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WORLD MARITIME UNIVERSITY
Malmö, Sweden

APPLICATION OF RISK-BASED DECISION MAKING ON PLANNING VTS

By

YAOTIAN FAN
The People's Republic of China

A dissertation submitted to the World Maritime University in partial
Fulfilment of the requirements for the award of the degree of

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2005

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Abstract

Title of Dissertation: **Application of Risk-Based Decision Making on Planning VTS**

Degree: **MSc**

The dissertation is a study of the methodologies of applying risk-based decision-making (RBDM) on planning VTS, under the framework of Formal Safety Assessment (FSA) recommended by IMO.

The concept of safety and risk as well as their relationship is introduced and discussed. A brief look is taken at the traditional and risk-based approaches to decision-making in terms of their concepts, principles, and comparison so that the advantages and necessity of RBDM to maritime safety are highlighted. With the presentation of the concept and principle of VTS, the significance of FSA on planning VTS is specified. The problem under analysis and its boundaries related to planning VTS is defined and a model for identifying a list of risks and hazards with associated scenarios, prioritized by risk level, is introduced. After some recommended models were examined, new methods based on the risk index theory are demonstrated in order to practically estimate the risk level and determine risk acceptability for planning VTS. Then, for uncovering the underlying factors of traffic accidents, the m-SHEL model and a new model based on the Reason model, which are especially suitable for specifying the relevant risk control options in the context of waterways management, are presented. The cost-benefit analysis for a prioritisation of the risk control options is elaborated in order to determine whether to implement the options. The dissertation concludes with an emphasis on the importance of RBDM on planning VTS, and gives a number of suggestions aimed at the further promotion of a proactive policy on planning VTS.

KEYWORDS: Safety, Risk Assessment, FSA, VTS, Decision-making

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LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
BF	Beaufort Force
CBA	Cost-Benefit Analysis
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea, 1972
DMA	Danish Maritime Authority
EPA	United States Environmental Protection Agency
ETA	Event Tree Analysis
FMEA	Failure Mode and Effect Analysis
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Studies
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICOM	Integrated Coastal and Ocean Management
IMO	International Maritime Organization
ITOPF	International Tanker Owners Pollution Federation Limited
ITU	International Telecommunication Union
MOC	Ministry of Communications of China
MSA	Maritime Safety Administration
PSSA	Particular Sensitivity Sea Area
RBDM	Risk-Based Decision-Making
RCM	Risk Control Measure
RCO	Risk Control Option
RCT	Risk Contribution Tree
SAR	Search and Rescue
SFE	System Failure Event
SHEL	Liveware, Hardware, Software and Environment

SOLAS	International Convention for the Safety of Life at Sea, 1974
TSS	Traffic Separation Scheme
UNCLOS	1982 United Nations Convention on the Law of the Sea
USCG	United States Coast Guard
VTM	Vessel Traffic Management
VTS	Vessel Traffic Service

Introduction

Due to the development of larger and less manoeuvrable ships, the increasing traffic volume, dangerous cargoes and the potential for environmental pollution, establishing a VTS to reduce these risks, as a valid measure, has been a practical solution in many ports and waterways around the world. The number of VTS systems worldwide has increased rapidly during the last two decades and there are now about 500 of these services available in total. In particular, with the recent booming seaborne trade and reinforced awareness of a friendly marine environment, the implementation of new VTS and the re-assessment of an existing VTS worldwide are reaching a new high tide. However, constructing a VTS is a considerable investment and its subsequent operation is also very money-consuming. Consequently, how to plan a VTS perfectly, which will result in fulfilling its functions validly, contributing in reaching its purposes to the greatest extent as envisaged, and establishing whether the investment required is justified, are key considerations faced by each VTS stakeholder.

Risk-based decision-making (RBDM) has become a hot topic recently in industry and government, and the maritime community is no exception. The need for RBDM in maritime policy is obvious, as the resources that the public and private sectors can devote to navigational safety, traffic efficiency and environmental protection are finite. If these limited resources are spent dealing with low-risk problems at the expense of high-risk ones, then the industry will be exposed to higher risks that cannot be withstood due to an imbalance in resources distribution. The application of RBDM in the maritime sector could remedy these situations. It provides a powerful tool that can help ensure that limited public and private resources are allocated more

effectively to reducing risks, maximizing the protection of maritime safety and the environment as well as increasing traffic efficiency.

The traditional approach to safety in the maritime sector has been reactive - to react to problems as they occur. Instead of reacting in an *ad hoc* way to a problem, a careful analysis of the risk situation should be carried out while keeping financial and resource constraints in mind, which is of special importance to the concerned stakeholders and decision-makers. So in order to lower risks rationally as much as possible, it is suggested that when planning a VTS, decision-makers should use proactive methods, which could be the application of the principle of risk-based decision-making on maritime fields.

A practical framework recommended by IMO for RBDM on maritime fields is Formal Safety Assessment (FSA). This gives decision-makers a clearer insight into the policy and a trustworthy platform on which they form policies and can assist them to evaluate the rationality, necessity and cost-effectiveness of a marine project. So it is very useful and significant to do the research concerning the application of FSA, a framework of RBDM on the maritime sector, when planning for a VTS.

This dissertation outlines a process for developing an evaluation tool to be used as the basis for a systematic approach for planning VTSs. The main issues are illustrated through a detailed case study, the Wuhan Port in China, which demonstrates the large range of an area that can be tackled successfully using several newly introduced approaches in the framework of FSA. Thus, the objectives of this paper are:

• To determine the factors to be taken into account when considering VTS and identify the suitable currently used risk assessment and cost/benefit analysis methods and models for planning VTS.

• To provide decision-makers with useful tools and references for the planning of a new VTS or the re-assessment of an existing VTS, for the purpose of achieving the ultimate goals of marine safety and environmental protection as well as efficient traffic.

• To develop comprehensive marine traffic risk assessment models in order to assess the adequacy and efficiency of the existing mitigation and control systems, develop supplementary measures to tackle the risks, if required, establish a basis for deciding the implementation of measures which can reduce the risk in planned area, as well as form a basis for prioritising the individual risk control options.

As a matter of fact, the work to identify, analyse and manage maritime risks for a planned VTS area is generally vast, and it is not possible within such a short paper to present all the necessary information in detail. However, the author tries to present a quick and fresh look at maritime risks and the need for analysis with a focus on a large area. The result of this study could be useful for those concerned with the planning of large maritime projects or waterways management. In this sense, this work could also be a complementary tool in developing a comprehensive, structured and systematic decision-making process for the maritime field.

CHAPTER 1

Risk-based Decision-making in Planning for a VTS

The purpose of a Vessel Traffic Service (VTS) is to improve the maritime safety and efficiency of navigation, safety of life at sea and the protection of the marine environment and/or the adjacent shore area, work sites and offshore installations from the possible adverse effects of marine traffic in a given area (IALA, 2002). Its performance regarding these aspects greatly depends on the rationality, justifiability and cost-effectiveness related to planning such a large maritime project.

This chapter will introduce the basic concepts of safety and risk as well as their relationship. The traditional approach to making decisions concerning maritime safety will be re-examined, then the concept of risk-based decision-making will be introduced and examined with the aim of identifying its advantages and necessity for marine safety. Next, the concept and principle of VTS will be presented, and the significance of Formal Safety Assessment (FSA), a framework for RBDM recommended by IMO, on planning VTS will be specified.

1.1 Safety and risk

Safety was not considered to be a matter of public concern in ancient times, when accidents were regarded as inevitable or as the will of the gods. The modern notion of safety was developed only in the 19th century as an outgrowth of the industrial revolution, when a terrible toll from industrial accidents aroused humanitarian concern for their prevention (Pillay & Wang, 2004). Today safety is of deep concern

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to the whole of human society and has become the province of the public and private sectors.

The term "safety" is discussed widely in literature from different perspectives and its definition is interpreted variously. For instance, safety is defined in the Concise Oxford Dictionary, as "freedom from danger", while Kuo C. (1998) interprets: safety is "perceived quality that determines to what extent the management, engineering and operation of a system is free of danger to life, property and the environment". Although safety has different definitions, a generally accepted view of safety could thus be embodied from these definitions: absolute safety is not available and there is always room for achieving more freedom from danger (Kuo, 1998).

Similarly, the term of risk is mentioned in different contexts, by different scholars, and is defined in different literary expressions. For instance, the US Presidential/Congressional Commission on Risk Assessment and Risk Management (1997) defines risk as "the probability of a specific outcome, generally adverse, given a particular set of conditions"; Warner (1992) proposes a definition with two factors: "risk is a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence" (Warner 1992 cited in Jones and Hood 1996).

No matter how risk is defined, there is a consensus in realistic society: zero risk does not exist and what people can do is to reduce the risk to the level toward which they can be satisfied. This level is related to human risk perceptions, which could vary with different individuals, or different circumstances. For example, the public has become accustomed to thousands of fatalities caused by car accidents annually, however it cannot tolerate an incident such as the "Prestige" occurring again.

Having examined the meaning of safety and risk, the relation between them would be easy to figure out. According to the definition of risk, people could show the extent,

to which the system presents danger to life, property and the environment, by risk. Consequently, safety could also be expressed by risk in the reverse direction: higher risk, less safety; lower risk, more safety. Thus just like what could be drawn from the popular definition of safety "**safety** is a state where the level of **risk** has been reduced to a baseline of as low as reasonably practicable", it is feasible and reasonable to improve safety by controlling and reducing risks.

In addition, safety is an abstract term, while the term of risk is more concrete and can be qualified and quantified by various means. It is therefore practical to represent safety by means of risk and improve safety by managing risks (Xie, 2001).

1.2 Traditional approach to making decisions concerning maritime safety

Rob Dixon (2003) states in his book that "decision-making, which lies at the heart of management, is a process of thought and action that leads to a decision". Managers spend their time choosing between alternative courses of action on the basis of the information available to them at the time. Since the first wooden canoe of primitive build challenged the vast oceans and seas, the marine industry has always been regarded as a risky business, accordingly people have been struggling with mitigation of marine risk and improving maritime safety constantly through history in order to maintain and promote this indispensable industry to world trade, while decision-makers have also been developing relevant marine policies to achieve the above attempts.

The traditional approach to making decisions concerning marine safety is based on "learning from experiences", the essence of which is that what people learn and accumulate from past experiences predominates over their decision-making process and outcomes. It is a typically reactive method; Figure 1 illustrates the basic principle of this approach.

An old example of this approach is the Titanic incident: after this disastrous casualty people realized the importance of sufficient lifesaving equipment and damage stability, so that the decision to create a new Convention (SOLAS, 1914) was made. A recent example is the introduction of double-hull tankers: people drew lessons from severe oil pollution accidents such as the *Exxon Valdez* accident in 1989 and the *Prestige* accident in 2002 etc. and stipulated marine policies to phase out single-hull tankers.
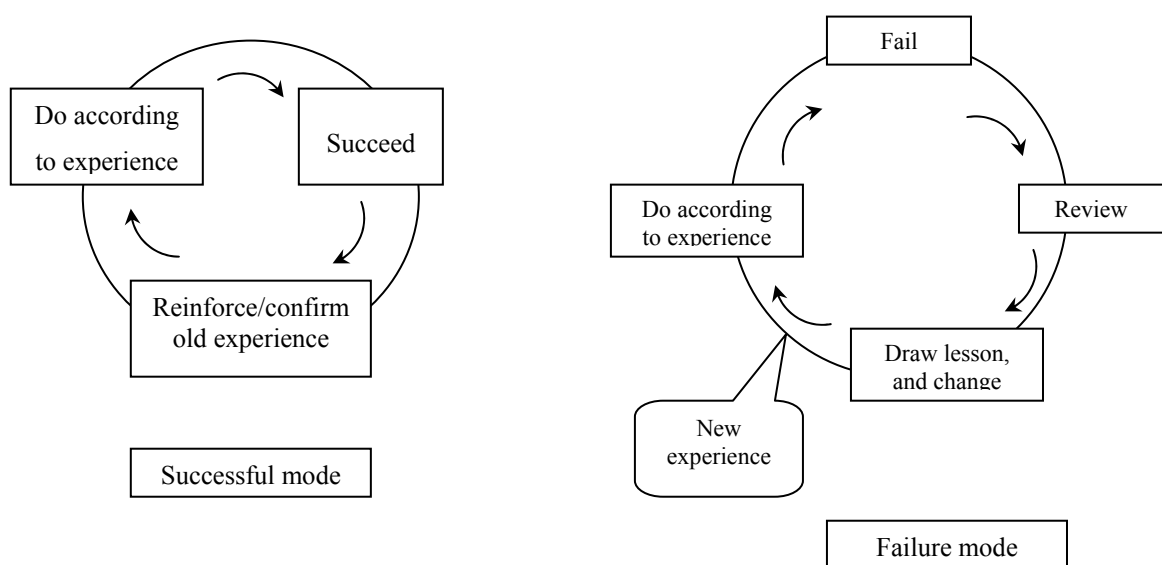
Figure 1: the basic principle of the traditional approach to decision-making

Source: Xie. (2001). *Risk-based Approach to Maritime Safety*. Unpublished master's dissertation, Malmö, Sweden: World Maritime University.

In the marine sector, people have identified considerable hazards and risks as well as developed relevant policies, decisions and regulations to safeguard the shipping industry by using this traditional approach. However, in the public mind the marine industry is still crowned with the title of high risk and is always associated with frequent tragic marine casualties and startling oil pollution etc. People cannot help asking: are there any more appropriate approaches?

1.3 Risk-based decision-making (RBDM)

Risk-based decision-making has become a hot topic recently in industry and government, and the maritime community is no exception. The United States Coast Guard (USCG, 2005) defines it as "a process that organizes information about the possibility for one or more unwanted outcomes into a broad, orderly structure that helps decision makers make more informed management choices".

The adoption of different maritime policies will result in various outcomes. Some are what we want while others are unwanted outcomes which include the harmful effects on safety and health, environmental damage, property loss, or mission failure etc. An obvious feature of risk-based decision-making differing from the traditional approach to decision-making is that the information about the possibility for one or more unwanted outcomes is considered. RBDM adds to the decision-making process a systematic consideration of diverse risks that may be important to various stakeholders. A wide range of risk analysis tools (from very simple to very sophisticated) is available to help decision-makers develop the right information about risks to support their decision-making. Macesker & Myers (2005) say: "The question is not, 'Should I use risk-based decision-making?' The question is, 'How should I use risk-based decision-making?' The key is to focus on using the most suitable tool(s) for detailed situations."

The need for risk-based decision-making in maritime policy is obvious, as the resources that the public and private sectors can devote to navigational safety, traffic efficiency and environmental protection are finite. If these limited resources are spent dealing with low-risk problems at the expense of high-risk ones, then the industry will be exposed to higher risks that cannot be withstood due to an imbalance in resources distribution. The application of risk-based decision-making could remedy these situations. Risk-based decision-making provides a powerful tool that can help ensure that limited public and private resources are allocated more

effectively to reducing risks, maximizing the protection of maritime safety and environment as well as increasing traffic efficiency (AIChE, 1997).

1.4 Vessel Traffic Service (VTS)

Vessel Traffic Service (VTS) can be defined as a service implemented by a competent authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area (International Maritime Organization, 1997). The first VTS was established in Douglas, Isle of Man, in 1948, in the form of a shore based radar station which could provide traffic images in order to keep maritime traffic flows moving in port areas and their approaches against the impact of poor visibility conditions, especially dense fog that had seriously delayed and shut down the port operations. The early VTSs were intended primarily to avoid traffic delays and to increase the efficiency of traffic flows in general. However, attention was also being given to the number of accidents and the way in which these might be reduced. The studies indicated that the number of traffic accidents decreased significantly due to the establishment of VTS (International Association of Marine Aids to Navigation and Lighthouse Authorities, 2002). In the nineteen seventies major oil tanker disasters (e.g. Torrey Canyon, Amoco Cadiz etc.) aroused public awareness of the importance of protecting marine environment and people began pondering how to develop the role of VTS in pollution prevention. In the meantime, IMO became concerned and discussed VTS issues with IALA. In 1997, IMO adopted a new Assembly Resolution on VTS (A.857(20)), "Guidelines For Vessel Traffic Services", which superseded the old one adopted in 1985. This Guideline, associated with SOLAS regulation V/8-2, describes the principles and general operational provisions for the operation of a VTS and participating vessels.

Due to the development of larger and less manoeuvrable ships, the increasing traffic volume, dangerous cargoes and the potential for environment pollution, establishing a VTS to reduce these risks, as a valid measure, has been a practical solution in many ports and waterways around the world. The number of VTS systems worldwide has increased rapidly during the last two decades and there are now about 500 of these services available in total. In particular, with the recent booming seaborne trade, the implementation of new VTS and the re-assessment of an existing VTS worldwide are reaching a new high tide. However, constructing a VTS is a considerable investment and its subsequent operation is also very money-consuming; some VTSs do not play an important role as people anticipate; many seafarers regard VTS simply as a party they have to contact when passing through reporting lines while some VTS cannot provide sophisticated services for crew or cannot meet local waterborne traffic requirement; some VTSs have had to close down because of financial considerations, (for instance New York VTS stopped its services in 1988 and reopened in 1990 due to budget problems etc.). All these depressing news has prompted those persons, who were enthused to establish VTS once, to speculate calmly about what is wrong with it.

The maritime industry operates in an increasingly complex world in which changes – technological, financial, organizational – take place more quickly, are more extensive and run deeper than ever before. Rapid changes lead to higher risk and a greater need to understand and analyse the risk. The final results will depend on how these factors are dealt with in practice in advance and how the important elements are analysed (Ullring, 1998). Consequently, how to plan a VTS perfectly, which will result in fulfilling its functions validly, contributing in reaching its purposes to the greatest extent as envisaged, and establishing whether the investment required is justified, becomes key considerations faced by each VTS stakeholder.

The traditional approach to safety in the maritime sectors has been reactive - to react to problems as they occur. Instead of reacting in an *ad hoc* way to a problem, a

careful analysis of the risk situation should be carried out while keeping financial and resource constraints in mind, which is of special importance to the concerned stakeholders and decision-makers. So in order to lower risks rationally as much as possible, it is suggested that when planning a VTS, decision-makers should use proactive methods, which could be the application of the principle of risk-based decision-making on maritime fields. A practical framework recommended by IMO for RBDM on maritime fields is Formal Safety Assessment (FSA).

1.5 Formal Safety Assessment (FSA)

FSA was originally developed partly at least as a response to the *Piper Alpha* disaster of 1988, when an offshore platform exploded in the North Sea and 167 people lost their lives (IMO, 2005). As a result of the studies with respect to scientific decision-making for years, two organs of IMO, MSC and MEPC, jointly developed and approved "the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process". As the Guidelines (2002) mention, FSA is a structured and systematic methodology, aimed at enhancing maritime safety, including the protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment. It provides a framework for applying the principle of RBDM in the IMO rule-making process.

Member Governments are also recommended to apply FSA when it is deemed necessary. IMO (2002) stresses that its application would be particularly relevant to proposals for regulatory measures which have far-reaching implications in terms of either cost (to society or the maritime industry), or the legislative and administrative burdens which may result. FSA may also be helpful when there is a need for risk reduction but the outcomes of the required decisions are unclear. This gives Member Governments a clearer insight into the policy and a trustworthy platform on which they form policies. Similarly, it can assist stakeholders or decision-makers to evaluate the rationality, necessity and cost-effectiveness of a marine project. So from

the author's point of view, it is very useful and significant to do the research concerning the application of FSA, a framework of RBDM on the marine sector, when planning VTS.

According to the IMO Guidelines (2002), FSA should comprise the following five steps:

.1 identification of hazards;

.2 risk analysis;

.3 risk control options;

.4 cost benefit assessment; and

.5 recommendations for decision-making.

