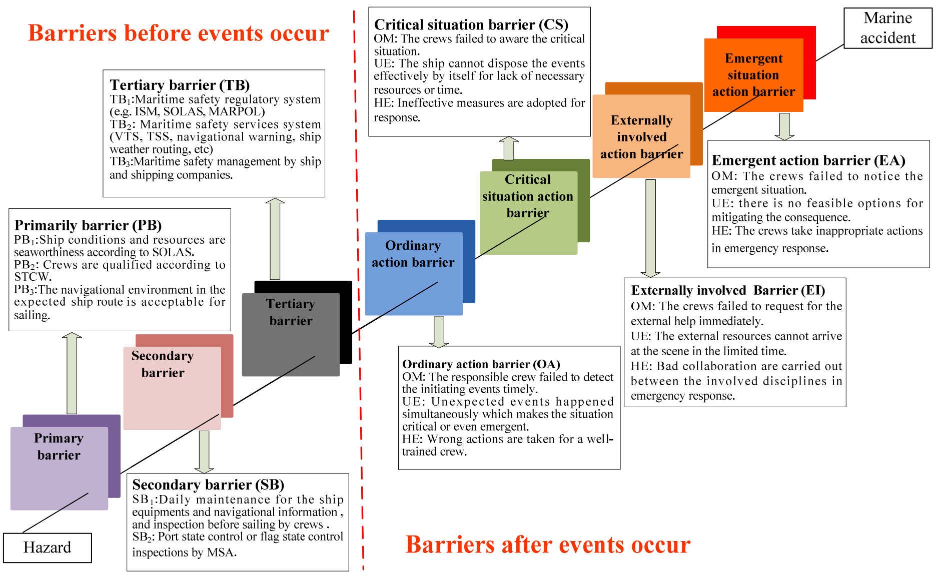

Figure 11. Two-phase barrier system for maritime accidents

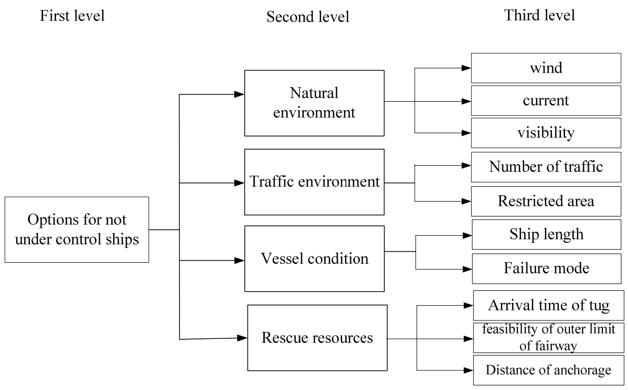

Figure 1 Three-level decision solution for not under control ships

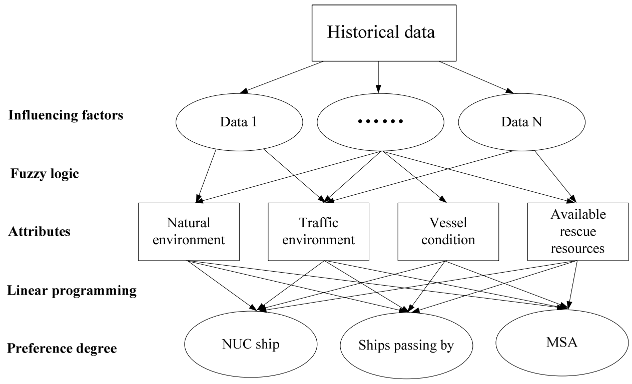

Figure 2. Decision support framework for selection of safety control options

The multiple-layer decision framework is always introduced for maritime accidents handling. Take the not under control ships for example (Wu et al., 2016); the developed three-layer decision framework is shown in Fig.1. In this decision framework, the first level is the alternative level, which are the available options used for emergency response. The second level is the attribute level. Traditionally, this level is used to facilitate the decision-making process and the decision-maker only has to make decisions in terms of evaluation on these attributes. The last level is the influencing factors level, where the influencing factors are always indentified from the historical data and expert experience.

In practice, after identifying the influencing factors, in order to select the best option for maritime accidents, there are two problems need to be addressed. Also take the not under control ships for example, and the process for decision support is shown in Fig.2. The first problem is to obtain the weights of the attributes. As the weights of the attributes are always obtained from the expert judgments, which may have different preference formats, for example, interval numbers, crisp values, fuzzy numbers, incomplete information, a method should be proposed to integrate these different formats. For example, the linear programming method is used for the not under control ship. Another problem is to integrate the influencing factors to obtain the attribute values. In this process, the Fuzzy logic (Wu et al., 2016; Mokhtari et al., 2012), Bayesian network (Davies & Hope 2015), and Evidential reasoning are widely used methods (Yang, 2001; Yang & Xu 2002).

3.2 *Resource allocation for maritime accidents*

One significant reason why maritime accidents pose high risk is owing to the harsh navigational environment caused by the offshore activities. This makes the resources for emergency response is constraint and the majority of existing researches focused on how to allocate the restricted resources for emergency response. For example, Cunha (et al. 2014) intended to manage the contaminated marine marketable resources after oil spill. Lehikoinen (et al. 2013) proposed an optimized model for oil recovery in the gulf of finish using Bayesian network. Siljander et al. (2015) used the cost distance module in the geographic information system for search and rescue planning. Garrett et al. (2017) proposed a dynamic oil spill response planning model by considering the accident development in the arctic.

In the Yangtze River, the harsh navigational environment should be taken into consideration for resource allocation, and one important problem is to allocate enough resources before accident occurs. For example, in the bridge area, where the navigable waterway is reduced due to the construction of the bridge, the resource allocation should be enhanced. In our previous work (Wu et al., 2013), we proposed a risk-based approach to allocate the patrol marine vessels in the Yangtze River, which can be used for emergency response to maritime accidents to make both the bridge and ship safe. The as Low as reasonably practicable (ALARP) is introduced in this model, and the principle of defining the relationship between risk level and resource allocation is shown in Table 1.

Table 1. Relationship between risk level and resource allocation

Risk level	Risk based resource allocation
Negligible	Risk can be ignored and no resource should be allocated
Acceptable	The risk is acceptable and traditional maintenance should be carried out
ALARP	Risk is relative high and additional resources should be allocated
Unacceptable	The risk is too high to construct such critical infrastructure

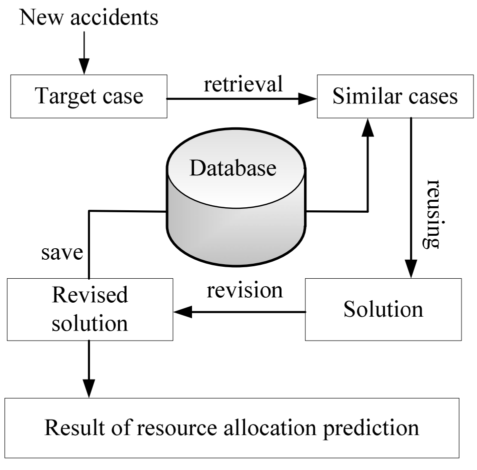

Figure 3. Resource allocation prediction using case based reseaning

Another important problem is to allocate the resources after accident occurs. One practice in the Yangtze River is to use the similar and existing cases to predict the required resources in the new case, which is known as the case based reasoning method (Deng et al., 2014). The principle of this method is shown in Fig. 3. Once the new accident occurs, the similar cases will be retrieved and the associated solution will be given by using this case based reasoning method. However, considering the distinguishing character of the new case, some revision on the recommended solution may also be carried out, which is the final solution for the new accident.

3.3 *Emergency maritime simulation system*

Maritime simulation system is widely used owing to the distinguishing advantages of immersive, intuitiveness, low-cost and interactive for training. Currently, there are some acknowledged simulation systems for training the crews such as Kongsberg and Transas. However, these simulation systems manages to promote the ability of ship maneuvering, while only a few attention have been focused on the emergency response to ships after maritime accidents. Varela (et al. 2007) proposed a virtual environment for the ship damage control; moreover, they also presented a simulation system for the ship flooding recently (Varela et al., 2014).

Different from the simulation system used for training the crews, Wu et al. (2014) proposed a simulation system for training the staffs in the maritime safety administration, who are in charge of maritime safety in the Yangtze River. The system architecture of this system is shown in Fig. 4. The system involves five components, the accident evolution and intervention logic, accident virtual environment, emergency training simulator, hardware-in-the-loop and human-in-the-loop. In this system, different types of maritime accidents as well as the virtual environment of accident development can be simulated, and the involved multiple people can carry out the accident drills in this system. Moreover, the effectiveness of emergency response performance can also be carried out in this simulation system (Gui et al., 2016).