Figure 2 depicts a flow chart of the FSA methodology.
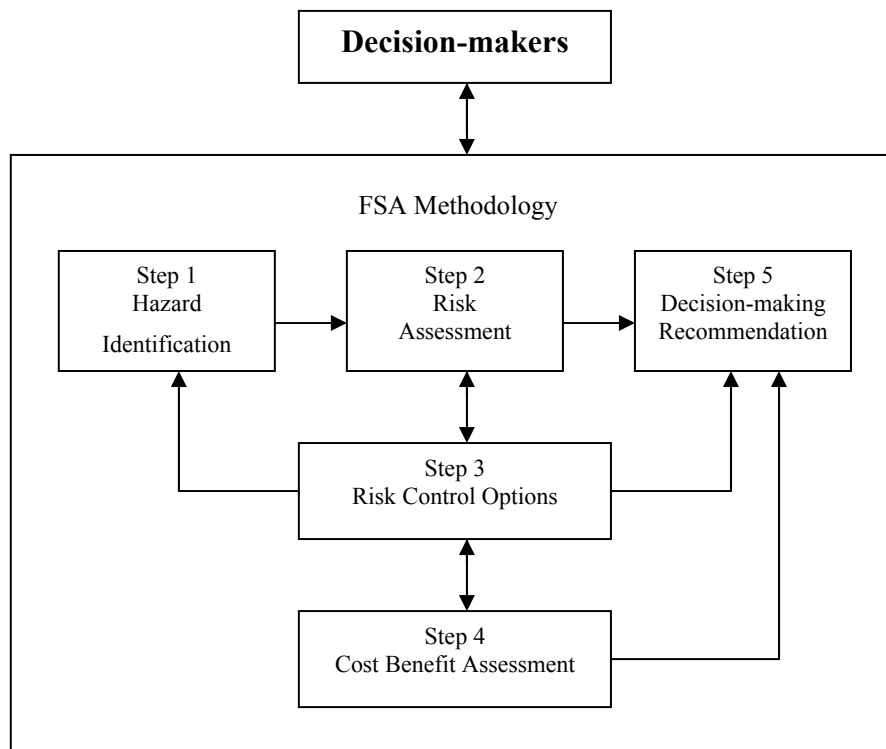
Figure 2: Flow chart of the FSA methodology
Source: International Maritime Organization. (2002). *Guideline for Formal Safety Assessment (FSA) for Use in the IMO Rule-making Process* (MSC/Circ.1023, MEPC/Circ.392). London: Author

Many scientific disciplines deal with FSA in order to develop solutions for applications in their particular field of interest. As a result of the often-interdisciplinary nature, numerous approaches for a variety of safety and security problems have been developed over the years. Although there are many different methodologies available in order to evaluate different kinds of risks they all follow similar principles, which can be seen in the following Figure 3 (Schröder, 2005).
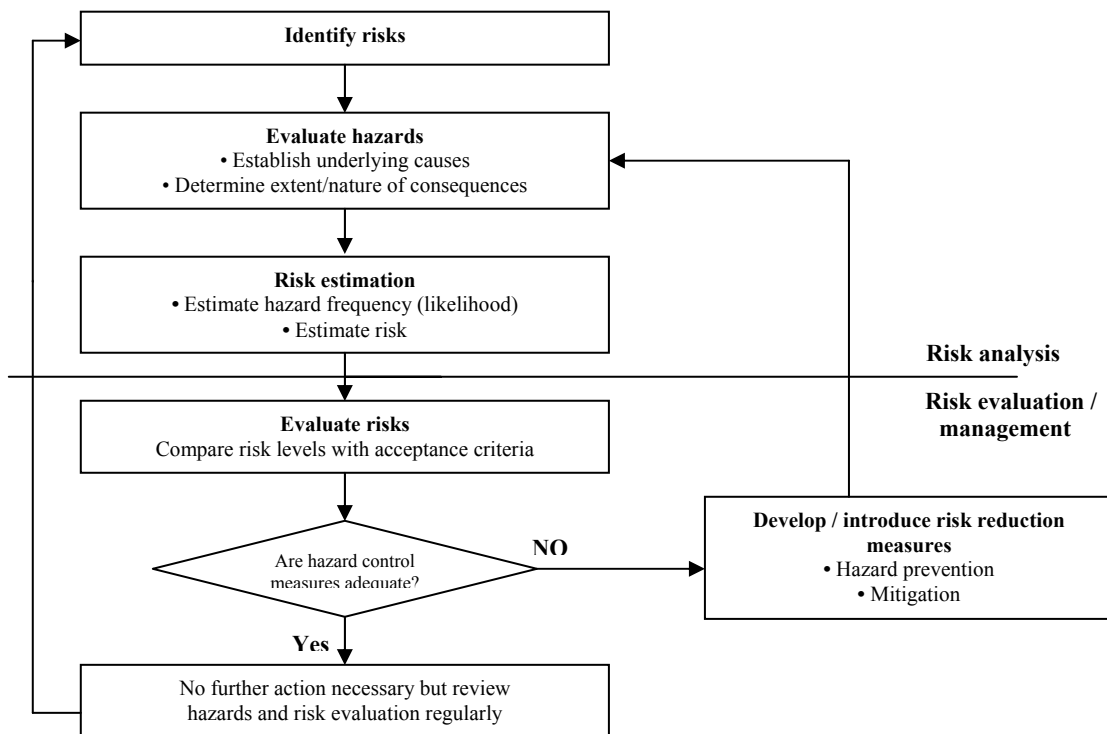
Figure 3: General risk assessment process
Source: Waring & Glendon (1998)

In practice, the process of FSA begins with the decision-makers defining the problem to be assessed along with any relevant boundary conditions or constraints, then for any potential problem or operation to be safeguarded risks and hazards need to be identified first. Next, the identified risks need to be estimated and evaluated separately or integrated against the defined risk acceptance criteria. If the assessed risk is higher than the criteria, the corresponding risk control options need to be specified in order to limit the risk down to a level with which the stakeholders or

decision-makers would be satisfied or accept. In further steps, the specified options need to be determined whether or not they are worthwhile through conducting a cost-benefit analysis. The option that is assessed as a cost-effective one will generally be adopted and presented in decision-making recommendations.

Undoubtedly, the above concepts and framework similarly are applicable to the RBDM for planning VTS. However, VTS, as an option in implementing waterways management, is different from other options in terms of principles, scale, scope, costs and stakeholders. Consequently, detailed application of FSA on planning VTS would definitely have its own features and characteristics, which have some significant discrepancies from other options. In the following chapters, the author will introduce the detailed methods and models, some of which are demonstrated and interpreted through a concrete example of Wuhan Port, that in particular are suitable to the general application of FSA on planning VTS. A short introduction to Wuhan Port can be seen in Appendix A.

CHAPTER 2

Identification of Risks and Hazards

In the previous chapter, the concept and process of FSA was briefly introduced. FSA, as a practical framework for RBDM on maritime sectors, adds to the decision-making process a systematic consideration of diverse risks and hazards that influence the various stakeholders. So identification of the risks and hazards is logically regarded as the first step of FSA, which comprises five steps in total as seen in Figure 2.

At the inception of FSA, the first step is to answer the question of what categories of hazards exist in the defined system, which lead to the failure or unacceptance of the system. In its guideline for FSA, IMO (2002) points out that:

> The purpose of step 1 is to identify a list of hazards and associated scenarios prioritized by risk level specific to the problem under review. The purpose is achieved by the use of standard techniques to identify hazards which can contribute to accidents, and by screening these hazards using a combination of available data and judgement.

As far as planning VTS is concerned, what categories of risks and hazards should be identified depends on the purpose of VTS. As mentioned above, VTS may play an important role, mainly in respect of improving maritime safety, the protection of the marine environment and the efficiency of navigation. Consequently, it is necessary to take into account those factors which directly determine the risk levels in these three aspects or the deeper layer of factors which indirectly, however more systematically

and essentially uncover the underlying causes behind the levels that can not be accepted by decision makers and need to be improved by the means of establishing a new VTS or upgrading an existing VTS. These two tiers of factors correspond to the two approaches used for hazard identification. The former is achieved by using an analytical technique whereas the latter is put into effect using creative methods. In the Guidelines on Risk Management, IALA (2000) recommends that the two approaches be combined in order to identify as many relevant hazards as possible.

In hazard identification methodology, the analytical element ensures that previous experience is properly taken into account and typically makes use of background information as followed in terms of planning VTS:

1. the existing navigational regulations;

2. historical statistical data on maritime accidents;

3. traffic volume per year within the planned VTS area;

4. main mixture of traffic flows (main crossing traffic flows against main traffic flow);

5. the category and amount of dangerous cargoes loaded and discharged within the defined port per year;

6. the local conditions like geography, hydro/meteo, tides and weather;

7. the local marine environment affected by shipping industry.

The creative element is to ensure that the identification process is proactive through aiming at identifying the causes and effects of accidents and relevant hazards instead of confining it only to hazards that have materialized in the past. As is known to all, the human element is the most important contributory aspect to the causation and avoidance of incidents. So appropriate techniques for incorporating human factors should be used. In Resolution A.947 (23), IMO (2003) states that:

> The human element is a complex multi-dimensional issue that affects marine
>
> safety, security and marine environmental protection. It involves the entire
>
> spectrum of human activities performed by ships' crews, shore-based

management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively.

In applying FSA when planning for a VTS, the decision-makers shall focus on how errors in respect of ships' crews, shore-based management and regulatory bodies lead to the failure of the system which can be defended to reach an acceptable standard by implementing waterways management, especially by establishing a VTS in a planned area. In the third step of FSA, risk control options (RCOs) will be elaborated and potential risk control measures (RCMs) could be identified through analysing these human errors, so the underlying causes may also be left to step 3 to be uncovered.

2.1 Define problem

As a structure and systematic methodology by using risk analysis and cost benefit assessment, FSA may be applied widely in fields from the IMO rule-making process to a maritime administration proposal for regulatory measures, and from the formulation of a new IMO instrument to planning a maritime project regardless of its scope. Although FSA has a similar principle, concept and steps in all kinds of research as long as it is applicable, decision-makers should take into account different factors determining the performance of a system and its corresponding range of study when aiming at a specific project or a category of projects so that the problem under analysis and its boundaries could be carefully defined stating the associated risk issues. This is the most important phase in FSA and it both guides the whole process, how to be within a proper boundary, and guarantees that the limited research resources are appropriately utilized and deployed.

The problem boundaries of a formal safety assessment study can be developed in the following manner (Pillay and Wang, 2004):

- Range of the vessel

- Geographical boundaries

- Risks to be considered

- Vessel systems

- Relevant regulations

- Measures of risks

Based on the above proposal of the specialists, as well as the features and functions VTS has in doing waterways management, problem definition in terms of planning VTS may focus on the following six aspects: VTS vessels, types of VTS, traffic rules and regulations, risks to be considered, geographical boundaries and determination of risks.

2.1.1 VTS vessels

VTS vessels mean the participating vessels in VTS. The targets that ship traffic management aims at are the vessels in an assigned area, which generally do not cover all vessels. In IMO Resolution A.857(20), it is recommended that vessels navigating in an area where vessel traffic services are provided should make use of these services and vessels should be allowed to use a VTS where mandatory participation is not required. However, VTS vessels have to be equipped with the necessary navigational aids and radio communication apparatus in accordance with SOLAS 74 while communication with the VTS and VTS vessels should be conducted on the assigned frequencies or channels according to established ITU and SOLAS chapter IV procedures. This is a mandatory requirement for VTS vessels in respect of equipment. It has been shown that IMO does not coerce all ships into participating VTS and it would be difficult to implement traffic management on those vessels

especially when they do not possess any capability of communication. Generally speaking, VTS services are rendered via VHF. Consequently, VTS vessels may be defined as the vessels carrying VHF in the VTS area.

In the water area of Wuhan port, all ships must at least be equipped with VHF working on channels 8 and 16 in accordance with the norm of Chinese river ship construction and classification or SOLAS 74, except a very small number of wooden fishing boats and barges without power which are always towed or pushed by tugs. This provides a prerequisite for establishing VTS because communication, as one of the essential ingredients of the VTS system, makes sure the establishment of valid relations between VTS organization and VTS vessel.

2.1.2 Types of VTS

A VTS can improve the safety of traffic through the foresighted prevention of situations of unacceptable risk, by contributing to safe encounters from the above foresighted measures and by assisting ships to keep within navigable waters (IALA, 2002). In the process of FSA, the application of which would be particularly relevant to proposals which may have far-reaching implications in terms of either cost or the legislative and administrative burdens that may result, cost/benefit analysis plays a vital role in justifying the discussed projects or measures. The benefits achievable by a VTS depend on its types which may be divided by the services provided and the functions performed, as follows:

The Information Service ensures that essential information is available in a timely manner to the shipboard decision process, either by broadcasting at fixed times or if deemed necessary by the VTS. This is normally provided to general traffic.

The Traffic Organisation Service is concerned with the forward planning of movements to prevent the development of dangerous situations.

The Navigational Assistance Service assists the navigational decision-making process on board, participating by giving information and services.

The Co-operation with allied services and other interested parties is a supporting service for exchanging information, using common data bases and action agreement.

(IALA, 2002)

When planning VTS, decision-makers should determine the type of planned VTS and associated level of the above mentioned services on the basis of the outcomes of hazard identification (step 1) and risk analysis (step 2).

2.1.3 Traffic rules and regulations

Although COLREG 1972 has a predominant status in worldwide seaborne traffic, as far as port areas, coastal areas and other sensitive waters are concerned, navigation safety and efficiency generally need to be reinforced through adopting and implementing the relevant traffic rules and regulations which may include not only those defining the navigational requirements such as traffic routes, speed limits, anchorage areas etc, but also any special requirements such as compulsory pilotage and pilot boarding areas, traffic separation schemes, ship reporting systems and prohibited or precaution zones etc. In other words, the risk level of an area depends on its traffic patterns to some extent.

The Port of Wuhan is a typical river port within which the Chinese River Code for Preventing Collisions is the principal traffic rules. Meanwhile, the Code is complemented by some local traffic rules and regulations promulgated by the Yangtze MSA and Wuhan MSA in order to implement more effective waterways management in the waters of Wuhan port. Compared to COLREG 72, the provisions of the Code are much more complicated due to the features of the river and its traffic.

However, as shown in Figure 4, the principle of the Code could be summarized in one sentence: ships sailing down go by swift flow whereas ships going upstream navigate by slow flow.
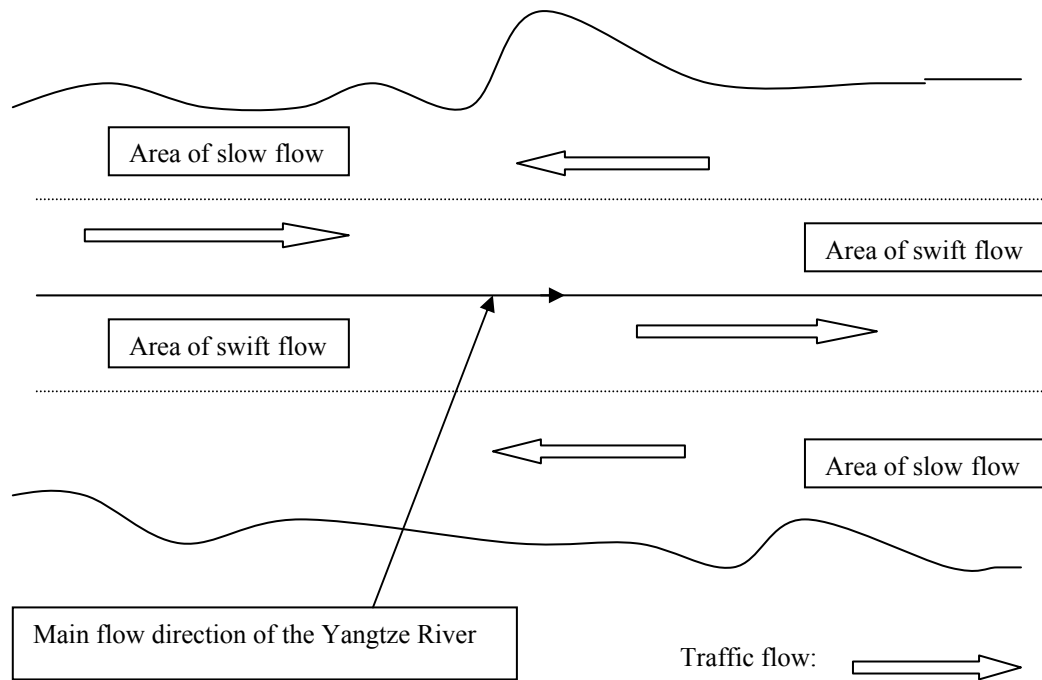
Figure 4: an illustration of the principle of the Chinese River Code for Preventing Collisions

Another important traffic pattern is called the sailing cross area, as shown in Figure 5, where ships going upstream have to cross the traffic flow sailing down due to the existence of a concave area shown as the shaded area in Figure 2, which can influenced negatively the manoeuvrability of ships going upstream. Nevertheless, the establishment of this area increases the probability of ship cross encounters and collisions.

Sailing cross area

Main flow direction of the Yangtze River:

Traffic flow of going upstream: Dangerous concave area:
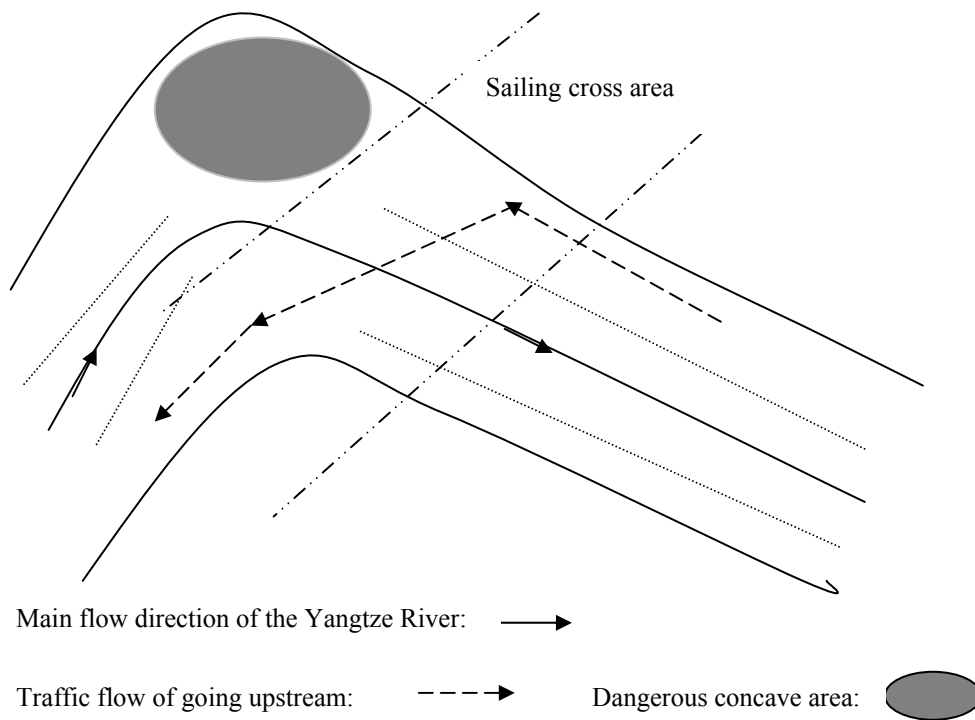
Figure 5: an illustration of the sailing cross area

2.1.4 Risks to be considered

What is risk? Is it synonymous to hazard? The report of a Royal Society Study Group (1992) defines risk as "the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge where an adverse event is an occurrence that produces harm". As to hazard and harm, the report (1992) states that "hazard is seen as the situation that in particular circumstances could lead to harm, where harm is the loss to a human being (or to the human population) consequent on damage and damage is the loss of inherent quality suffered by an entity (physical and biological)".

The risk management of waterways involves the systematic identification, evaluation and control of potential losses, which may arise from future events which have an

impact on the safety of the ship, marine environment and traffic efficiency. Examples of these events are fires, explosions, environmental damage, release of toxic gases, collisions, groundings, extreme weather, structural failure and loss of stability etc. (Monioudis, 1997). So from the angle of the marine industry, risk can be explained as the probability that a maritime incident occurs during a stated period of time.

Different agencies define marine incidents in different ways. In the Code for the Investigation of Marine Casualties and Incidents (IMO, 1997), it is stated that:

> Marine incident means an occurrence or event being caused by, or in connection with, the operations of a ship by which the ship or any person is imperilled, or as a result of which serious damage to the ship or structure or the environment might be caused.

The Regulations of China on the Investigation and Handling of Maritime Traffic Accidents (1990) is applicable to the following accidents occurring to vessels and installations:

> (1) Collision, strike or damage by waves;

> (2) Hitting hidden rocks or running aground;

> (3) Fire or explosion;

> (4) Sinking;

> (5) Damage or loss of machinery parts or important tools during a voyage which affects the vessel's seaworthiness;

> (6) Other maritime traffic accidents which cause losses in property and human lives.

However, in planning VTS, risks to be considered only comprise those accidents related to movements and the dynamics of vessels that could be prevented or decreased by VTS, including collision, grounding, hitting hidden rocks, contact, wave damage etc, plus damage to the environment or fire and explosion if caused by the above incidents. On the other hand, when making a cost/benefit analysis in the fourth step of FSA, the decision-makers should take into consideration of other accidents in estimating the benefit that the establishment of VTS can contribute to, because VTS could participate in SAR activities and mitigate the consequence of those accidents. For instance, an explosion caused by crew smoking on board the ship should be excluded in identifying the risks and hazards of FSA step1, whereas it should be considered in doing cost/benefit analysis if VTS is involved in the rescue of this ship.

2.1.5 Geographical boundaries

There are three categories of VTS: Port or Harbour VTS, Coastal VTS and River VTS. A Port VTS is mainly concerned with vessel traffic to and from a port or harbour or harbours, while a Coastal VTS is mainly concerned with vessel traffic passing through the area (IMO, VTS Guidelines, 1997). A River VTS which usually renders information services as well as navigational assistance and traffic organization services, could be regarded as a combination of these two types. In its Guidelines, IMO sets out eleven criteria for an area in which VTS is particularly appropriate if the area meets any of them. In fact, these criteria also theoretically determine the geographical boundaries of a planned VTS. In FSA, the decision-makers may refer to these criteria to define what areas need to be studied.

Wuhan port, as one of the busiest river ports in China, has a high traffic density, complex navigation patterns and difficult hydrographical and hydrological elements. Consequently, the whole water area of Wuhan port should be considered in applying

FSA when planning Wuhan VTS. The Geographical boundaries of this study are the same as those described in a brief view of Wuhan port in Appendix A.

2.1.6 Determination of risk

Mathematically, risk is defined as the probability of an adverse event times its impact. The probability can be simply expressed as the mean number of marine accidents per year or be more complicatedly estimated by establishing mathematical models, while the impact, provided that it occurs, can be calculated in different ways. There are monetary methods, count methods and index methods.

Monetary methods are particularly appropriate to evaluate the loss in the form of damage to property or economy. They also facilitate the analysts to categorize the accidents in terms of loss as well as make acceptability and cost/benefit analyses in the process of FSA due to its obvious comparability. However, in some circumstances, it is not always easy to calculate the loss in monetary terms, especially when life loss, damage to the environment and impact on mentality and psychology are involved. Instead, it is sometimes easier to simply count the amount of loss that happened in the stated years. Index methods, which determine the level of risk by giving weight value to individual accidents, are a variety or a combination of the former two kinds of methods. All these three types of methods can be used by decision makers at their discretion in FSA according to the data and information they can collect.