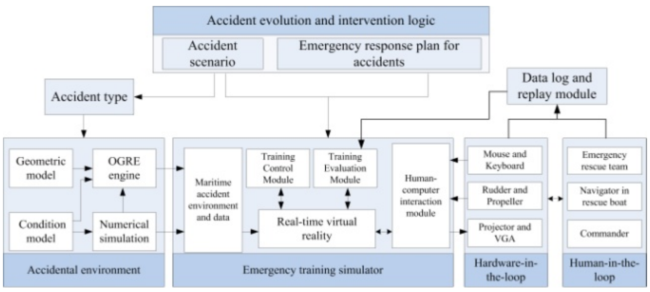

Figure 4. System architecture of emergency maritime simulation system

Moreover, one thing need to be mentioned is the software system. As there are some systems for early warming and accident handling in the Yangtze River, these systems are all simulated in order to establish an immerse environment, the cooperation among multiple person is shown in Fig.5 (Yan et al., 2015). They are automated identification system (AIS), Closed Circulate Television (CCTV), Vessel Traffic Service system (VTS), decision support system (DSS) and search and rescue (SAR) system.

Figure 5. Multiple person involved emergency maritime simulation system

The simulation software used for calculating the consequences is also important for the management of maritime accidents. That's because when the consequences can be predicted, the response actions can be adjusted according to the predicted consequences. Although some developed models such as Bayesian network can also be used for predicting the consequences using historical data (Zhang et al., 2013; Zhang et al., 2016), the simulation software should be better since it predict the consequence with better accuracy. The associated simulation software for different types of maritime accidents is shown in Table 2.

Accident type	Simulation software	References
Collision and grounding	GRACAT	(Friis-Hansen and Simonsen 2002)
	ANSYS	(Montewka et al., 2014)
fire	FDS	(Su and Wang 2013)
Oil spill	OILMAP	(Krohling and Campanharo 2011)
Life salvage	HECSALV	ABS

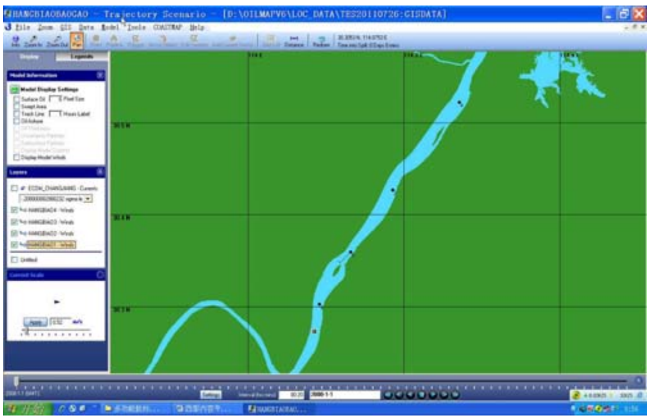

Figure 6. Oil spill simulation using OILMAP

In Yangtze River, these software have also been introduced for the management of martiime accidents. Fig. 6 shows the oil spill simulation in the using OILMAP while Fig. 7 shows the simulation of fire development using FDS.

Figure 7. Fire simulation in engine room using FDS

3.4 *Effectiveness of emergency management*

Effectiveness analysis is to discover whether the management is effective or not so that counterpart measures can be carried out to enhance the management. When the international safety management (ISM) code was introduced, the effectiveness of it was also conducted both in UK (Bhattacharya et al., 2012) and in Greece (Tzannatos and Kokotos 2009). Similar work for analyzing the effectiveness of safety management was also carried out in the gulf of Finland by using Bayesian network (Hänninen et al., 2014) and also on-board ships (Akyuz and Celik 2014).

In the Yangtze River, the MSA have used the five index (i.e. incidents, graded accidents, shipwreck, causalities, economic loss,) method to measure the effectiveness of emergency management. In order to obtain a comprehensive result, Zhang et al. (2014) used a generalized Belief Rule Base (BRB) methodology to evaluate the performance of the MSA in the Yangtze River by using search and rescue data. The framework of this approach is shown in Fig. 8, where the MSA performance is evaluated by using the safety situation and cost attributes.

However, as the abovementioned method cannot take the navigational environmental factors into consideration, Wu et al. (2015b) proposed a data envelopment analysis (DEA) based method to evaluate the effectiveness of emergency management. In the DEA method, the navigational environmental factors are treated as the inputs, while the accident data as the outputs. The principle of this method is to maximize the relative efficiency subject to a linear inequality constraint that the weighted outputs are no more than the weighted inputs. The inputs and outputs are shown in Fig. 9, which is also the developed DEA model.