2.2 Identification of risks and hazards

It is recommended that the output from this step comprises a list of risks / hazards / unwanted events and their preliminary description. The prioritisation of risk is fundamental to the following analysis of risks. There are a number of ways in which

this can be done and these will vary depending upon the risks under consideration and the particular methodology being employed (Dickson, 2003).

The Chinese VTS project group (1989) thought that there are a lot of factors contributing to marine accidents in harbours and affecting the level of port traffic environment, which could be generally categorized into three main groups as shown in Figure 6: hydro/meteo factors, fairway factors and vessel traffic factors. These factors can be regarded as risks and hazards that need to be identified in planning VTS.
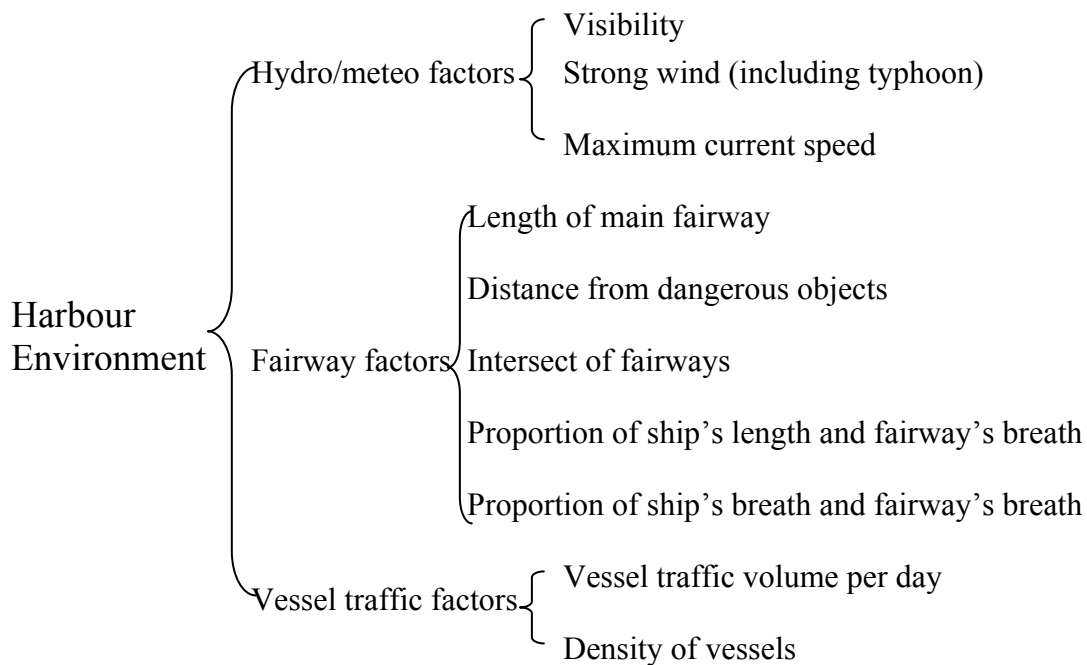
Figure 6: Factors contributing to marine accidents and affecting the level of port traffic environment
Source: Chinese VTS project group. (1989). *Research Reports on Class Division of Vessel Traffic Management In Coastal Harbour of China*. Dalian: Author.

However, with globally seaborne transport for crude oil and dangerous cargoes on the sharp increase, as well as reinforcement of public awareness on aspects of a friendly environment, marine pollution has come more and more under the spotlight, especially after the disastrous oil spill incidents such as the Exxon Valdez, Erika,

Prestige etc. Consequently, it is necessary to add the factors covering dangerous cargoes and marine pollution into the above lists for more comprehensive identification of the local traffic hazards.

Then according to a preliminary description of these hazards, as well as qualitative and quantitative analysis, the whole water area being studied in planning VTS can be divided into several sub-areas which are ranked in view of the sensitivity of navigation safety and the marine environment. Moreover, through collecting and analysing the historical maritime accident data in the evaluated area, local accidents or risks can also be ranked by considering types of accidents, types of loss and their geographical distribution. Next, the comparison and combination between rank of areas and rank of risks could result in a prioritized list of areas and a prioritized list of risks. The model for Step1, identification of navigational and environmental risks, is indicated in Figure 7:
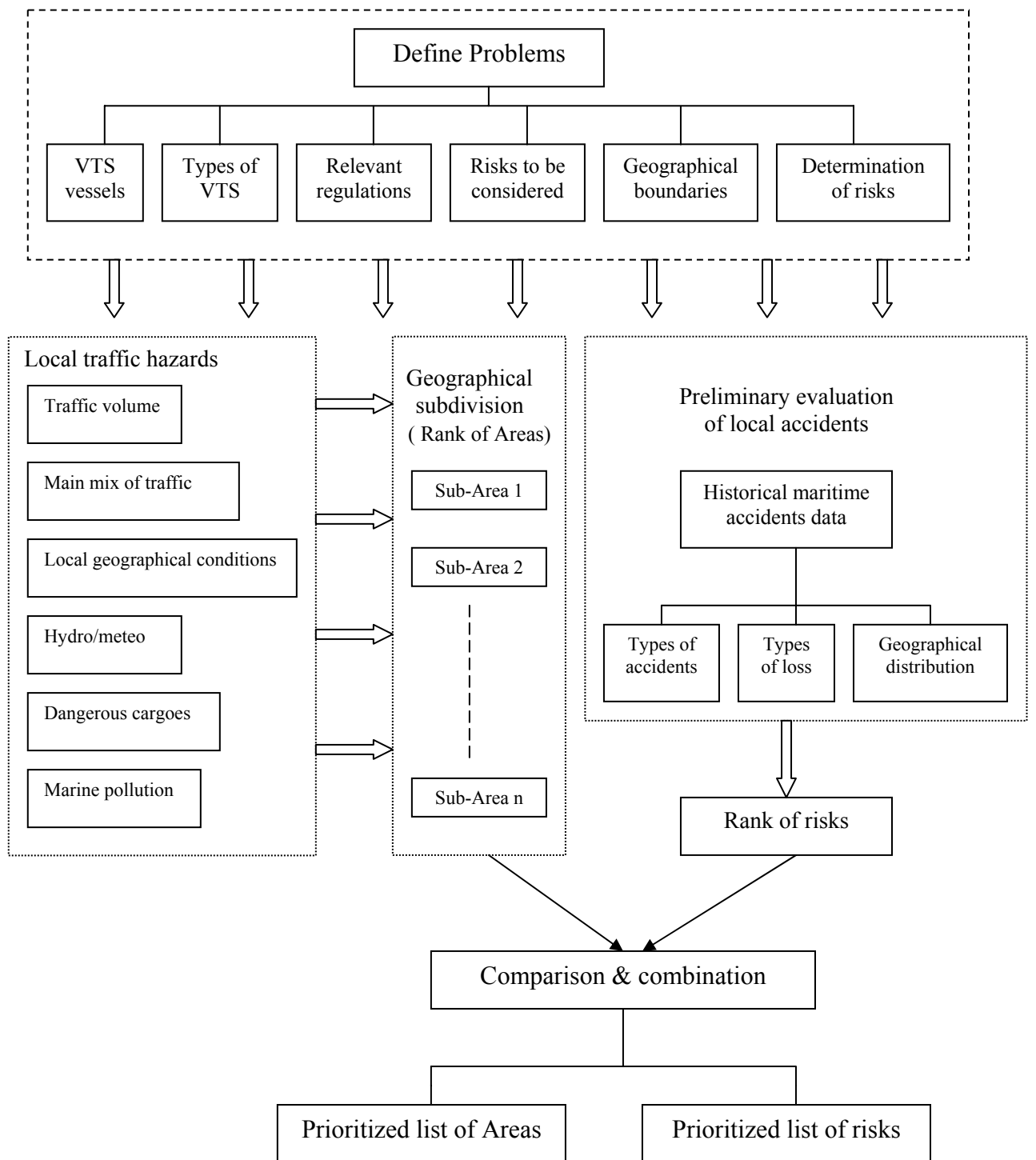
Figure 7: Step1 Identification of navigational and environmental risks

2.2.1 Local traffic hazards

• Traffic volume

Traffic volume means the sum of amount of vessels in a specific area during a stated time, including transit traffic, entry/leave port traffic and internal traffic, which reflects to what extent the area is busy or congested. Generally speaking, more traffic volume could result in higher maritime risks. Fujii & Matui (1984) give two mathematic formulas as followed when estimating frequency of collisions with objects and groundings as well as frequency of ships collision:

$$Nau1 = \iiint \rho VD \, \phi dL dV dt \tag{1}$$

$$Nau2 = \iiint \iiint \iiint (\rho^2/2)\phi_1\phi_2 V_r dL_1 dL_2 dV_1 dV_2 dS dt \tag{2}$$

Nau1 --- the number of ships in collisions with objects and groundings;

ρ --- the density of traffic;

V --- traffic flow speed;

D --- the cross section;

Φ --- the normalized distribution function of the ship length and the velocity;

L --- length of traffic flow;

t --- time;

Nau2 --- the number of collision of ships;

Φ_1, Φ_2 --- normalized distribution function of the ship size and velocity;

Vr --- the relative speed

S --- area.

The above formulas not only indicate the relation between density of traffic and number of accidents but also illustrate that traffic volume is a considerable factor that influences the local traffic risk.

The calculation of traffic volume in a defined area can be done through a visual survey and looking up vessel arrival/departure/in-port traffic records. Due to the limitation of human power and resources, it is impossible for researchers to carry out a visual survey 365 days a year. Generally visual survey, which particularly is appropriate to estimate the transit and entry/leave port traffic volume, is implemented by recording the number, types and sizes of vessels passing through the observation lines in three or four continuous days per three months or half a year. The result, as a sample, can be used to estimate approximately the whole year traffic volume passing those lines. Yang & Wu (1992) gave the formula as follows for calculating traffic volume per year. The traffic volume per year (1999-2003) in Wuhan port and its distribution can be seen in Appendix B.

$$K = \frac{1}{m}\sum_{j=1}^{m}(K_j + \frac{365}{n}\sum_{i=1}^{n}K_{ji}) \qquad (3)$$

K: the mean traffic volume per year;

m: the number of years carrying out visual survey;

K_j: internal traffic volume in No.j year;

n: the number of days carrying out visual survey per year;

K_{ji}: visual survey traffic volume in No.i day in No.j year.

• **Main mix of traffic**

It is easily understood that most collisions between ships happen in crossing situations rather than in the case of overtaking and head-on. The mix of traffic is a very important factor determining the complexity of local traffic. Baldauf (2003) gave statistics concerning the comparison of accident numbers in the previous traffic mode and the new one adopting the Traffic Separation Scheme (TSS) in the UK coastal area from 1957 to 1981, as follows.

Table 1: Accident number in UK coastal area from 1957 to 1981

Sea area	1957-1961	1962-1966	1967-1971	1972-1976	1977-1981
Strait of Dover	52	56	36	14	12
Southern North Sea	79	81	66	29	19
English Channel	23	30	22	21	14
Total	154	167	124	64	45
Close to/in TSS	128	140	89	34	24
Outside TSS	28	36	29	30	21

Source: Baldauf, Michael (2003). Statistics about the Comparison of Accidents Number in Previous Traffic Mode and New One Adopting TSS in UK Coastal Area From 1957 to 1981. *The Personal Communication*. Wismar University: Author.
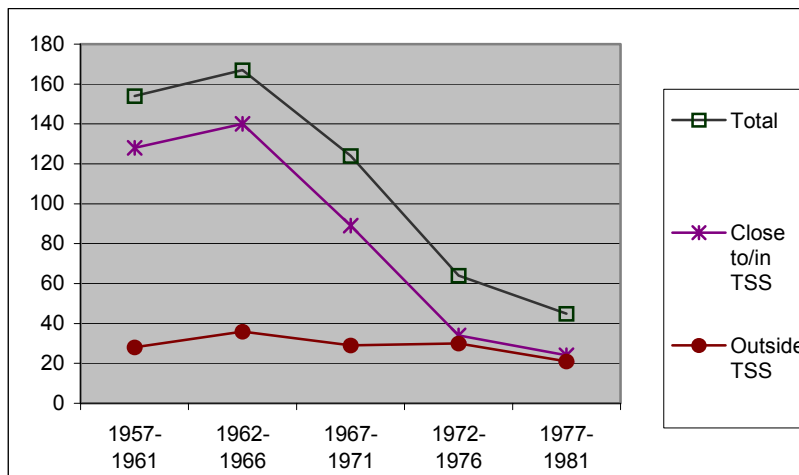
Figure 8: Accident number in UK coastal area from 1957 to 1981
Source: Baldauf, Michael (2003). Statistics about the Comparison of Accidents Number in Previous Traffic Mode and New One Adopting TSS in UK Coastal Area From 1957 to 1981. *The Personal Communication*. Wismar University: Author.

TSS is one kind of ships' routing, which provides for the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes, reduces dangers of collision between crossing traffic and ships in established traffic lanes as well as simplifies the patterns of traffic flow in converging areas (Transport Canada, 1991). For the above statistics indicated in Table 1 and Figure 8, it can be concluded that where close to / in TSS, the number of marine accidents dramatically decreased while outside TSS the level of traffic risk was still kept relatively invariable. So the more line intersects created by the max of traffic in the defined

area, the more complicated the traffic mode is and the more probabilities of marine incidents there will be. The quantity of encountering points can be regarded as one of the parameters for evaluating and prioritizing the areas in terms of risks. The main mix of traffic in Wuhan Port is briefly introduced in Appendix B.

• **Hydrology / meteo**

In respect of hydrology / meteo, the factors giving influence to accident probability mainly include visibility, current and wind.

Poor visibility is caused by fog in most circumstances. It tremendously reduces the amount of information that seafarers on board vessels can obtain from outside due to the limitation of their visual sense so that officers manoeuvring vessels have great difficulty in making appropriate decisions. In harbour and river areas, the local Maritime Authority generally promulgates strict navigation rules upon a vessel's behaviour in poor visual range while COLREG states in Rule 19 (conduct of vessels in restricted visibility) that every vessel should proceed at a safe speed adapted to the prevailing circumstances and restricted visibility. Fujii and Yamanouchi (1974) divided 562 collisions and 354 groundings in six Japanese straits from 1966 to 1971 into groups with respect to the visual range and the analysis with these data and the frequency of visual ranges indicates that the ratio of the number of accidents is inversely proportional to the visual range for both collision and grounding. Furthermore, when visibility is below a certain extent, vessel traffic in harbour could have to stop totally. So poor visibility has a considerable impact upon traffic efficiency and traffic safety.

Wind and current also influence the traffic volume and frequency of accidents. Strong winds can lead to a ship's deviation from planned lines and restriction in its ability to manoeuvre, which may possibly result in a grounding or collision especially in narrow channels and fairways. After studying the relationship between

the number of relative accidents and wind speed, Qi (1991) gave the following formula:

$$k_w = 7.9v_w - 11.6 \,, \quad k_w \geq 0$$

k_w --- number of relative accidents;

v_w --- wind force on the Beaufort scale.

This formula indicates that there is a linear feature between k_w and v_w and different wind forces have different impacts on vessel traffic safety.

The effects of current on vessel traffic mainly focus on two aspects: one is the influence on movement and manoeuvre functions of a vessel while another is on traffic volume. When a vessel goes upstream within the current, its rudder effect will generally improve. Conversely when it sails down, it is more difficult for the crew to manipulate the ship due to the poorer rudder effect. In addition, cross currents may give rise to a ship's deviation from correct lines and lead to traffic accidents. In some harbours affected by tide, small boats often catch tides for easily entering into or departing from the harbours so that traffic volume sharply increases at that time. Kandori (1972) analyzed the influence of current and wind and indicated that collision risk increases three times for tidal current over six knots in Hayatomoseto but a survey in Oseto did not underwrite this tendency. His study showed a considerable increase in the risks of both collision and grounding in the Kanmon Strait for winds over 20 knots. From these studies, we can also draw a conclusion that visibility, current and wind are the hazards that need to be identified in planning VTS. A short introduction of visibility, current and wind in Wuhan Port can be seen in Appendix B.

• Dangerous cargoes and marine pollution

The harmfulness of dangerous cargoes mainly consists of their operational, intentional and accidental discharge into oceans, seas and rivers as well as the second-effect on seafarers, ships and environment such as fire, explosion and spills

etc., when vessels carrying them are involved in marine accidents. The briefing of dangerous cargoes in Wuhan Port is illustrated in Appendix B.

Seas, rivers and marine shoreline areas are important public and ecological resources. Water environments affect human health as they are often used for drinking water. The water and shoreline also provide public recreation area throughout the world and serve as homes to a variety of wildlife species including mammals, aquatic birds, fish, microorganisms, and vegetation. However, their cleanliness and beauty, and the survival of the species that inhabit them, can be threatened by accidents that occur when oil and dangerous products are produced, stored and transported (EPA, 1999). In addition, once pollution happens, the associated costs for clean-up operations including shoreline clean-up and recovery of sunken oil may be significant even when only small quantities of spilled oil are involved.

Figure 9 illustrates that there is no linear relationship between spill cost and size of tanker (which might in turn be considered indicative of spill volume). Indeed, some of the most expensive spills have been caused by relatively small tankers. In these cases the most important factor has been the type and place of oil spilled. For example, both the NAKHODKA and ERIKA spilled heavy fuel oil, which is highly persistent and came ashore along long lengths of coastline (ITOPF, 2004). So maritime pollution also ought to be identified as a kind of hazard in applying FSA on planning VTS.
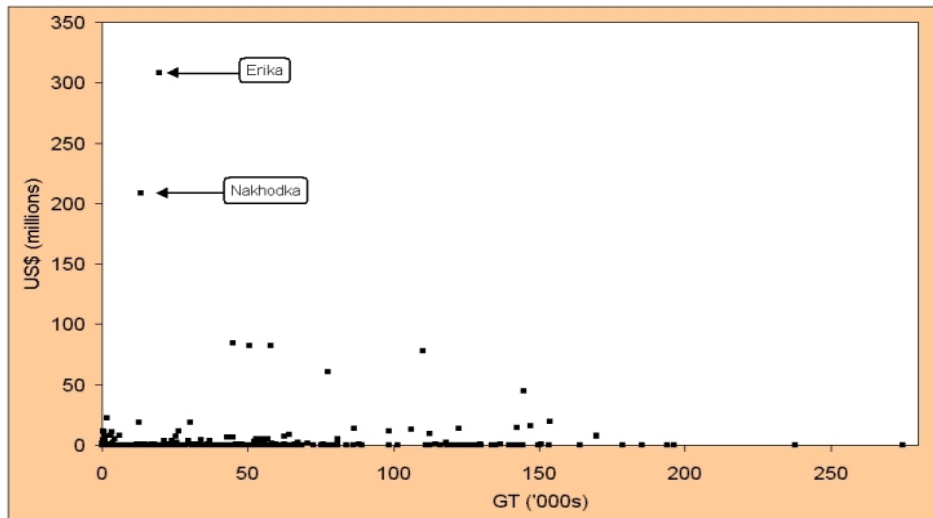
Figure 9: The costs of oil spills

Source: International Tanker Owners Pollution Federation Limited. (2004). *The Costs of Oil Spills*.
From the World Wide Web: http://www.itopf.com/costs.html

• **Local geographical conditions**

To the impact of geographical conditions, IALA (2002) states: "The local geography
will be the determining influence on the size of the area to be covered by a VTS. In
the case of ports these vary enormously in their geography. Some ports, are
extremely simple and are little more than an indentation in the coast protected by
breakwaters. Entry/exit is through a passage between the breakwater heads, which
give direct access to the open sea. Vessels are only restricted in their freedom to
manoeuvre as they pass through the breakwater and into the port itself. At the other
extreme are estuarial ports, often far from the open sea with long approaches
encumbered by shallow, shifting sandbanks. Vessels using these ports will be
restricted navigationally and possibly be unable to anchor or reveres course over long
stretches of their passage. The prevailing weather, in particular visibility and wind
together with the tidal range and stream, may impose difficulties on the ability to
navigate safely. Together with the local geography they determine the degree of

navigational difficulty likely to be encountered by a vessel." The geographical conditions in Wuhan Port are briefly introduced in Appendix B.

2.2.2 Geographical Division

The whole water area studied can be geographically divided into several sub-areas and ranked if necessary, especially when the size of the area is immense, according to the scenario of those factors determining the level of risks in the studied area in the process of planning VTS.

Wuhan Port is spanned about 150 km along its main channel and 55 km along its branch channel. By considering the above principle, the Port can be delimited into four sub-areas. Their geographical descriptions are shown as follows:

Sub-area1: from the downriver boundary of Wuhan Port to Qingshanxia anchorage;
Sub-area2: from Qingshanxia anchorage to Wuhan third bridge of Yangtze River;
Sub-area3: from Wuhan third bridge of Yangtze River to upriver boundary of Port;
Sub-area4: the Hanjiang section of the Port.

2.2.3 Preliminary rank of sub-areas

As mentioned above, local traffic hazards comprise six factors: traffic volume, main mix of traffic, hydro/meteo, dangerous cargoes, marine pollution and local geographical conditions. The ranking of sub-areas can be identified through a comparison of their respective rank in six factors. For instance, a certain factor has different levels of risks in different sub-areas. As far as this factor is concerned, one sub-area will be given a higher value if this factor in this sub-area is more severe to navigation safety, environmental protection and traffic efficiency than that in another sub-area. Then all the values to different factors in each sub-area are

comprehensively evaluated and weighed in order to appropriately rank the different sub-areas.

Wuhan Port is divided into four sub-areas. One sub-area is characterized as 4 with regard to a factor if this sub-area has the highest risk in respect of this factor among all the sub-areas. However, it will be valued as 1 if it has the lowest risk. According to the scenario of these factors, four sub-areas in Wuhan Port are assessed as shown in Table 2 and Figure 10.

Table 2: Rank of sub-areas in Wuhan Port

factors to be considered	sub-area1	sub-area2	sub-area3	sub-area4
traffic volume	3	4	2	1
main mix of traffic	2	4	3	1
hydro/meteo	4	4	4	1
dangerous cargoes	4	3	2	1
marine pollution	3	4	3	4
local geographical conditions	3	4	2	1
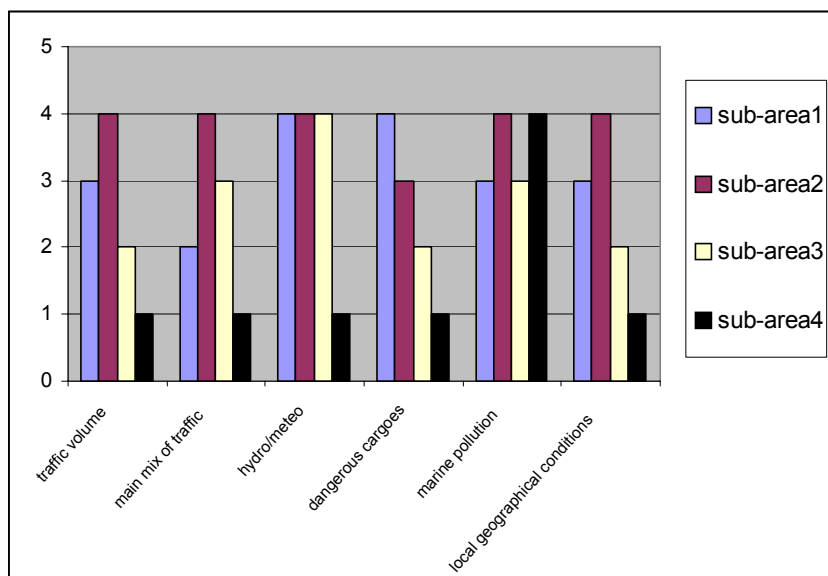
Figure 10: Rank of sub-areas in Wuhan Port

Table 2 and Figure 10 indicate that sub-area2 has the highest risk in all factors except dangerous cargoes while sub-area4 has the lowest risk in each factor except marine pollution. Consequently, the preliminary ranking of sub-areas in terms of risk can be approximately identified from high to low as follows:

{ sub-area2; sub-area1; sub-area3; sub-area4 }

2.2.4 Preliminary evaluation of local accidents

The evaluation of risks depends on the accuracy and volume of collected data on casualties. Therefore, the collection of data would be a vital element in the successful objective application of the FSA, although it is possible to use subjective evaluation as an interim means with a reasonable degree of accuracy (Sekimizu, 1997). In the preliminary evaluation of local accidents, historical maritime accidents data can be collected from the Maritime Administration and analysed through identifying types of accidents, types of loss and the geographical distribution of accidents so that a justified rank of risks can be formed.

Figure 11 illustrates the distribution of incident types in Wuhan Port. It can be noted that almost 70% of all accidents recorded by the Maritime Safety Administration were collisions, groundings, contact, contact bridge, hitting rock or wave damage that is related to the movements and dynamics of vessels and can be called traffic accidents.
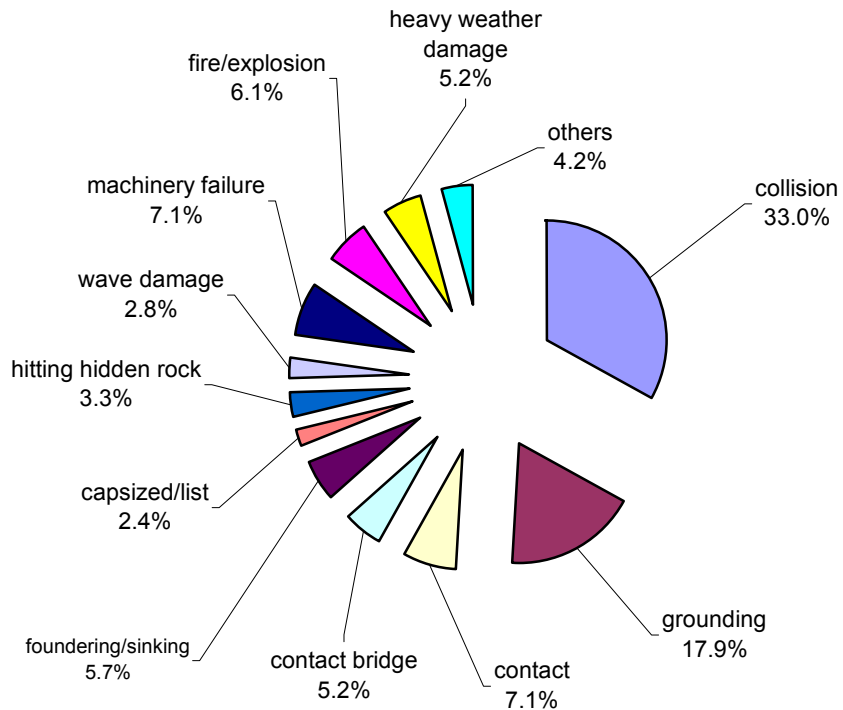
Figure 11: Average Distribution of Incident Types in Wuhan Port (2000-2004)
Source: Wuhan MSA. (2000-2004).

Figure 12 illustrates the distribution of loss types in Wuhan Port from 2000 to 2004. It can be concluded that loss was severest in 2002 and 2003 whereas it was relatively minor in 2001.

Loss

	loss of life (persons)	total loss (vessels)	direct economic losses (RMBX 100000)	environmental losses (oil spill klx10)
■ 2000	5	5	9.34	13.2
■ 2001	2	3	1.742	10.8
□ 2002	9	8	13.08	21.7
■ 2003	3	5	15.48	15.6
■ 2004	3	4	4.267	8.4
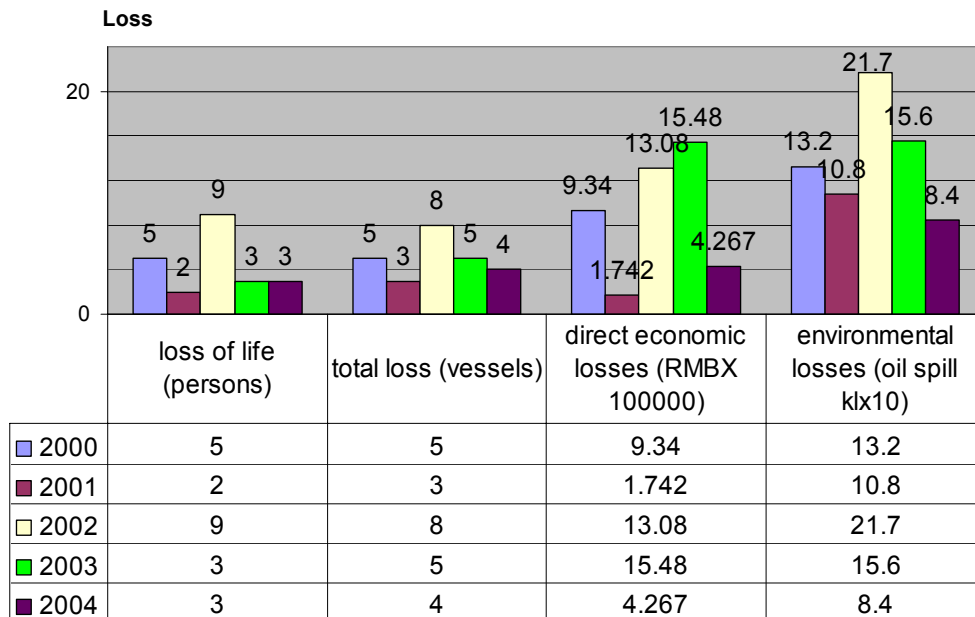
Figure 12: Distribution of Loss Types in Wuhan Port (2000-2004)
Source: Wuhan MSA. (2000-2004).

The geographical distribution of all reported marine traffic incidents in Wuhan Port, developed from data for 2000 to 2004, is shown in Figure 13. the majority of incidents were concentrated in sub-area2 and sub-area3.

From the above analysis of historical data, the outcome for ranking of risks can be roughly expressed from high to low as follows:

{ collisions, grounding, contact, contact bridge, hitting rock, wave damage }

{ sub-area2, sub-area3, sub-area1, sub-area4 }
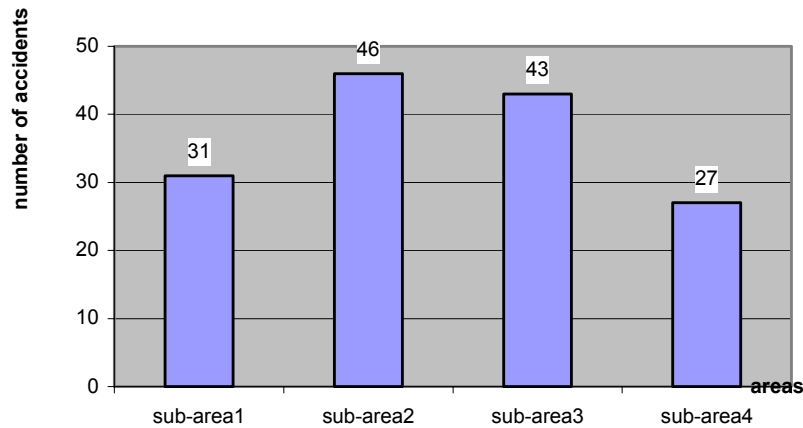
Figure 13: Geographical Distribution of Traffic Incidents in Wuhan Port (2000-2004)
Source: Wuhan MSA. (2000-2004).

2.2.5 Comparison and combination

The output from Step 1 of FSA comprises a prioritized list of risks/hazards/unwanted events by risk level and a preliminary description of the risks/hazards/unwanted events, which can be generated by comparison and combination of the identified scenarios of local traffic hazards, geographical subdivision, rank of sub-areas and rank of risks that all have been completed in previous phases. In order to reach the goal, methods of qualitative or quantitative analysis can be available, mainly depending on the scope of the collected data and the perspective of analysing the problems.

Wuahan Port suffered from the fewest marine casualties in 2001, when its traffic volume was also the lowest, among the recent five years. It can partially underline the hypothesis that traffic volume is an important factor determining the risk level in Wuhan Port because other factors influencing risk level remained relatively unchanged in these five years. Meanwhile, a statistical analysis of environmental factors has been conducted to identify if there is any close correlation between

collisions / grounding / contact / contact bridge incidents and poor visibility, high wind, adverse weather and strong currents; however, none has been identified as having high enough significance. So, it can be said that these incidents making up the majority of all incidents, were mainly caused by the factors of traffic volume, local geographical conditions and traffic mix instead of hydro/meteo factors.

2.2.6 Conclusion

The outcome of the above analysis can promote the formation of prioritized lists with respect to risks, hazards and sub-areas. The lists for Wuhan Port are displayed by risk levels from high to low, as follows:

Sub-areas: { sub-area2, sub-area3, sub-area1, sub-area4 };

Risks: { collisions, grounding, contact, contact bridge, hitting rock, wave damage };

Hazards: { traffic volume, local geographical conditions, main mix of traffic, dangerous cargoes, hydro/meteo, marine pollution }.

CHAPTER 3

Risk analysis

In the previous chapter it has been shown how a framework addresses the identification of risks and hazards in a planned VTS area in the context of planning VTS. When those identified risks occur there will always be an effect upon the risk level of the planned area. Therefore, their frequency and consequence have to be not only measured in some way but also assessed in a combined way by the stakeholders in order to determine whether or not they will be accepted.

The preceding step in FSA is to answer the question of what categories of hazards exist in the defined system while the second step is to reveal how and to what extent they lead to the failure or unacceptance of the system. In its guideline for FSA, IMO (2002) points out that:

> The purpose of the risk analysis in step 2 is a detailed investigation of the
>
> causes and consequences of the more important scenarios identified in step 1.
>
> This can be achieved by the use of suitable techniques that model the risk.
>
> This allows attention to be focused upon high risk areas and to identify and
>
> evaluate the factors which influence the level of risk.

As far as planning VTS is concerned, the choice of risk analysis model depends on the features of system that decision makers are studying or concentrating on. VTS is a complicated and large marine project, the establishment of which does not focus on the safety of a certain ship or a certain kind of marine incident but concerns the

navigation safety of all VTS vessels and their traffic efficiency as a whole as well as all marine traffic accidents in a vast VTS area. It determines that the applicable risk analysis model for planning VTS is macroscopic rather than microcosmic although macroscopic may be made up of several microcosmic units.

Ayyub (2005) states: "When assessing and evaluating the uncertainties associated with an event, risk is defined as the potential for loss as a result of a system failure, and can be influenced by a pair of factors, one being the probability of occurrence of an event, also called a failure scenario, and the other being the potential outcome or consequence associated with the event's occurrence". This pairing can be represented by the equation:

$$Risk\left(\frac{Consequence}{Time}\right) = Likelihood\left(\frac{Event}{Time}\right) \times impact\left(\frac{Consequence}{Event}\right) \quad \text{(Ayyub, 2005)}$$

So risk analysis is assumed to include two major sub-activities, risk estimation and risk evaluation, where risk estimation comprises event-probability assessment and consequence assessment, and risk evaluation requires the definition of acceptable risk and a comparative evaluation of options.

3.1 Risk estimation

Information produced from the hazard identification phase will be processed to estimate risk. In the risk estimation phase, the likelihood and possible consequences of each System Failure Event (SFE) will be estimated, either on a qualitative basis or a quantitative basis (if the events are readily quantified) (Pillay & Wang, 2004).

The purpose of frequency analysis is to determine how often a particular scenario might be expected to occur over a specified period of time. These estimates are often based on historical data, where judgements about the future are based on what has occurred in the past. If there are no relevant historical data available, or if these data are sparse, other methods such as fault-tree, or event-tree analysis, or other

mathematical or econometric models may be used. Estimates may also be based on expert experience and judgement. Most often, frequency estimates are based on a combination of these methods (IALA, 2000).

In planning VTS, consequence analysis mainly involves estimating the impact in respect of navigation safety, traffic efficiency and the marine environment, which is determined by the purpose of establishing a VTS. The impact on navigation safety can be measured by three factors: numbers of injuries or deaths, property loss and other direct economic loss caused by traffic accidents while the impact on traffic efficiency can be estimated in two different ways: the annual day numbers of bad visibility which could stop local waterborne transport and the traffic density which could lead to traffic congestion in a certain area once it is too high. Impact on the marine environment has to some extent to do with the type and place of oil spilled as well as the local ecological environment and its sensitivity, which can be measured by numbers of wildlife affected, how heavy the influence on the quality of human life is and the associated costs for clean-up operations.

3.1.1 Recommended models for risk estimation

In IMO's guidelines for FAS, several techniques are recommended for use in the process of risk analysis, which include fault tree analysis (FTA), event tree analysis (ETA), failure mode and effect analysis (FMEA), hazard and operability studies (HAZOP), the what-if analysis technique, risk contribution tree (RCT) and influence diagrams. However, each method has its own appropriately applied fields and limitations, especially when they are intended to be used in a large marine project such as planning for VTS.

● **Fault tree analysis (FTA)**

Fault tree analysis is a technique that, by means of tree structures, visually models the logical causal relationship between events that singly or in combination cause accidents, and determines the probability of a top event, which may be a type of accident or unintended hazardous outcome (IMO, 2002). One of applications of FTA on planning VTS for Wuhan Port can be exemplified as shown in Figure 14:

Contact bridge probability in Wuhan Port (P_c) = 0.9x (9.1 E $-$4) + 0.1x (1.87 E $-$3) $\approx$ 1.01 E -3
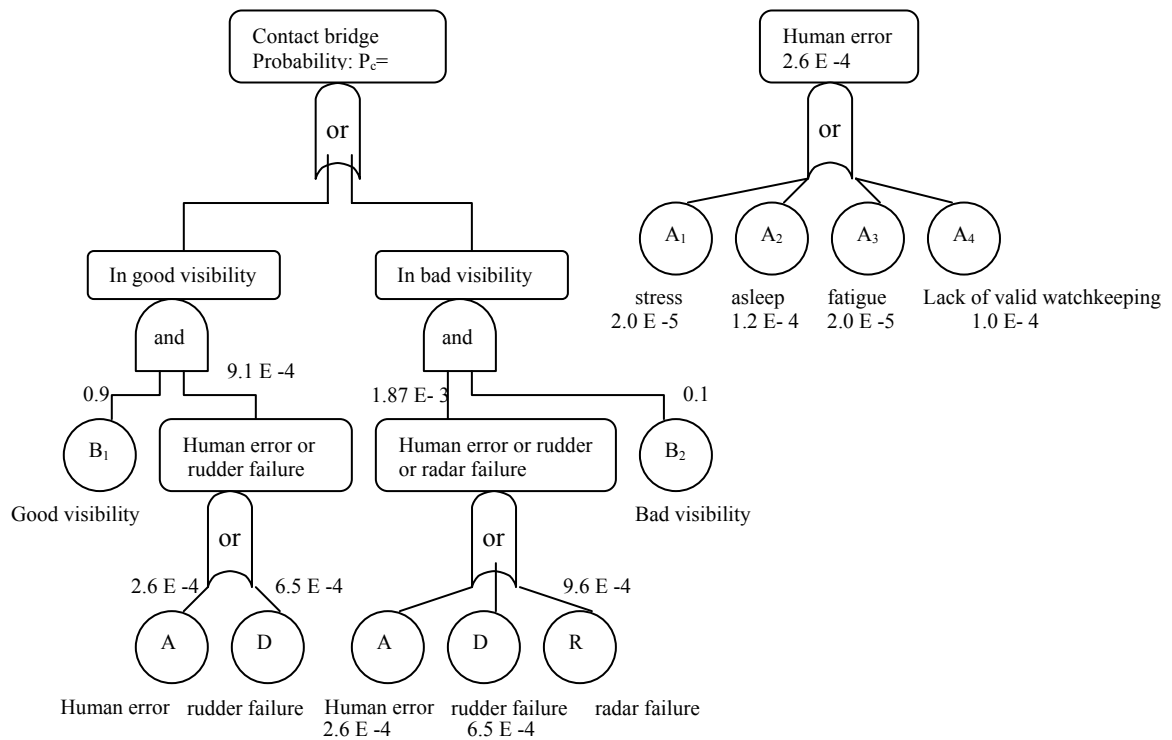
Figure 14: Contact bridge FTA in Wuhan Port
Source: Based on Friis-Hansen' model (2005)

FTA can be conducted qualitatively and quantitatively. Qualitatively the relationship among events is illustrated; quantitatively the risk level and the relative importance of various events can be calculated. FTA is able to analyse common cause failures and failures caused by events in combination. It is effective when used to analyse the root causes of specific accidents with relatively complex combinations of events (Xie, 2001). However, FTA is a technique with a narrow focus; it only examines one

specific accident of interest. More fault trees should be developed in order to analyse other types of accidents. The quantification of analysis requires significant expertise and reliable statistical data (USCG, 2005).

- **Event tree analysis (ETA)**

Event tree analysis is a technique, which by means of a tree structure, visually models the possible outcomes of an initiating event. The model illustrates how safeguards and external influences, called lines of assurance, affect the path of accident chains (USCG, 2005). One example of ETA, which may be used in the process of risk analysis for planning VTS, is indicated in Figure 15 and Table 3:
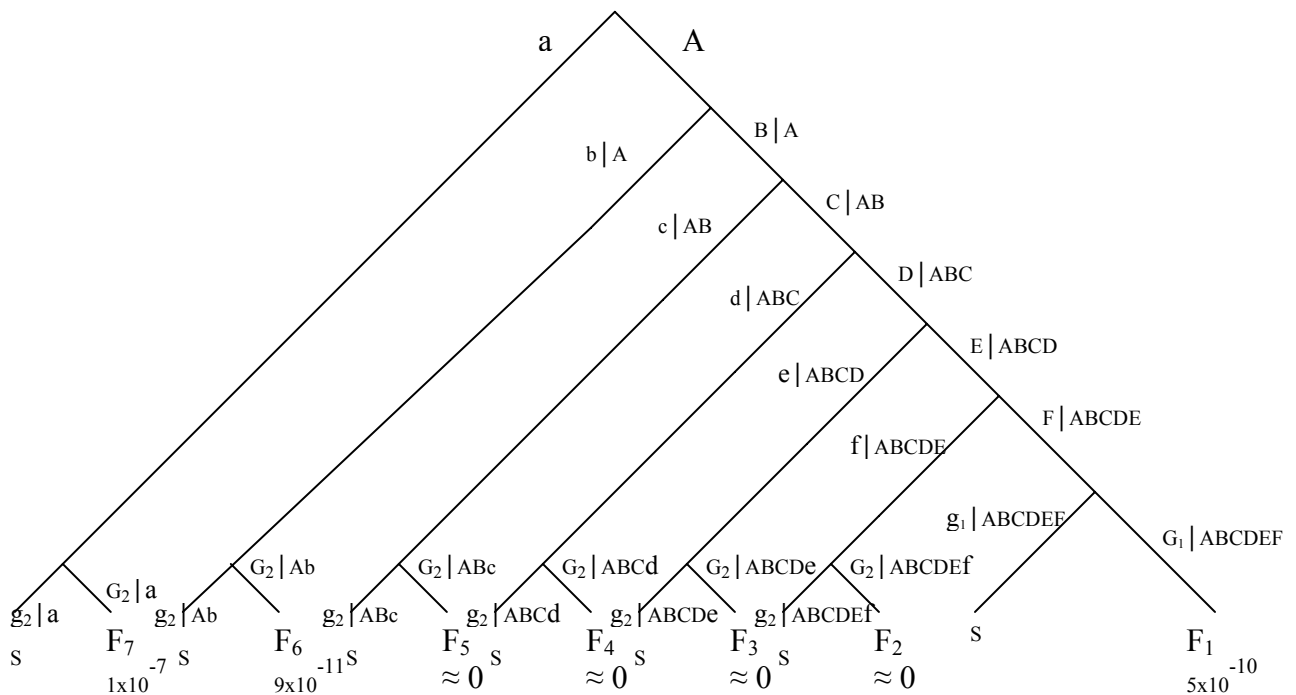
Collision with an inspected vessel = μ x ($PF_1+PF_2+PF_3+PF_4+PF_5+PF_6+PF_7$)

$$\approx (3650/yr) \times (1.006 \times 10^{-7}) \approx 3.67 \times 10^{-4}/yr$$

Where: μ is the number of times per year that a passenger ferry is on a collision course with an inspected vessel (assuming that it is 0.5 time when it passes through the Yangtze River and it passes 20 times a day, so μ = 0.5 x 20 x 365 = 3650/yr); s is safety while F is failure.