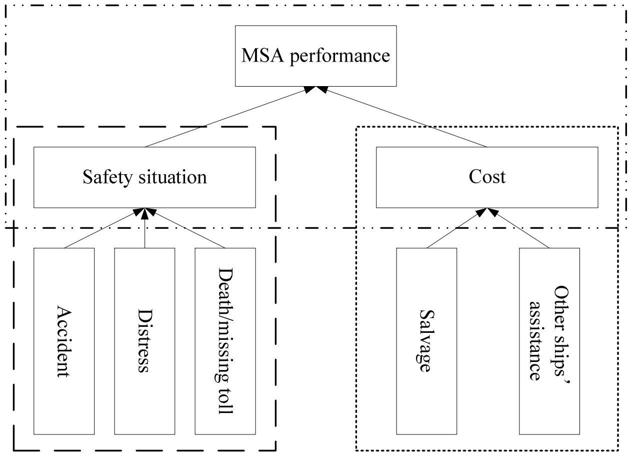

Figure 8. Framework for MSA performance assessment

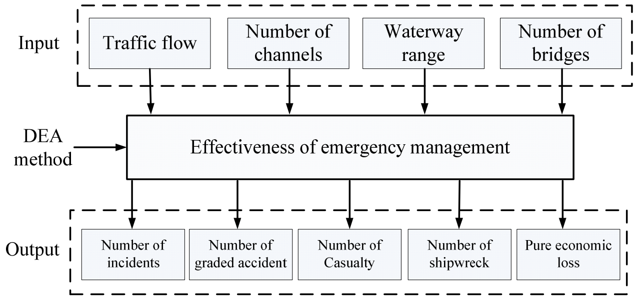

Figure 9. The proposed DEA model layout

4 FUTURE TREND OF MARITIME ACCIDENTS MANAGEMENT

From the above analysis of the practices and problems of the emergency management in the Yangtze River, much attention has been attracted to the micro emergency technologies. However, Macro-simulation system, which can reappear the maritime accidents development, should also be incorporated into the maritime emergency simulation system. This is different from the virtual simulation system (micro simulation) that manages to promote the ability of search and rescue in the virtual environment, the macro simulation system manages to promote the ability of emergency management especially the resource optimization and decision support in the real environment, i.e. the safety management system. The reason why this is important it's that the emergency management is a part of the safety management and the emergency management should be carried out in the real environment.

Artificial societies, Computational experiments, and Parallel execution (ACP) is widely used in the safety engineering. The principle of ACP is to establish one or more virtual environment based on one real environment. This method has been widely used in the transportation engineering. For example, the Asian Games in 2010 has introduced this for traffic management (Xiong et al., 2013), Ning et al. (2011) used it for high-speed train management, while Duan et al. (2011) used it for public health emergency management.

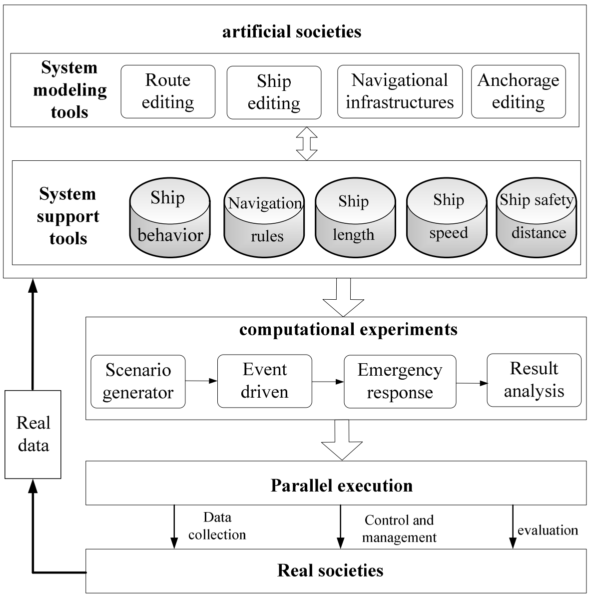

Figure 12. Framework of parallel emergency management system

The proposed framework of parallel emergency management system based on ACP approach is shown in Fig. 12. First, artificial societies are established according to the real world, which includes the system modeling tools and system support tools. The artificial societies should be established owing to the complexity of real world and the dynamic feature of maritime accidents. Second, the computational experiments are carried out on the artificial societies to discover the accident development mechanism. Third, the parallel control and management can be carried out to enhance the emergency management.

5 CONCLUSIONS

The contribution of this paper is to summarize the problems of maritime accident management, including the time limitation, resource constraint, multiple organization cooperation and dynamic development, are proposed by learning from the "Eastern Star" major accident in this paper. Moreover, the practices of maritime accident management in the Yangtze River, which includes decision support, resource allocation, emergency simulation and effectiveness analysis, are also presented. Last, an artificial societies, computational experiments, and parallel execution based framework is also proposed.

However, although some practices have been carried out in the Yangtze River and some insights have been gained; the problems of emergency management of maritime accidents should also be carefully addressed owing to the occasionality and uncertainty of maritime accidents. Moreover, different perspectives of public safety management should be introduced to the marine engineering, such as the above-mentioned ACP approach and also the hierarchical task network planning.

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