Figure 15: ETA for passenger ferry on collision course with inspected vessel in Wuhan Port
Source: Based on Guthrie' model. (2000).

Table 3: Failure Description in ETA

Safety symbol	Failure symbol	Failure Description	Estimated Conditional Probability
a	A	passenger ferry officer fails to observe inspected vessel on radar	0.001
b	B	passenger ferry co-officer fails to observe inspected vessel on radar	0.1
c	C	passenger ferry officer fails to observe (see or hear) inspected vessel	0.01
d	D	passenger ferry co-officer fails to observe (see or hear) inspected vessel	0.1
e	E	passenger ferry wheelman fails to observe (see or hear) inspected vessel	0.5
f	F	no communication to passenger ferry from other vessel	0.01
g_1	G_1	passenger ferry fails to adequately maneuver in time to avoid collision with inspected vessel given inspected vessel is not observed	1.0
g_2	G_2	passenger ferry fails to adequately maneuver in time to avoid collision with inspected vessel given inspected vessel is observed	0.0000007

Source: Based on Guthrie' model. (2000).

Qualitatively ETA shows the development path of accidents from the initiating events while it quantitatively presents the frequency, consequence of various sequence, and the relative importance of various sequence and contributing events. It is applicable for almost any kind of system while its scope is limited to only one initiating event; it is very effective to model accidents for the system with multiple safeguards and to determine the consequence brought about by various initiating events while it is not effective to be used to identify all causes that can result in accidents. The subtle dependency among various lines of assurance could be easily overlooked, which may lead to a certain uncertainty and incompleteness in the analysis (USCG, 2005).

● **Failure mode and effect analysis (FMEA)**

FMEA is an analysis tool assuming that a failure mode occurs in a system / component through some failure mechanism and the effects of this failure at this level and at high levels are then analysed and evaluated to determine their severity on the system as a whole while relevant actions are identified in order to eliminate or mitigate these effects. The application of this technique has been introduced in IMO High Speed Craft Code.

Being a systematic and highly structured technique, FMEA is primarily used in mechanical and electrical systems. In the application of FSA on planning VTS, it may be suitable to help analysing single failure modes causing onboard system failures such as radar, steering engine etc., that lead to marine casualty influencing the risk level in the planned area.

FMEA only analyses the effects of a single component failure; it can identify single failure modes that may cause system failure, however it is not possible to analyse the problems caused by combinations of component failures. In addition, FMEA focuses on how equipment failure can occur, those human factors, external influences that do not cause equipment failure are often overlooked although they may present dangers directly to human beings or the system as a whole (USCG, 2005).

• **Hazard and operability studies (HAZOP)**

HAZOP is a qualitative method used to analyse hazards in a system with the aim to eliminate or minimise them. It uses "guidewords" to identify hazards and studies deviations from the design objectives of a system and components in order to seek answers to the causes and consequences of these deviations and how to eliminate or defend them. Dickson (1987) developed a sheet for HAZOP to record the findings of the analysis under columns for guidewords, deviation, cause, consequences and actions. Table 4 is an example of the sheet for HAZOP:

Table 4: Hazard and operability studies (HAZOP)

Guidewords	Deviations	Causes	Consequences	Actions
No	No flow	tank empty, inlet valve V1 is shut, pump is not working, hose blocked.	no petrol gets to vehicles, petrol seeps out of pipes, hose bursts.	regular checking of tank, vavles to be checked everyday, regular maintenance of the pump.

Source: Dickson (1987)

HAZOP is used primarily for systems with a continuous process, especially fluid, air and thermal systems. Its disadvantages are that it requires a well-defined system; investment of time is expensive; in case the system is simplified to facilitate the study, there is the risk that certain aspects may be omitted; and it focuses only on identifying single failure so that it is not able to analyse failure caused by a combination of events (Xie, 2001).

• **What-if analysis technique**

What-if analysis is a brainstorming approach that uses broad, loosely structured questioning, for instance, "what if the relieve valve fails to open?" and suchlike queries, to assume potential failures that may result in accidents or system performance problems and ensure that appropriate safeguards against those problems are in place.

As a qualitative technique, it may be generally applicable for almost every type of risk assessment application, especially those dominated by relatively simple failure scenarios but is most often used to supplement other, more structured risk analysis techniques. In addition, the loose structure of what-if analysis relies exclusively on the knowledge of the participants to identify potential problems. If the team fails to ask important questions, the analysis is likely to overlook potentially important weaknesses (USCG, 2005).

• **Risk contribution tree (RCT)**

RCT may be used as a mechanism for displaying diagrammatically the distribution of risk amongst different accident categories and sub-categories. Structuring the tree starts with the accident categories, which may be divided into sub-categories to the extent that available data allow and logic dictates. The preliminary fault and event trees can be developed based on the hazards identified in step 1 to demonstrate how

direct causes initiate and combine to cause accidents (using fault trees), and also how accidents may progress further to result in different magnitudes of loss (using event trees) (IMO, 2002). One example is attached, as shown in Figure 16, to illustrate how to use this approach in the phase of risk analysis for planning VTS.

Accident categories:

| Event Trees for consequences of collisions happening in planned area |

| Grounding | Wave damage | Collision | Contact | Contact bridge | .... |

| Crossing situation collision | Head-on situation collision | Overtaking situation collision | Suction between ships | —— Accident sub-categories

or

Cause A   Cause B

and   or

E₁   E₂   Cause C   Cause D

Fault Trees for causes, initiating events and probability of overtaking situation collision

Figure 16: Risk contribution tree (RCT) for planning VTS
Source: Based on IMO's model. (2002).

Comparing the above models, RCT would be the more appropriate provided that these models are singly used for risk analysis of the planned area, because one RCT can deal with all accident categories which need to be analysed in planning VTS. However, the outcome of RCT consists of different risk levels brought about by different categories of marine accidents, which are measured by two parameters including probability and consequence. The question of how to integrate these risk levels corresponding to different categories of accidents into a comprehensive risk

level for the planned area, which will determine the acceptability of stakeholders, is still not answered.

3.1.2 Risk index approach for risk estimation

From the above introduction, it can be put forward that these models may be used for risk estimation in planning VTS to some extent, nevertheless with their peculiar drawbacks and limitation, they are all appropriate especially to relatively small and simple projects instead of large and complicated ones such as VTS, if they are used singly, because what each of them can bring to light is just a tiny corner of the iceberg compared with the whole scenario that needs to be researched in planning for a VTS. Although it is theoretically feasible that risk estimation for planning VTS is conducted through a combination of these models, the process would be tremendously wearisome and miscellaneous so that analysts easily lose their way in so complex a wordplay and figure game. Therefore it is necessary to seek a new model exclusively for risk estimation for planning for a VTS.

The so-called risk estimation virtually predicts the future risk in a planned area which can be conducted through two distinct schools, where one uses the past to predict the future by analysing historical data whereas the other predicts the future qualitatively and / or quantitatively with the aid of mathematical models or expert experience and judgement. However as far as the latter is concerned, the establishment of models and expert views are actually still based on previous or historical experience as well, so they have a common character in this point with the former. Both of them are dominated by unpredictable uncertainty to some extent.

In step 1 of FSA, the local traffic hazards, including traffic volume, main max of traffic, local geographical conditions, hydro/meteo, dangerous cargoes and marine pollution, are identified and it is easily understood that a combination of them approximately determines the local traffic risk level. In these six factors, **traffic**

volume in a defined area always varies with the fluctuation of the maritime industry while others keep relatively unchanged over a period. So it can be said that variety in traffic volume is a crucial factor influencing the change of risk level in a defined area and there should also be a close correlation between traffic volume and risk level. This conclusion can be given support to by many experts' opinions and statistical data, including the Wuhan Port scenario.

In his book, Wu (1992) put forward an approach called the **risk index theory**, which can be easily implemented and has a fairly good operability and comparability. The theory states that the traffic risk state in an area in a period can be measured by the **ratio** of **numbers of marine accidents** and **traffic volume** in the area in the period:

$R = P / Q$ *(R: risk index; P: numbers of marine accidents; Q: traffic volume)*

Contact, grounding, contact bridge, hitting rock and wave damage etc. can be all regarded as collisions between ship and stationary objects. Thus nearly all marine traffic accidents can be classified into collision. Qiu (1991) cites a formula, as follows, from a scholar studying the collisions between gas molecules to illustrate the relationship between **vessel traffic density** and the **number of collisions**:

$$P = \frac{KV\rho}{\rho_{max} - \rho} \exp\left[\frac{-C\rho}{V\rho_{max}}\right]$$

> *P: number of collisions;*
> *V: ships' mean speed;*
> *ρ: vessel traffic density;*
> *ρ_{max} : maximum vessel traffic density;*
> *K: domain coefficient 1;*
> *C: domain coefficient 2.*
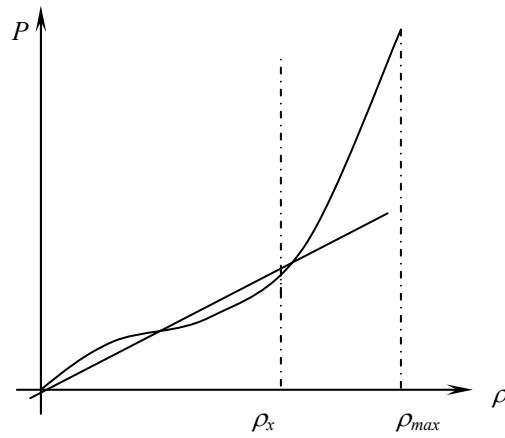
Figure 17: Relation between vessel traffic density and the number of collisions
Source: Based on Qiu' formula. (1991).

Figure 17 describes the formula showing that **number of collisions** P will increase with the **traffic density** ρ (nearly linear relation) especially when ρ is not too much (when ρ ranges from $0 \sim \rho_x$). This obvious correlation between P *and* ρ can justify Wu's theory that traffic risk state in an area in a period can be measured by the **ratio** of **numbers of marine accidents** and **traffic volume** in the area in the period.

As, in a planned area, there exists much diversification in respect of ships' categories and sizes as well as traffic accidents' categories, scale and loss, it is necessary to **weight** the **traffic volume** and **number of traffic accidents** in order to more objectively reflect and describe the risk state in a planned area over a period.

3.1.2.1 Weighted vessel traffic volume Q_k

Each ship is given a weighted coefficient according to its size (length or tonnage) and the sum of the weighted coefficients for all ships stands for the weighted vessel traffic volume Q_K in the area. Table 5 shows the weighted coefficients that can be used in the Wuhan Port case.

Table 5: Weighted coefficient according to ship's size

ship's length(LOA: m)	0~<10	10~<30	30~<50	50~<75	75~<100
weighted coefficient	0.25	0.5	1	1.18	1.41

ship's length(LOA: m)	100~<150	150~<200	200~<250	250~<300	300~
weighted coefficient	1.7	2	2.5	3	4

Source: Based on Wu' risk index theory. (1992).

3.1.2.2 Weighted number of traffic accidents P_k

$$P_k = \sum_{j=1}^{5} f_j P_j$$

j: accident classification (1 ~ 5);

f_j : weighted coefficient for No.j class of accident;

P_j: number of No.j class of accidents happening in the area.

Table 6: Weighted coefficient according to accident' severity

accident classification (j)	1	2	3	4	5
severity	catastrophic	severe	significant	medium	minor
weighted coefficient (fj)	10	6	4	1	0.5

Source: Based on Wu' risk index theory. (1992).

The division of severity, as developed by the Japanese Maritime Safety Agency (1991), and referred to in Table 7, defines casualties, where *a* represents the loss of ship and cargo, *b* stands for amount of oil spilled and *c* indicates the number of life loss. If the following formula is reached, the casualty will be defined as a relevant classification:

$$a / A + b / B + c / C \geq 1$$

This method for division can be easily conducted. In addition, it gives consideration to the marine environmental protection through putting the oil spilled quantitatively into the ingredient of accidents.

Table 7: Defining casualties

severity / accident categories	total loss A (GT)	amount of oil spilled B (Kl)	loss of life C (*person*)
catastrophic	20000	20000	20
severe	3000	3000	5
significant	500	500	1
medium	100	100	injure
minor	20	20	…..

Source: Japanese Maritime Safety Agency. (1991).

As far as planning for a VTS is concerned, the risk level is also influenced by vessel traffic efficiency because high efficiency is one of the goals that establishing a VTS pursues. In most circumstances, traffic efficiency is compromised by poor visibility, however its consequence can hardly be calculated precisely. One of the solutions is to count up the number of fog days per year and regard one fog-day as a medium marine casualty.

3.1.2.3 Risk index

To sum up, the **risk index** in a planned area over a period can be obtained through:

$$R = \frac{P_k}{Q_K} = \frac{\sum_{j=1}^{5} f_j P_j}{Q_k}$$

Figure 18 and Table 8 show the **risk index** in Wuhan Port, which is calculated according to the data available from 1999 to 2003. The trendline for these data can be expressed as the formula: $y = 1.4448x$, on the basis of which, Q_K *and* P_k for the next five years (2005 ~ 2009) can be estimated as shown in Table 8, assuming that Q_K rises 2% per year from 2003.

Risk index in Wuhan Port (1999 ~ 2003)

$y = 1.4448x$
$R^2 = 0.9151$
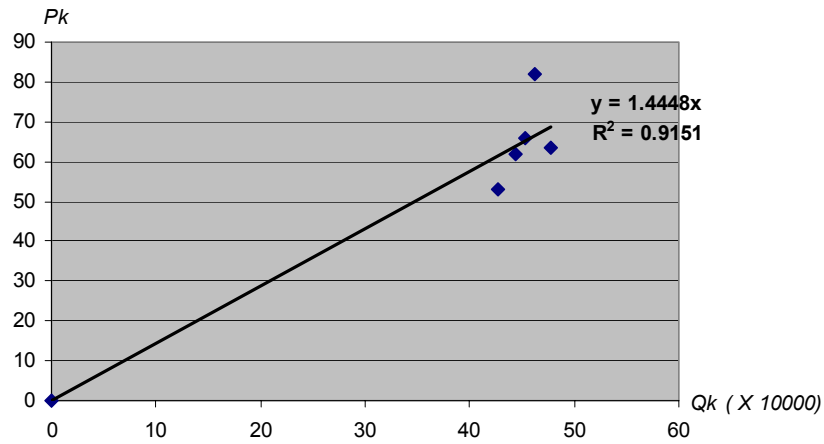
Figure 18: Risk index in Wuhan Port (1999-2003)

Table 8: Weighted traffic volume and number of traffic accidents in Wuhan Port

year	1999	2000	2001	2002	2003	2005	2006	2007	2008	2009
P_k	62	66	53	82	63.5	71.7	73.1	74.6	76.1	77.6
Q_K $(X10^4)$	44.3671	45.3308	42.723	46.2745	47.6921	49.6189	50.6112	51.6235	52.6559	53.7091

3.2 Risk evaluation

Once the risk level has been estimated, its result will be evaluated in terms of risk acceptance criteria in order to determine whether further measures should be taken to reduce the estimated risk level to the level that stakeholders are satisfied with. In its guideline, IALA (2000) states that:

> The purpose of risk evaluation is to identify the distribution of risk, thus
>
> allowing attention to be focused upon high-risk areas, and to identify and
>
> evaluate the factors, which influence the level of risk. The risks, as estimated
>
> in section B.2.1, are evaluated in terms of the needs, issues, and concerns of

stakeholders, the benefits of the activity, and its costs. The result of this exercise is a determination of the acceptability of these risks.

The current best practice is to recognize that there are three levels of risk in terms of division of risk acceptability: intolerable, as low as reasonably practicable (ALARP) and negligible (IMO, 2002) :

- Intolerable — The risk is very high and cannot be justified except in extraordinary circumstances so that measures have to be taken to reduce risk level regardless of cost.
- Negligible — The risk has been made so small that neither further precaution nor risk reduction is necessary.
- ALARP — The risk falls between the above two states. It is also called Tolerable level, meaning that the risk is tolerable in this region. Risk reduction measures may or may not be taken depending upon the cost-benefit analysis of them. If the risk reduction measure is cost-effective, it should be taken to reduce the risk as low as reasonably practicable, on the contrary, no action needs to be taken to reduce the risk (Xie, 2001).

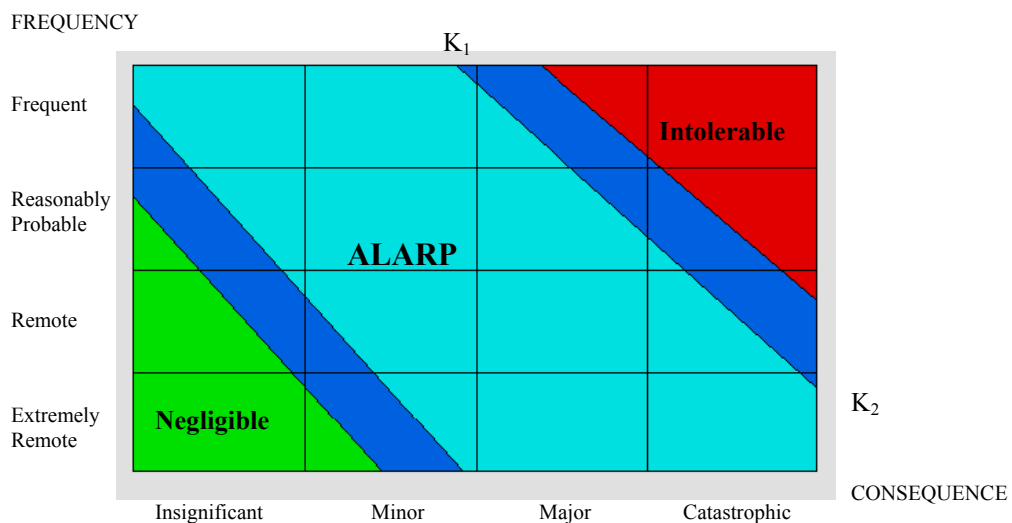This concept can be illustrated in Figure 19 (IALA, 2000).

Figure 19: ALARP Matrix
Source: IALA. (2000).

3.2.1 Stakeholders involved in planning VTS

In risk evaluation, the criteria of risk acceptability/tolerability depend on the needs, issues and concerns of the stakeholders. Due to discrepancies in respect of social and economic development, political system, administrative philosophy as well as public awareness, different stakeholders may be involved in planning VTS in different states, and even in a country, each stakeholder has its own rights, duties and responsibilities, interests and value preference. So it is very tough to model these needs, issues and concerns in a satisfactory way and in a uniform mode in terms of the world.

With the rapid increase in coastal and ocean uses, as well as those inland activities having effects on ocean and coastal environments, which can possibly conflict each other, the establishment of VTS is not merely the business of the shipping industry and maritime administration but also involves other parties such as fisheries, mariculture, mining, offshore oil and tourism etc. because they could be the beneficiaries or investors of VTS, or be affected by implementing VTS.

In the early 1990's, a new concept of integrated coastal and ocean management (ICOM) came into existence, which can be defined as a continuous and dynamic process to ensure that the decisions of all sectors (e.g., fisheries, shipping, water quality) and all levels of government are harmonized and consistent with the coastal policies of the nations in question for the sustainable use, development, and protection of coastal and marine areas and resources (Cincin-Sain & Knecht, 1998). In this principle, decision makers for planning VTS should take into account four aspects of integrations: intersectoral, intergovernmental, spatial and international in order to develop an integrated criterion of risk acceptability for the planned area.

Intersectoral integration involves the harmonization of interests and solution of conflicts between relevant marine sectors, coastal sectors and land-based sectors. For

instance, establishing VTS can contribute to marine environmental protection which is beneficial to fisheries, however fishing boats might have to be restricted by the VTS rules. Spatial integration involves integration between ocean activities and land-based activities. They may influence or be dependent on each other and need to achieve compatible goals and policies. Intergovernmental integration intends to deal with those problems arising due to different roles, public needs and perspectives among different levels of government (national, provincial, local) while the international integration should take place when planning VTS involves multiple states. VTS in the Malacca Strait is a good example of international integration, which is an outcome of a three-state cooperation: Malaysia, Indonesia and Singapore.

3.2.2 Risk Perceptions

Theoretically, the stakeholders' acceptability of risk can be expressed by a straight line which crosses the two points K_1 and K_2 in the above ALARP Matrix. It is mainly affected by risk perception. Royal Society Study Group (1992) states: "From the perspective of the social sciences, risk perception involves people's beliefs, attitudes, judgements and feelings, as well as the wider social or cultural values and dispositions that people adopt, towards hazards and their benefits."

Different stakeholders have different risk perceptions. For example, in planning VTS, the port authority may mainly focus on the influence on traffic efficiency by bad visibility whereas tourism may emphasize the risks caused by marine pollution; among the decision-maker team, technical experts are inclined to form their own perception according to technical factors such as the probability of traffic accidents and their impact on navigation safety and the marine environment while the public's perception of risk may be influenced by many things, including age, gender, region, value, level of education, public opinion, time and previous serious hazards. Therefore, it is necessary to create an integrated and accepted risk perception for all the concerned stakeholders in order to determine the criterion of risk acceptability.

Although it may not be suitable to achieve the criterion for planning for a VTS in inflexible rules, as far as risk criteria for ships are concerned there are still some principles that can be complied with:

(1) the activity should not impose any risks which can reasonably be avoided;

(2) the risks should not be disproportionate to the benefits;

(3) the risks should not be unduly concentrated on particular individuals;

(4) the risks of catastrophic accidents should be a small proportion of the total.

(Spouse 1997)

3.2.3 Evaluation of risk acceptability/tolerability

In the step of risk estimation, the **risk state** in a planned area can be described by the **risk index** that includes two parameters Q_K and P_k. Both of them cannot be used directly in the ALARP Matrix because its two axes respectively represent **Frequency** and **Consequence** and the Matrix is especially appropriate to illustrate the risk level that results from an accident or a category of accidents instead of **an integrated risk level** that is reflected by all relevant accidents in a planned area and can be used in planning VTS. So the ALARP Matrix needs to be transformed into a new model for its application when planning for a VTS.

In the ALARP Matrix, the horizontal axis (**Consequence**) has the same implication as the **weighted number of traffic accidents (P_k)** because P_k is calculated according to two categories of scenarios: **number of traffic accidents** and **their impacts**. The vertical axis (**Frequency**) has a close relationship with the **weighted vessel traffic volume (Q_k)**: the more the **traffic volume**, the less the **Frequency**. Therefore, the Matrix can be changed as shown in Figure 20:
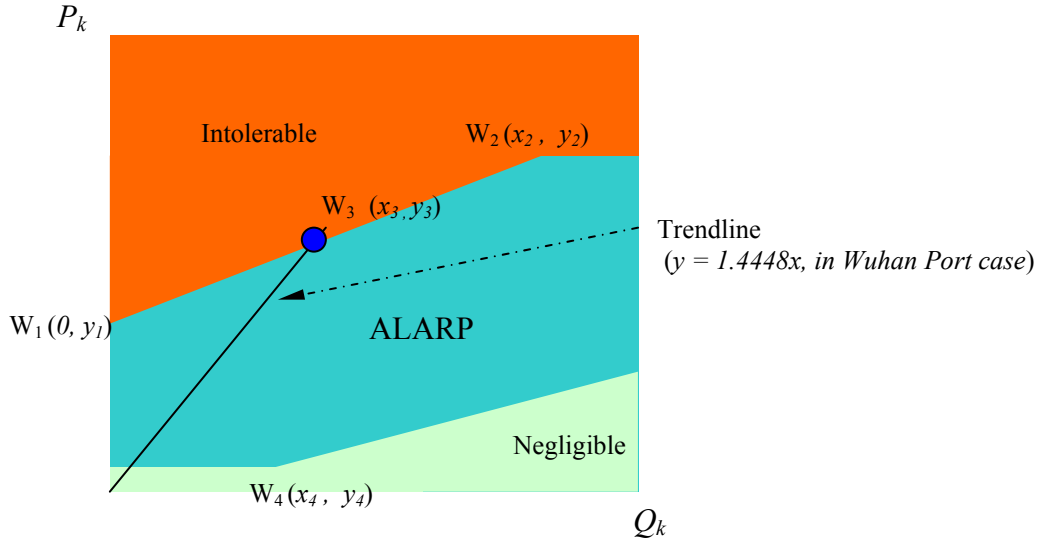
Figure 20: ALARP Matrix based on risk index

In Figure 20, the coordinates of Point W_1 and W_2 can be determined by the decision-makers according to their risk perception. Point W_2 means that once P_k is more than y_2, the risk level in the planned area is absolutely intolerable no matter how much Q_k is. Point W_4 means that once P_k is less than y_4, the risk level in the planned area is negligible no matter how little Q_k is. The formula of **the straight line** crossing Point W_1 and W_2 can be indicated as:

$$y = \frac{y_2 - y_1}{x_2} \bullet x + y_1$$

In the Wuhan Port case, its **trendline** could intersect with **the straight line** at Point W_3, the horizontal coordinate of which is calculated as: $x_3 = y_1 x_2 /(1.4448x_2 + y_1 - y_2)$. So, quantitatively, provided that the estimated Q_k per year (2005 ~ 2009) in Wuhan Port is above the value of x_3, the risk level for the next five years will fall into an intolerable degree theoretically, then the process of FSA will have to proceed to Step 3 for specifying the risk control options.

CHAPTER 4

Risk control options

In Chapter 3 a framework addressing risk analysis has been constructed, the ultimate purpose of which is to determine whether or not the risks identified in Step 1 of FSA will be accepted by stakeholders related to planning for a VTS. There will be one of three types of outcome resulting from the above risk analysis exercise. If the decision makers draw a conclusion that the risk level in a planned area is acceptable, then the FSA process ends here and no further action is necessary other than reviewing the risk level in the area periodically. If the risk level is considered intolerable, or it is necessary to take cost-effective measures to reduce it although it is tolerable, the FSA will initiate Step 3 — Risk Control Options (RCOs) to develop new risk reduction measures. In its guidelines, IMO (2002) states that the purpose of Step 3 is to propose effective and practical RCOs, which comprises the following four principal stages:

> .1   focusing on risk areas needing control;
>
> .2   identifying potential risk control measures (RCMs);
>
> .3   evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2; and
>
> .4   grouping RCMs into practical regulatory options.

4.1 Areas needing control

When decision-makers plan for a VTS, the area that they are concerned with might be so large that it is impossible or unnecessary to establish VTS covering the whole

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area due to the limitation of the resources and budgets. Therefore, the risk control options must be given priority in the areas most needing risk control so that the planned VTS can generate its functions to a greater extent and the risk level in whole area can be improved more effectively.

In Step 1 of FSA, the whole water area studied can be geographically divided into several sub-areas, and ranked according to the identified hazards or historical traffic data. In Step 2, the **risk indices** in these sub-areas are also calculated respectively and it is easily understood that the sub-area with a higher **risk index** has a higher risk level. Generally, the outcome in the form of a prioritized list of sub-areas from these two steps is consistent and the area most needing risk control can be obviously identified. If the results conflict, the decision-makers have to make an assessment of which sub-area has the highest priority at their discretion through comparing their importance between the sub-area having the highest probability of accident occurrence and the sub-area contributing to the highest severity outcomes.

4.2 Alternative risk control options

By reviewing the definition of risk and a pair of factors influencing the risk level, risk control measures can be classified into two groups: preventive measures and mitigating measures. Preventive measures are designed to reduce the likelihood of failures and accidents, in short, control the frequency, whereas mitigating measures aim at reducing the severity of failures and accidents, in short, controlling the escalation of failures and accidents when they have happened (IMO, 1997).

Figure 21, created by Hahne & Galle (1993), illustrates how measures to safeguard safety in shipping are categorized more in detail. There are wide means available to the maritime industry for improving safety levels, for instance, from international legislation to company management, from land based systems to ships' design and construction etc.

As far as VTS is concerned, it is not only a kind of land based safety system but also a method of doing waterways management. So when planning for a VTS, decision-makers should specify the risk control options in the range of waterways management instead of those broad-sense measures mentioned above.

In the planned area, reduction of the risk level may be achieved by implementing waterways management that also can be divided into preventive measures and mitigating measures. Preventive measures mainly refer to a land-based safety system which includes passive systems and active systems. Passive systems are systems where there is no action required to deliver the risk control measures and the involved ships self-consciously comply with the requirements of systems, for instance buoyancy, ship routing and traffic rules etc. Active systems are systems where the risk control is provided by the action of safety facility or operators and the involved ships receive the services or instructions from systems, such as ship reporting, pilotage, VTS and so on. Mitigating measures are taken to reduce the severity of the outcome of the event or subsequent events when they occur. Typical examples are Search and Rescue (SAR), Contingency Plans, Places of Refuge, Maritime Assistance Service, Particular Sensitivity Sea Area (PSSA) etc.

Although both kinds of measures can contribute to risk reduction, one is proactive whereas the other is reactive. Proactive means the identification of factors at an early stage that may adversely affect maritime safety and the immediate development of regulatory action to prevent undesirable events, as opposed to just an after-the-fact ad-hoc reaction to a single accident. Methodologies such as FSA are considered as prime instruments for the development of proactive policies (Psaraftis, 2002).

When planning for a VTS, decision makers may confront two questions. Firstly, those options in waterways management can be in favour of safety in a planned area to some extent, however, which contributes most or is the most cost-effective?

Secondly, is there one option which is adequate to reduce the risk to a level which the stakeholders can be satisfied with or is it necessary to take a combined measure?

Compared with other options in the context of waterways management, VTS has its distinctive advantages. VTS can play a role that overlaps with both preventive measures and mitigating measures. Through providing the information and services as well as monitoring the vessels' movement, VTS results in the decline of accident probability. Moreover, through attending the support of allied services or Search and Rescue, VTS can contribute in blocking the escalation of accidents happening in the VTS area. In particular, operators of VTS can remind crew on board of the coming dangers or even give warning messages / instructions if necessary; VTS can also ensure traffic safety and efficiency, especially in bad visibility etc. These functions are exclusively offered by VTS rather than through other options in waterways management.
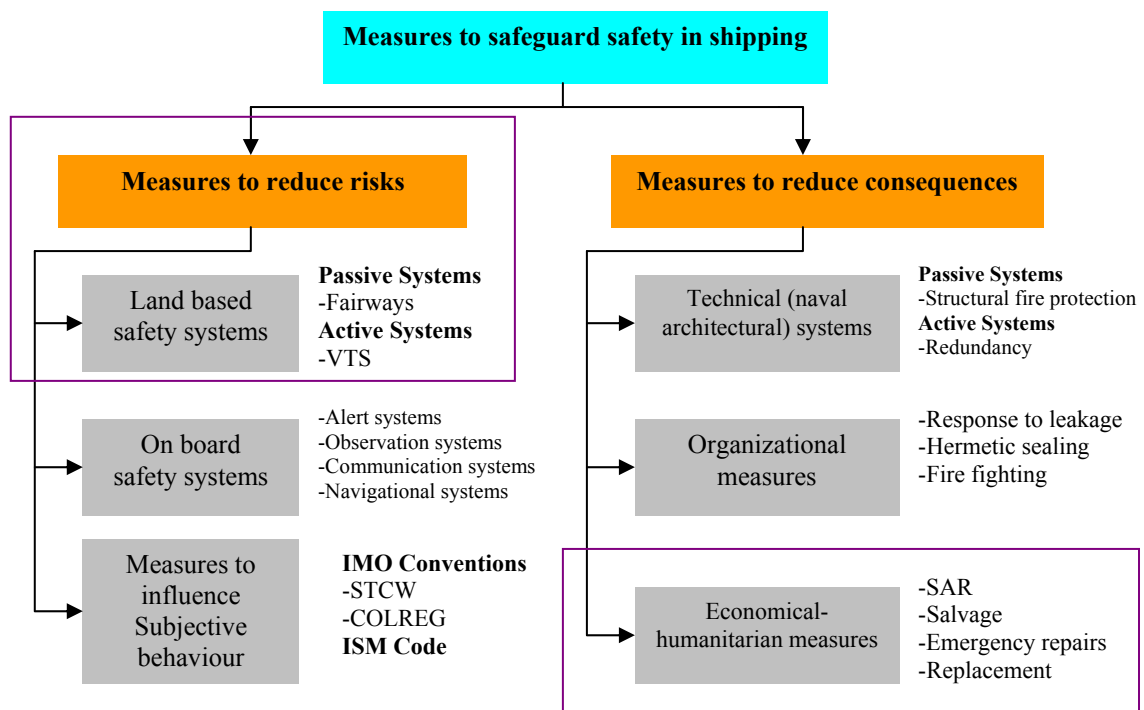

Figure 21: Measures to ensure safety in shipping
Source: Hahne & Galle (1993)

Consequently, when applying FSA in the stage of planning for a VTS, decision-makers should make clear three issues:

1. Suitability; is VTS able to reduce the risk level in the planned area significantly?
2. Optimization; is it the most appropriate method or the first option?
3. Effectiveness; is it adequate or need it be complemented by other options?

4.3 Identifying risk control options

A structured review model ought to be created for identifying new risk control options for risks that are not sufficiently suppressed by the existing measures. The core part of this model is to find out the risk attributes and underlying factors of accidents. Risk attributes relate to how a measure might control a risk and the prime purpose of assigning attributes is to facilitate a structured thought process to understand how a risk control option works, how it is applied and how it would operate (IMO, 2002). Underlying factors relate to how and why accidents have happened so that risk control can be introduced and stop them happening again.

In step 1 of FSA, collected historical traffic accident data has been used to categorize and prioritize them and form a prioritized list of risks. Then aiming at different types of accidents such as collision, grounding and contact etc., marine incident investigation, with the incorporation of the human element, is respectively conducted to uncover a group of underlying factors for each type of accident and prioritize these factors according to their influence on system failure. The outcome is a prioritized list of underlying factors for each type of accident in the planned area.

Commonly, different types of traffic accidents may have similar underlying factors. For instance, collision, grounding and contact all might be caused by a crew's lack of a proper look-out or fatigue. So the next step when specifying RCOs is to combine and prioritize those identified underlying factors into a list of factors, then put

forward a relevant group of RCOs for each factor. For different factors, there might be similar measures which can be taken to defend the system. For example, both VTS and pilotage services can counteract the influence of a crew's lack of a proper look-out or fatigue to some extent. Eventually, all specified RCOs in all groups are combined into a list of RCOs. This list includes the suggested options that cover all the identified underlying factors. The above principle for specifying risk control options is illustrated, as shown in Figure 22.
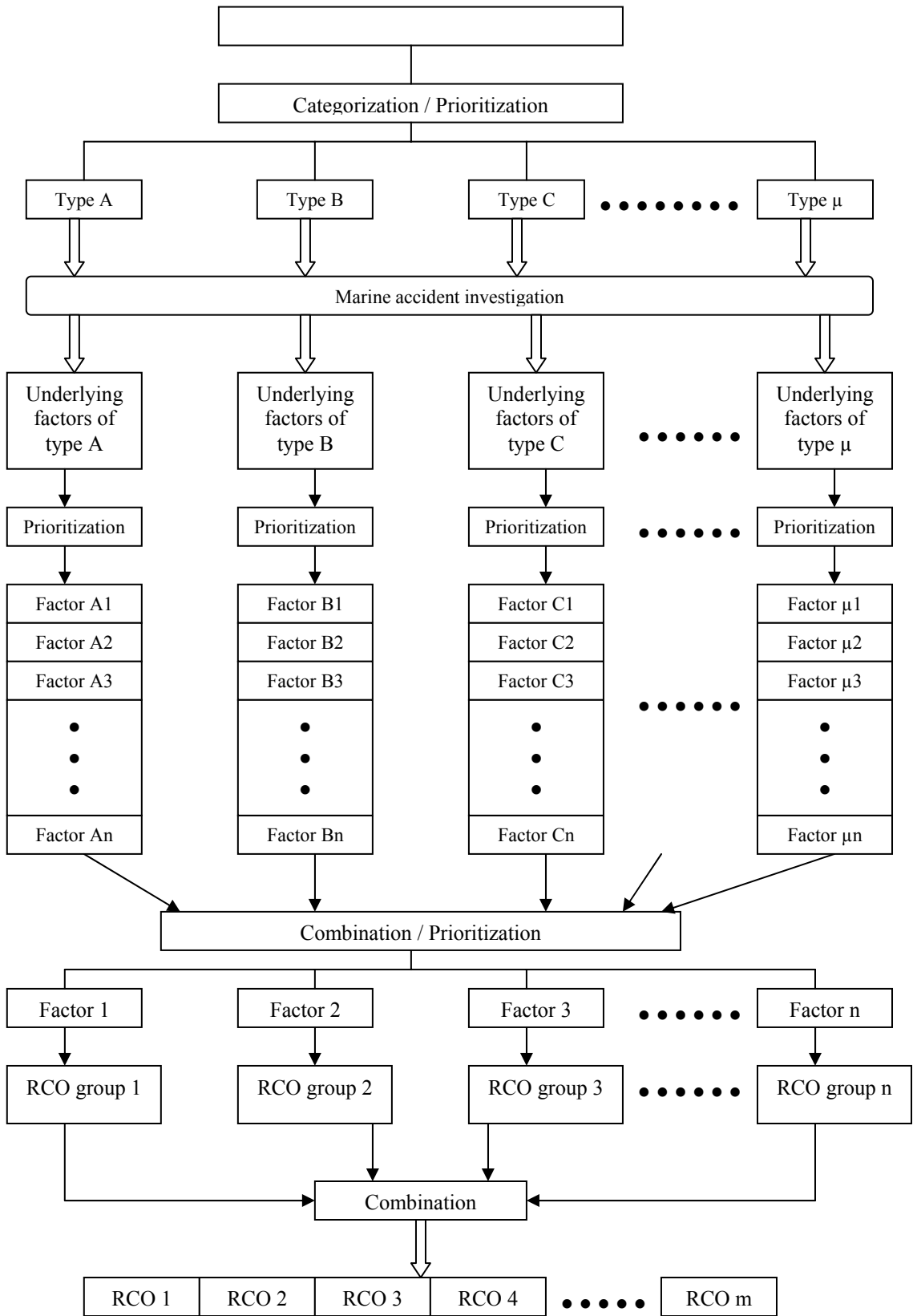
Figure 22: Specify risk control options

4.4 Marine incident investigation

Under IMO conventions each flag State has a duty to conduct an investigation into any casualty occurring to any of its ships when it judges that such an investigation may assist in determining what changes in the present regulations may be desirable while under UNCLOS where a casualty occurs within the territorial sea or internal waters of a State, that State has a right to investigate the cause of any such casualty which might pose a risk to life or the environment, involve the coastal State's SAR authorities, or otherwise affect the coastal State (IMO, 1997). From this point of view, marine incident investigation may assist in determining whether the establishment of a VTS is justified in the planned area. In the context of waterways management, the objective of the investigation is to prevent similar accidents in the future through adopting appropriate risk control options for waterways management.

Needless to say, the human element plays an important role in the origin of accidents, and it is commonly thought that about eighty percent of transport accidents involve the human element while even some specialists claim that all accidents involve the human factor ultimately. Consequently, human element issues should be systematically incorporated into the FSA framework, associating them directly with the occurrence of incidents and underlying causes.

In 1997, IMO adopted the Code for the Investigation of Marine Casualties and Incidents. The Code was amended in 1999 to provide practical advice for systematic investigation of human factors in marine casualties and incidents. This instrument can be used by decision makers when planning VTS to develop an applicable framework to identify all the possible underlying factors leading to accidents in planned areas so that corresponding risk control options can be figured out logically.

• **SHEL model**

The SHEL Model was originally developed by Edwards and modified later by Hawkins. It has been considered to be a useful means of defining information requirements during an occurrence investigation. Once the information requirements are identified, the investigator can gather the facts from appropriate sources (IMO, 2000). There are four components to the model: Liveware, Hardware, Software and Environment.

The SHEL Model is commonly depicted graphically to display, not only the four components, but also the relationships, or interfaces, between the Liveware and all the other components. A mismatch of the interface can be a source of human error and identification of a mismatch may be the identification of a safety deficiency in the system (IMO, 1999).

In planning VTS, the purpose of the SHEL model is to assist decision-makers to understand the types of human interaction with environment where a person is working. It helps to get information concerning "what, where, when and who happened" and identify influencing factors on each type of interfacing rather than explaining how or why accidents have occurred.

In 2002, Kawano created the m-SHEL model, as shown in Figure 23, that is a variation of the SHEL model and adds "m- (management)", which represents the control of whole system, to the SHEL model. In their article, Itoh & Mitomo apply the m-SHEL model for analysis of human factors at ship operation. They highlighted the interface between liveware and management, which involved four aspects: duties of employers and captains, duties of politics, hand skills on to the next generation as well as accumulation, analysis, and sharing of experiences (Itoh & Mitomo, 2004). In planning VTS, this model should be taken into account so that decision-makers can be aware of the interface between crew on board and existing land based safety system.

Figure 23: m-SHEL model
Source: Itoh & Mitomo. (2004).

● **Reason Model**

Although there are many different accident causation theories in use, the one which has been used most extensively is that of James Reason, based on the theories by Rasmussen *et al*. In order to analyse the causes of accidents, a theoretical framework that can be applied to events is needed. This framework can provide a theoretical basis for both the understanding of the causes of accidents and for the invention of practical remedial actions. For this framework to have credibility, it must lead to the improved remediation or prevention of incidents (Gordon & Mearns, 2000). Maurino *et al* (1995) states that all technological systems have the following common processes: organisational processes, local working conditions and defences, barriers and safeguards.

Reason's model, utilizing a production framework and facilitating further organization of the data collected by using the SHEL model, can be used by an investigator as a guide to developing an occurrence sequence in the way of arranging the information regarding the occurrence of events and circumstances around one of five production elements, i.e., decision makers, line management, preconditions, productive activities, and defense (IMO, 1999). On the basis of the Reason Model, a new one can be conceived to be applied when planning for a VTS. This should help

the decision-makers highlight the deficiencies and insufficiencies in waterways management in order to figure out new risk control options. This model is illustrated in Figure 24.
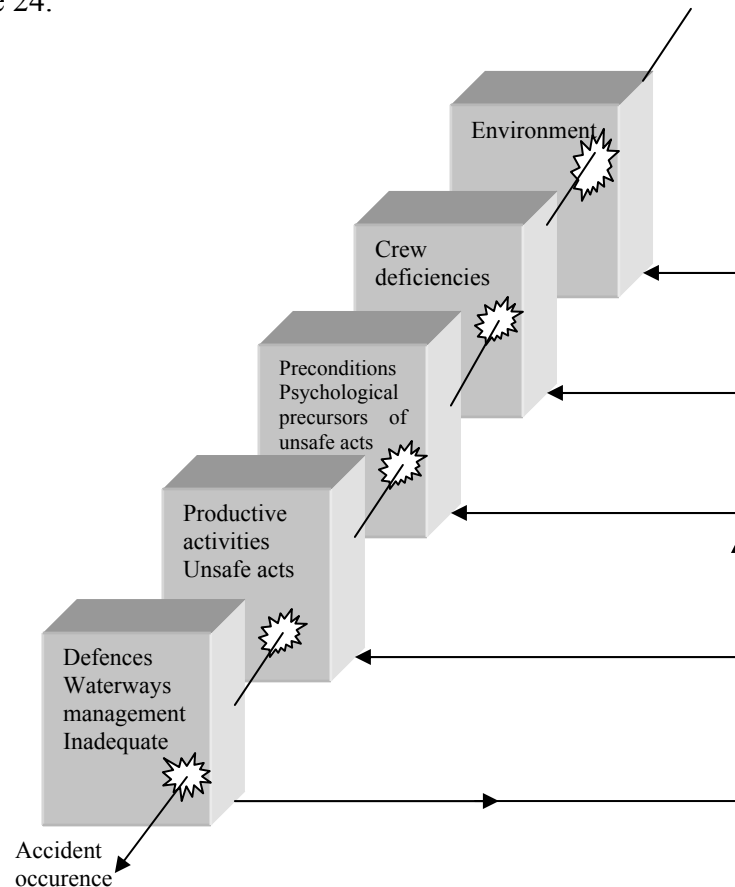
Figure 24: Model for highlighting the deficiencies and insufficiency
in waterways management
Source: Based on the Reason Model. (1999).

The principle of this model is that the whole system could be protected by defences (waterways management) and feedback loops from all system levels safeguarding the safety of the system. Human deficiencies result from the environment where one is working, and psychological precursors of unsafe acts (fatigue, stress etc.) in combination with the unsafe act lead to a limited window of accident opportunity, which might trigger an accident, if adequate waterways management is unavailable. The following case elaborates this theory.

On a night during the 1970's, a passenger ferry sunk in Japanese coastal waters after hitting a rock causing a serious fatality. The investigation report showed that the primary cause was the crew's lack of a valid look-out and recommended reminding crews of navigating cautiously in that area. Unfortunately, ten years later a similar casualty occurred again. The investigation indicated that in the first several years after the previous accident, the crew really operated with vigilance in that area. However in the course of time, the lesson from this incident was neglected unconsciously by seafarers and a similar cause led to similar accident once more. Later a lighthouse was installed on the rock and this kind of incident has not occurred since. An application of the model on this case for specifying risk control options is illustrated in Figure 25:
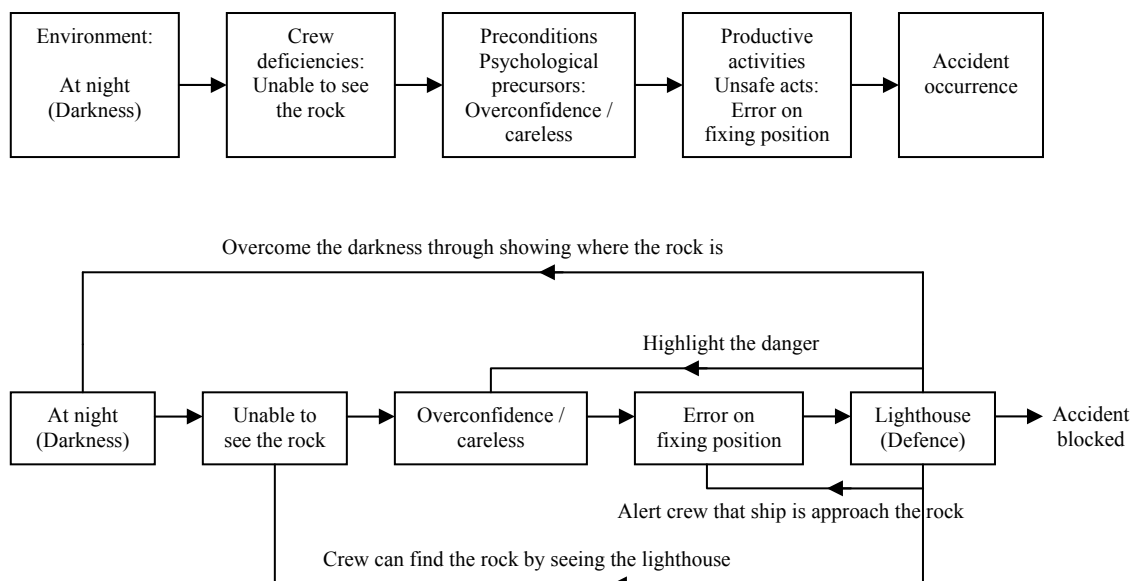
Figure 25: Model of a passenger ferry accident

From the above example, it can be concluded that the installation of a lighthouse could contribute to protecting the system at all levels. So a lighthouse should be considered as an identified risk control option. Similarly, VTS could also play an important role to prevent such accidents from happening in this respect.

The above model is an accident causation model while SHEL is a model that simply explains the types of human interaction without putting them into a context. In this step of FSA, these two models should be complementary to each other in order to facilitate decision-makers in finding out the appropriate risk control options for a planned area.

CHAPTER 5

Cost-benefit analysis (CBA) and recommendations for decision-making

In the previous chapter, Step 3 implies the development of Risk Control Options, which contain a limited number of Risk Control Measures (RCMs) for particular risk scenarios ranked by importance. These RCOs could be designed either to control the likelihood of initiation of accidents or control the escalation of accidents. The scope of Step 3 is a set of RCOs assessed according to their effectiveness of reducing risk (Melendez, 2004). Hereafter, FSA will activate its Step 4 – Cost-benefit analysis (CBA) to find the relation between the cost of the implementation of a RCO and the benefit obtained in terms of risk reduction.

There are two major kinds of cost-benefit analysis and they are *Ex ante* CBA and *Ex post* CBA. In the process of FSA, the applied CBA commonly refers to the former, which is conducted while a project or policy is under consideration or before it is started or implemented. On the contrary, the latter is done at the end of a project. *Ex ante* CBA assists in making the decision about whether scarce resources should be allocated by stakeholders to a specific project or policy and how to facilitate more efficient allocation (Boardman & Greenberg, 2001).

A VTS system is expensive to build and operate. It is necessary to conduct an extensive CBA to justify such large public and/or private investments. In its VTS Manual, IALA (2002) states that:

> Even if not all costs and benefits can be translated into monetary terms the
>
> CBA can assist in a more complete and rational decision-making process. It

can also contribute to the proper allocation of the cost recovery by the various

benefiting parties, as well as the determination of the system requirements.

Such a CBA forms an integral and essential part of the whole process for the application of FSA on planning VTS.

In the last step, several risk control options may have been specified. The CBA would ensure the balance among these risk control options. The principle is that if the cost of a RCO outweighs its benefit, the improved safety or the reduced risk that such a "cost" achieves, this RCO is not regarded as cost-effective, then it will be rejected unless the local risk level is considered intolerable.

In its guidelines, IMO (2002) recommends the procedures for conducting a CBA, which may consist of the following stages:

1. consider the risks assessed in step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2. arrange the RCOs, defined in step 3, in the way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3. estimate the pertinent costs and benefits for all RCOs;
4. estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5. rank the RCOs from a cost-benefit perspective in order to facilitate the decision-making recommendations in step 5.

This proposal may be used to develop a framework of conducting a CBA for planning for a VTS in order to determine whether the establishment of VTS in a planned area is justified or is the most cost-effective option among all the RCOs specified in the previous step. The following is a method which elaborates how to

implement VTS CBA, provided that VTS is one of the RCOs. This method may, in principle, also be applied on the CBA of other RCOs.

5.1 Definition of interested parties

The interested parties in this case can be defined as those who are directly or indirectly impacted by the existing risks or new risks generated by establishing VTS and those who intend to invest in a VTS or will benefit from the VTS. It is often contentious whether CBA should be conducted from an international, national, local or Maritime Administration perspective. In general, this poser may be solved according to the location and scale of the planned VTS, national maritime policy and administrative philosophy. When measuring the cost and benefit of a VTS, analysts may divide these interested parties into several groups and those in the same group may have common interests as far as the implementation of VTS in planned area is concerned.

5.2 Catalogue the impacts of VTS and determine measurement units

For a proposed RCO, its impacts can be classified as the anticipated beneficial impacts and the anticipated cost impacts. For a planned VTS, the anticipated beneficial impacts mainly include the time saved and reduced shipping costs for ships participating in a VTS (improvement of traffic efficiency); the residual value after the discounting period of 10 ~ 20 years; accidents avoided due to implementing VTS. The anticipated cost impacts are VTS construction costs and its additional maintenance and operational costs. All these impacts of VTS could be listed as benefits or costs in order to facilitate their measurement in the CBA.

The risk reduction of implementing VTS can be calculated relative to the present safety level. In a previous step, the safety level in a planned area is expressed as the **expected annual weighted number of traffic accidents P_k.** The risk reduction

resulting from VTS can thus be expressed as **the number of averted P_k if the option is implemented.**

The initial cost and its maintenance and the operating costs of VTS are estimated. By comparing all **costs** to **the number of averted P_k**, **the costs of averting a standard weighted traffic accident** can be computed. This number represents the cost-benefit of the planned VTS. When the costs of averting a standard weighted traffic accident have been calculated for all specified RCOs, decision-makers can possibly highlight an option which has the largest risk reduction for a certain amount spent.

5.3 Predict the costs of VTS

The objective of predicting the costs of VTS is to estimate the costs associated with implementing and operating the planned VTS. In its Manual, IALA (2002) sets out a framework for determining of the VTS costs:

> The cost components of a new VTS consist of two distinctive groups, namely the initial investment costs and the lifetime operating costs. Not only the costs for the VTS-organization need to be taken into consideration, but also the costs incurred by other parties. Often allied organizations and users need to invest to supply to or obtain information from VTS. All cost components should be identified and quantified, both in size (how much?) and time (when?). At the end of the lifetime of the VTS the investments might still have a residual value which needs to be deducted from the initial investment.

The estimates can be based on literature surveys and experience from other VTSs which have been established where a large similarity exists between them and the planned VTS in terms of scale, type, the services provided, the functions performed

and location etc. Table 9 shows those items that should be taken into account and can be used in estimating the costs of the planned VTS.

Table 9: VTS costs calculation

VTS costs	cost items (currency unit)	VTS 1	VTS 2	VTS 3	·······	VTS n	average costs
initial investment 1 (planning phase)	research						
	feasibility study						
	tendering						
	procurement						
	legislation						
	design						
	other costs						
initial investment 2 (construction)	land acquisition						
	building works						
	equipment purchase						
	equipment installation						
	spares purchase						
	recruitment of staff						
	training if staff						
	developing procedures						
	project management						
	other costs						
operating costs (operational phase) per year	maintenance and repairing of the building works						
	maintenance and repairing of the equipment						
	salaries						
	on-going training						
	consumables						
	up-to-date equipment						
	other costs						

After the initial investment costs (C_i) and annual operating costs (C_o) for a planned VTS are estimated, the total costs in the lifetime of the investment (C_t) can be expressed using the following formula:

$$C_t = C_i + C_o \times n - C_R$$

n: the expected lifetime of the planned VTS (generally 10 ~ 20 years);
C_R: the expected residual value of the planned VTS after n years.

Due to the influence of interest rates, for more objectively evaluating the VTS costs, facilitating comparison of costs and benefits as well as treating all costs, whether incurred early or late in the whole lifetime of VTS, in an equitable manner, it is necessary to discount the above C_t to a fixed point in time, generally the assumed starting point of the project, then the discounted value of all costs during the lifetime of a VTS can be calculated as follows:

$$C_t = [C_i / (1 + k)^y] + [C_o ((1 + k)^n - 1) / k (1 + k)^n] - [C_R / (1 + k)^n]$$

with:

> *k: interest rate*
>
> *y: the expected building years of planned VTS*

5.4 Risk reduction factor

The risk reduction factor can be defined as **the expected weighted number of traffic accidents P_k** after implementation of the VTS, divided by **the estimated P_k** without implementation of the VTS. Undoubtedly, this factor will lie between 0 and 1. It is not possible to precisely measure this factor because of the impossibility of considering the same area and time period with and without the VTS. Therefore, assessment of risk reduction factors can be based on an analysis of the operational modes of the planned VTS, including its type, the services provided and the functions performed as well as on literature surveys and calculations (DMA, 2002).

In its VTS Manual, IALA (2002) recommends four categories of approaches that can be used to assess the risk reduction factor for the discussed VTS: statistical evaluation of the existing situations and experiences (also elsewhere); consultation of experienced mariners, VTS-staff and consultants; mathematical models and simulation methods.

The first two can be conducted easily, inexpensively and without requiring detailed information, but the subjective judgement and historical data statistics, however they

may achieve a result having a big deviation from the actual performance of a planned VTS due to different situations and scenarios. These assessments are mainly implemented in forms of literature surveys and questionnaire. For instance, Glansdorp (2005) made studies in Dutch ports and drew the conclusion that VTSs in Netherlands contribute to a risk reduction in the VTS areas by nearly 30%; some research indicates that a full VTS can reduce accidents in areas of high traffic density by 50% (IALA, 2002); Harrald & Merrick (2000) assessed risk reduction due to VTM (vessel traffic management) through consulting two expert panels consisting of 8 licensed merchant mariners, 7 Coast Guard officers and 12 persons with knowledge of port operations, and concluded the overall ranking of the alternatives on a relative scale in risk reduction for the Norfolk/Hampton Roads area, as shown in Figure 26. These kinds of research outcomes and individual opinion can be used for reference by decision-makers in order to estimate the benefits of a planned VTS.
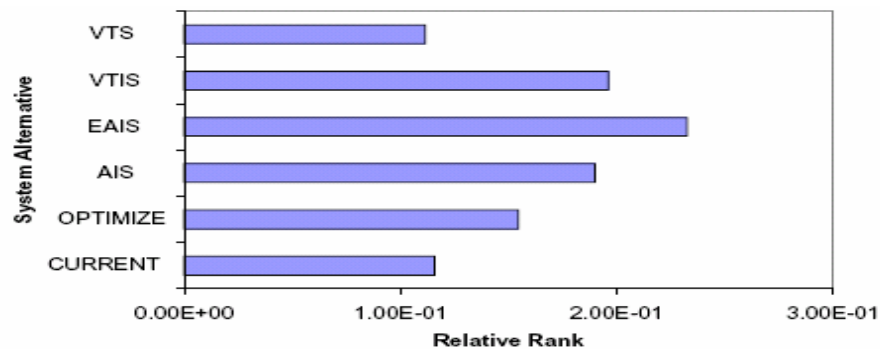
Figure 26: Ranking of alternatives in risk reduction for Norfolk/Hampton Roads area
Source: Harrald & Merrick. (2000).

While the last two approaches have more objectivity and allow different individuals to offer generally more uniform assessment, they have to be done much more costly or complicatedly and their accuracy depends on whether the models that they use are accessible enough to reality. In some circumstances, even they may not be as reliable as the first two approaches, because, after all, the models cannot cover all influencing factors and correspond with reality perfectly. In other words, each suggested method

has its own advantages and disadvantages and a combination of them may be necessary, depending on the situation.

5.5 Expected costs per averted weighted traffic accident for VTS

In step 2 of FSA, the traffic risk state in an area is expressed by its **risk index**, which is the ratio of **weighted number of traffic accidents P_k** and **weighted vessel traffic volume Q_k** in the area in a period. Then a trendline is developed in order to estimate the future risk index for the area. In addition, the **expected future Q_k** can be predicted through analysing the future economic and trade development. Therefore, **the expected total P_k** in the lifetime of VTS without implementing any risk control option **(P_0)** can be calculated according to the above outcomes. Assuming that the risk reduction factor for VTS is **f**, **the expected total averted P_k** in the lifetime of VTS due to implementing VTS **(P_w)** can be calculated as the following formula:

$$P_w = P_0 \, (1-f)$$

So **the expected costs per averted P_k** for VTS (RCO 1) can be calculated as:

$$C_{per\ 1} = C_t \, / \, P_w = C_t \, / \, P_0 \, (1-f)$$

A significant item when calculating **the expected costs per averted P_k** for VTS lies in the question, which specified RCO is the most cost-effective. This can be answered through a comparison with those **expected costs per averted P_k** for other RCOs. Generally, the RCO with the lowest expected costs per averted P_k is the most cost-effective and is considered worth giving the highest adoption priority.

For instance, when doing a risk analysis of navigational safety in Danish waters, the DMA (2002) computed **the costs per averted spill oil** for all identified RCOs. These RCOs were then ranked according to their cost-effectiveness, as shown in Figure 27.
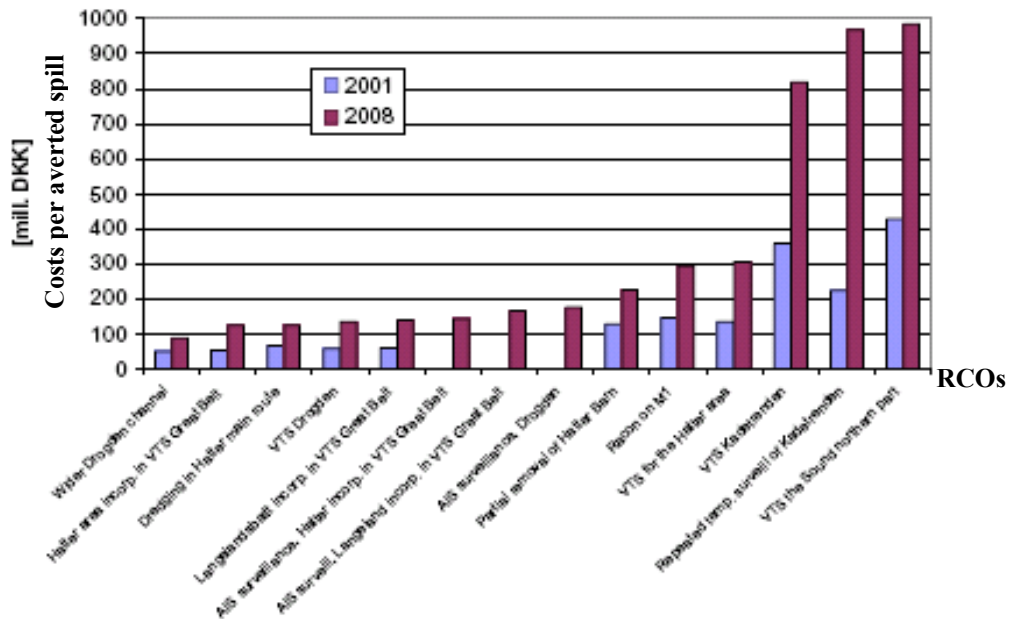
Figure 27: Costs per averted spill for all RCOs in situation 2001 and 2008 in Danish waters
Source: DMA. (2002).

It is evident that the four most beneficial RCOs are Wider Drogden channel, Hatter area incorporated into VTS Great Belt, Dredging in Hatter main route and VTS Drogden. They would be the most attractive choices to the decision-makers.

5.6 Estimate the benefits of VTS

The risk reduction benefits that would be derived from implementing VTS and costed in the above step need to be estimated now. Nevertheless, directly predicting the benefits of VTS is probably the most difficult and problematic task in the entire process of FSA. To simplify the method of predicting the benefits of the future VTS, it is necessary to develop an indirect approach.

In fact, all predictions are based on previous experience. The benefits of VTS can be comprehended as **the costs of averted accidents** which would be prevented because of adoption of the VTS. It can be assumed that **the costs of per averted weighted accident** equal **to the costs of per occurred weighted accident** in past years, which

can be calculated through dealing with historical accident data. So a thorny job (directly predicting the benefits of VTS) is translated into a relatively easy one (calculating **the costs of occurred accidents** in history).

● **Loss of life or injured**

Estimating the monetary worth of a human life is a sensitive issue, considering that occasionally, people are injured or die as a result of an accident. For the purpose of CBA, the value of a human life is inherently an estimate, one that is pondered upon regularly (IALA, 2002).

Researchers have used several benefit estimation techniques to estimate the value of life. These techniques either indirectly estimate the "price" people must be paid to be willing to take, or accept, certain risks by observing their behaviour in markets for commodities that embody risks, or directly elicit these amounts with hypothetical survey questions (Boardman & Greenberg, 2001). Many experts and scholars create their own model for elaborating and discussing this issue.

For instance, Miller, Fisher, Chestnut and Violette etc. (1999) estimate the value of life and injury costs in the United States through examining how much of a wage premium people working in risky jobs must be given to compensate them for the additional risks (Boardman & Greenberg, 2001). Figure 28 illustrates their research outcomes.

Plug-In Category (impact)	Shadow Price Value	Comments
VALUE OF LIFE	$ 2.5 million to $ 4.0 million per life saved . . .	Based primarily on Miller (1989). See also Fisher, Chestnut and Violette (1989) and Viscusi (1993). Should adjust for risk level if known
MONETARY INJURY COSTS 1) Eventually fatal 2) Hospitalized (nonfatal) 3) Nonhospitalized (nonfatal) 4) Average cost of an injury	1) $ 491000 per injured person 2) $ 53000 per injured person 3) $ 800 per injured person 4) $ 4300 per injured person	Based on Rice, Mackenzie, and associates (1989). Includes monetary costs only, not pain and suffering.
A) Motor vehicle injury B) Falls C) Firearm injuries D) Poisonings E) Fire injuries and burns F) Drownings and near-drownings G) Other	A) $ 14000 per injured person B) $ 4700 per injured person C) $ 83300 per injured person D) $ 7800 per injured person E) $ 4000 per injured person F) $ 100600 per injured person G) $ 1800 per injured person	
COST OF WORK-RELATED INJURY 1) Less serious 2) More serious	1) $ 31000 per injured person 2) $ 64000 per injured person	Based on Viscusi's (1993) survey of labor market studies; therefore, includes pain and suffering but not all social costs. Higher values involve loss of workdays.

Figure 28: Value of life and monetary injury costs
Source: Miller, Fisher, Chestnut and Violette etc. (1999) / Boardman & Greenberg. (2001).

Mishan (1988) put forward a formula for calculating the economic worth of a person's life (L) on the basis of discounting the person's expected future earnings to the present, where Y_t is the expected gross earnings of the person during the tth year, exclusive of any yields from his ownership of non-human capital. P^t_τ is the probability in the current, or τ^{th}, year of the person being alive during the tth year, and r is the social rate of discount expected to rule during the tth year.

$$L = \sum_{t=\tau}^{\infty} Y_t P^t_\tau \left(1+r\right)^{-(t-\tau)}$$

In his lecture, Friis-Hansen (2005) also estimated the socio-economical value of human life (Q) using the Life Quality Index, which combines gross national product per capita (G), life expectancy at birth (E) and working time (W): $Q = G^W E^{1-W}$.

Besides the above models, there are also a lot of other methods available to measure the monetary worth of a human life. Decision-makers can select an appropriate one at their discretion.

● **Economic losses**

Economic losses can be divided into two groups, hard losses and soft losses. The former mainly includes those obvious, tangible and direct losses of or damage to properties, caused by accidents, and relevant repair and replacement costs. They can be measured relatively easily through reviewing the historical accident data.

The latter mainly includes those associated indirect costs that may not be readily recognized, for example loss of earnings, loss of reputation, loss resulting from delay in the carriage by sea of cargo, passengers or their luggage, loss resulting from "down time" of both vessels and related shore based activities due to fog and other circumstances etc. These so-called soft losses should also be considered and translated into monetary terms. However, some factors are almost impossible to translate into monetary terms precisely, whereas they should at least be noted and mentioned in the outcome of the CBA so that decision-makers can make a more comprehensive analysis with these references (IALA, 2002).

● **Environmental pollution**

Similarly the costs of environmental pollution can be divided into two groups as well, tangible and intangible costs. The tangible costs include the direct costs of the accidents, costs of the Search-and-Rescue operation, those associated costs for clean-

up operations including shoreline clean-up and recovery of sunken oil, all arising from the occurred accident. These costs can be calculated easily through reviewing the historical data and records.

The intangible costs mainly include damage to public and ecological resources, the impact on the ecosystem and human health, the damage to public recreation areas and sustainable development, influence on the fishery industry, aquaculture and tourism, political costs etc. Some of these can be translated into monetary terms while others are almost impossible to be measured in monetary terms, so they should at least be noted and mentioned in the outcome of the CBA so that the decision-makers can make a more comprehensive analysis with these references.

5.7 Assessment of the worthiness for VTS

From the above steps, the costs of accidents during the past years can be calculated, and then these costs are discounted to a fixed point in time, generally the assumed starting point of the project, in a manner similar to that of calculating the costs of VTS. If the outcome is divided by **historical weighted number of traffic accidents P_k,** then **the costs of per occurred P_k** will be achieved.

Assessing the worthiness for a planned VTS can be made by comparing **the costs of per occurred P_k** to **the expected costs per averted P_k**. This knowledge is used together with political and other considerations to determine whether or not the planned VTS should be implemented (DMA, 2002).

As a general principle, a VTS should be implemented **if the expected costs per averted P_k are lower than the costs of per occurred P_k.**

5.8 Recommendations for decision-making

Output from the above steps can provide an objective answer for the question of whether the establishment of a VTS in a planned area is justified or worthwhile and how much its cost-effectiveness is. Similarly, the above principles and methods are also applicable to CBA of other identified RCOs. A comparison of their results can indicate which is the most cost-effective option among all RCOs. This facilitates and rationalizes the decision-making, and could be easily used by decision-makers without a requirement for specialist expertise.

In the final step of FSA, recommendations for decision-making that interacts with each of the other steps of FSA, recommendations should be presented in a form which can be understood by all parties irrespective of their experience in the application of risk and cost benefit assessment and related techniques. Those submitting the results of an FSA process should provide timely and open access to relevant supporting documents and a reasonable opportunity for, and a mechanism to, incorporate comments (IMO, 2002).

Generally, the recommendations are based upon the outcomes of previous steps: in Step 1, the comparison and ranking of all risks, hazards and sub-areas in the planned area; in Step 2, estimated P_k, Q_k and risk indices for each sub-area as well as their risk acceptability; in Step 3, the ranking of the underlying causes of those identified risks and hazards in Step 1 and the corresponding specified risk control options; in Step 4, the comparison and ranking of RCOs as a function of associated costs and benefits. Additionally, decision-makers must always be aware of residual risk, which is defined as any risk left after the implementation of the designated risk control option(s), and if appropriate, loop back in the process to determine if it should be further reduced, as shown Figure 3.

CHAPTER 6

Conclusions and recommendations

6.1 Conclusions

The main purpose of this dissertation is the introduction of RBDM techniques commonly used for planning VTS to evaluate whether establishing a VTS in a planned area is justified and cost-effective. This analysis requires a clear understanding of all the factors that the application of RBDM on planning VTS involves and the development of a RBDM framework based on these factors. This RBDM framework, the so-called FSA, serves as an adequate reference for the application of RBDM techniques on planning for a VTS.

Traditional approaches to decision-making have been partly successful and RBDM should be introduced in order to more greatly contribute to the improvement of safety in maritime sectors. RBDM is a systematic and scientific process of making decisions. FSA is a practical framework of the application of RBDM in the maritime industry, which is constructed using several mutually related modules: the identification of risks and hazards, risk assessment, the specification of RCOs, CBA and recommendations. As a framework of proactive approaches, FSA is considered as a prime instrument for the development of proactive marine policies.

The above chapters introduce some of the main concepts to be used in the process of doing a FSA when planning for a VTS. Firstly, the problems needing to be defined for establishing a VTS were highlighted and it was shown that they are mainly

related to six aspects: VTS vessels, types of VTS, traffic rules and regulations, risk to be considered, geographical boundaries and determination of risk, then the risks and hazards in the planned area were identified and ranked through analysing the historical traffic accident records and local traffic data.

Secondly, after some models recommended by IMO for risk analysis and the limitation of their application on planning VTS had been briefly introduced, a new method based on the risk index theory of Wu was demonstrated. This method can be used to estimate the future weighted traffic volume and traffic accident loss. Then, a new model evolving from the traditional ALARP Matrix was introduced illustrating the risk acceptability using two parameters, traffic volume and traffic accident loss, instead of risk frequency and consequence.

Thirdly, in specifying RCOs, the m-SHEL model developed from the SHEL model and a new model based on the Reason model were used. Their combination and mutual supplementation highlight the relevant RCOs, which are identified according to the underlying factors of traffic accidents, in the context of waterways management.

Finally, the concept of cost-benefit analysis was presented through a prioritisation of the RCOs with respect to cost-effectiveness and the subjective criterion, which is a comparison of the costs per averted spill to the costs of the occurrence of a spill, for the determination of whether to implement an RCO.

Based on the above concepts and analyses, some recommendations are then submitted to the decision-makers. Thus, a whole process of how to apply FSA when planning for a VTS was demonstrated. Each major project may be regarded as unique. Therefore, the detailed application of RBDM on planning for a VTS is definitely different from other maritime projects although the principles of RBDM are applicable and identical to all fields. Even, within various VTS projects, there are

many aspects which differ. However, the similarity on the principles, methods and purposes of planning and implementing each VTS means that it is possible and necessary to create a generally applicable methodology for RBDM when planning VTS. This dissertation presents a uniform scheme illustrating how to apply RBDM when planning for a VTS.

6.2 Recommendations

The real scale of VTSs, as well as the cost of their investment and operation, have expanded dramatically in recent decades. Such a large and expensive project indeed needs to be assessed with RBDM in order to determine whether or not it is justified. The RBDM approach presented in this thesis provides some other benefits which may prove far more important in the long term. These benefits include:

- A more transparent process in decision-making, which can help the stakeholders to understand the necessity for the suggested risk control option(s) and determine whether to establish a VTS in the planned area.

- Better and more definite risk perceptions that determine the risk criteria and acceptability, as well as their effects on planning for a VTS.

- Through identifying the underlying factors of risk with the incorporation of the human element, safeguards could be proactively taken in order to prevent accidents from occurring; this facilitates the assessment of the appropriate mix of ways to reduce risk.

- Documentation and integration of group knowledge which is usually composed of individual opinions and permits their reservation.

- Soundness testing of the assumptions in the future performance scenario of the planned VTS.

- Feedback into the decision-making process in terms of the suggested ways of preventing or avoiding risks in the planned area.

Taking into account the promotion of the application of RBDM when planning for a VTS, the author would like to propose the following recommendations:

- Decision-makers must understand the limitation of risk-based decision-making, which is still a developing science. The uncertainty is inherent in the process of RBDM, which is a major limitation of this approach and affects people's confidence in this approach.

- RBDM mainly provides relevant information, associated analysis outcomes and recommendations instead of the defined solutions to risks and hazards.

- Limited resources should be directed to the most severe risks in a cost-effective manner in order to create the maximum benefits.

- Each suggested RCO should be based on a scientifically and technically credible risk analysis and cost-benefit analysis.

- Each public agency that administers projects relating to navigational safety, marine environmental protection and traffic efficiency should undertake to establish regulatory and budgetary priorities to guarantee that the national resources are appropriately allocated.

- It is necessary to develop standard procedures and models, which should be as uniform as possible, for the conduct of RBDM when planning for a VTS.

- Risk control options should be evaluated in terms of cost, benefits, residual risks, risk reduction factor as well as the associated uncertainties in data and methods used to assess risks.

- Decision-makers must also be aware that the future is not a simple and linear extension of the existing situation, so more refined methods must be applied to assess the estimated risks including their consequences, for the upcoming years by taking into account all the foreseeable trends.

- Ranking the RCOs with respect to cost-effectiveness presents a recommended implementation sequence if cost-effectiveness were the only criterion. There are, however, other criteria which affect the final choice of RCO, for instance political objectives, co-funding of measures with other interested parties, consideration of natural resources, flora and fauna, professional and industrial bodies and the public. They may also have an impact on the preferences of the decision-makers.

- It is necessary to foster more advanced methodologies for assessing risks and mitigating the uncertainties of analysis, more enhanced information and data collection to improve the accuracy and relevancy of RBDM, and innovative risk control options to reduce risks to safety and the environment while increasing traffic efficiency to a greater extent.

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Appendix A

Port Of Wuhan: a brief view

Wuhan port, the second largest inland port in China, has the capability of handling over 30 million tons of cargo each year (Hubei Government, 2000). As a first-grade port open to the outside world, it serves not only the international sea-borne trade of the country with many boat lines leading directly to 14 countries and regions such as Russia, Japan, Singapore, Hong Kong and Macau, but is also at the centre of Yangtze river shipping and the key pivotal point of transportation which greatly contributes to the establishment of logistics between the central-western parts of China and Chinese coastal areas. According to the statistical data, the annual freight volume of Wuhan Port is 24.32 million tons with an annual passenger-traffic volume of 5.55million passengers (Gotravel, 2005).

Location

The geographical position of Wuhan Port is 30°-33'N and 114°-19'E. The port is attached to Wuhan City with more than 8 million inhabitants, located in the middle of China - about 1,200kms from Beijing, Shanghai, Guangzhou and Hong Kong. The city is the provincial capital of Hubei Province and a focal point for political, economic, scientific and cultural affairs for central China.

The harbour area covers 122.45 square kms, including a land area of 1.75 square kms, while its water area is composed of the Yangtze river section (the southern bank of 140kms from Bangzhou Tou to Sanjiang Kou and the northern bank of 188kms

from Shuihong Kou to Bahe Kou) and the Hanjiang river section of 55kms from Xingou to the Hanjiang Estuary where the Hangjiang river, as a tributary of the Yangtze river, converges into it within the Yangtze river section of Wuhan Port.

Harbour Facility

Due to its unique geographical advantage, Wuhan has been known since ancient times for its thoroughfares and golden rivers leading to different regions inside China and to various countries around the world. With 615 docking berths, Wuhan Port is one of the biggest passenger and cargo ports along the Yangtze River. Passenger traffic at Wuhan Port ranks first among all inland river ports in the Yangtze Basin and its cargo traffic ranks third in volume, behind Shanghai and Nanjing. All-year round, 5,000 ton-vessels can use the port while 10,000 ton-vessels can berth alongside during the wet season (Jipin, 2005).

Appendix B

Identification of risks and hazards in Wuhan Port

1. The traffic volume per year (1999-2003) in Wuhan port and its distribution

According to Formula 3, the traffic volume per year (1999-2003) in Wuhan port is estimated as 234904 while the volume per day is 643. With consideration to traffic properties in the dry and flood seasons and the local natural conditions, the visual surveys were undertaken continuously for four days respectively in May and November (1999-2003). The site was located in Wharf.22, on the opposite side of the river of which, a chimney in Guomiansi factory was selected as the reference target so that an observation line was kept vertical with the main traffic flow in the Yangtze River. The collected data consists of vessel classes, vessel sizes, going upstream or sailing downstream and the time when the vessel passed through the observation line. In addition, the internal traffic volume was obtained through investigating Wuhan Maritime Safety Administration records.

Figures 29 and 30 describe the distribution of vessel sizes and classes in Wuhan port. They show that ships ranging from 30m to 75m in terms of length form the principal part of the traffic flow and possess 63.77 percent of the total volume. Vessels identified in visual surveys and records were categorised into eleven classes for the purpose of analysis and four main types including cargo ship, barge-fleet pushed by tug, working ship and ferry, contribute to 79 percent of all vessels.
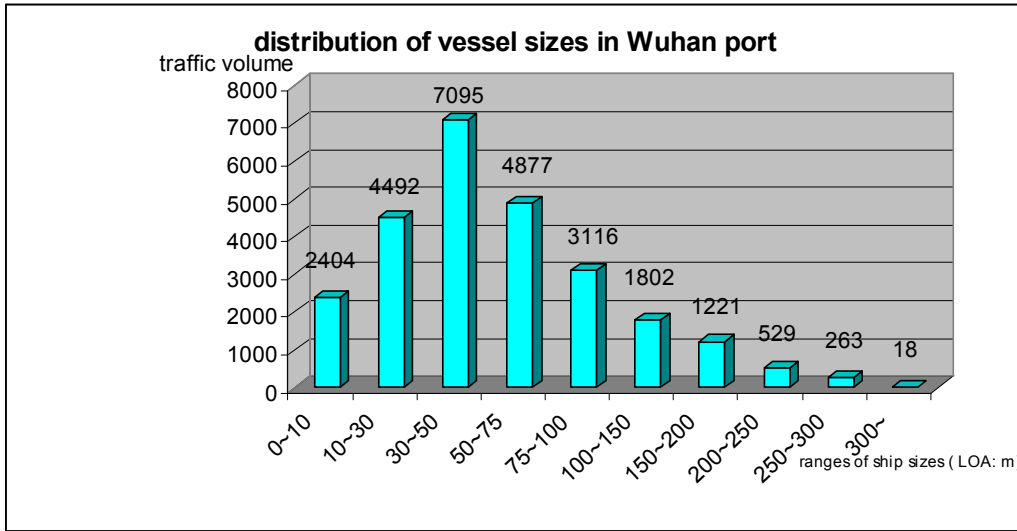
Figure 29: Distribution of vessel sizes in Wuhan Port (visual surveys, 1999-2003)

Source: Yangtze Maritime Safety Administration (2005).
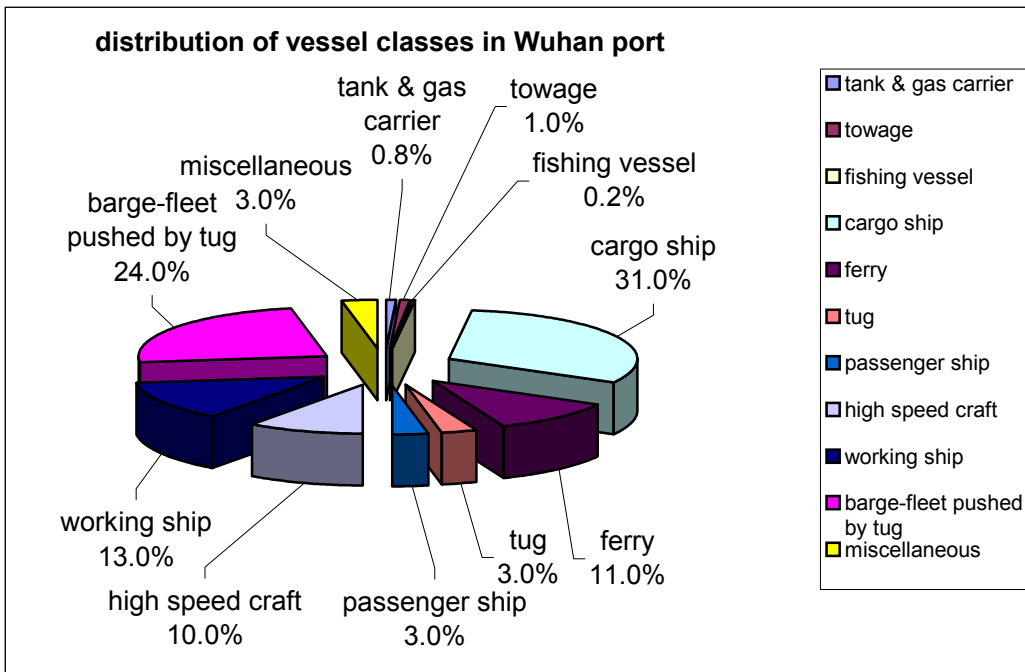

Figure 30: Distribution of vessel classes in Wuhan Port (visual surveys and MSA records, 1999-2003)

Source: Yangtze Maritime Safety Administration (2005).

2. Main mix of traffic in Wuhan Port

Wuhan Port is situated in the centre part of the Yangtze waters network comprising the main river and tributaries. Due to complicated geographical features and special traffic rules, there exists a large amount of altering course points and crossing traffic flows in the whole area. The main mixes of traffic in Wuhan Port occur in sailing cross areas and where ferry services are provided. As the above mentioned, sailing cross areas increase the probability of ship cross encounters and collisions. In its investigation report, Changjiang MSA (2004) states that about seventy percent of total collisions in the Anhui section of the Yangtze River in two recent years are related to sailing cross areas. Thus decision-makers should consider reducing the number of such areas to a level as little as practicable or take measures to control and monitor the traffic flows in those areas. Besides six sailing cross areas, Wuhan Port has eighteen ferry lines that include thirteen for passengers and five for automobiles, connecting the two sides of the Yangtze River and the Hanjiang River. The total number of main traffic mixes in Wuhan Port can be approximately calculated as follows: 18 x 3 + 6 = 60.

3. A short introduction to visibility, current and wind in Wuhan Port

The mean number of foggy days per year in Wuhan Port in the most recent five years is 33.1 days, ten of which happen most frequently in November. Commonly, fog forms in the morning and clears off by noon in the spring and winter. When fog is very thick above the surface of river, ferry services and other waterborne traffic will be suspended temporarily.

Wuhan Port is predominated by East and South winds in spring and summer whereas West and North winds prevail in autumn and winter. The average wind speed is 2.8 m/s and the wind force generally ranges from Beaufort Force (BF) 2 to 4 a year. The maximum wind speed in a year is commonly 19.1 m/s and an extreme 28 m/s of

strong gale was recorded once. There are on average 8.2 days for wind of BF above 7 to 8 in the most recent five years and with 16 days being the highest. The average maximum current speed is 2.70 m/s yearly which always happens in the flood season with the highest on record being 3.06 m/s (MOC, 2001). However, current is slow where close to the banks of the river. The tidal current can only affect up to Nanjing Port and never reaches Wuhan Port due to the long distance (1125 km) from Wuhan to the Yangtze River Estuary.

4. Dangerous cargoes and marine pollution

Wuhan Port has special wharves for dealing with dangerous cargoes including petroleum and chemical products. In 2004, the volume of freight handled for these cargoes reached 1.87 million tonnes. Meanwhile, many vessels carrying dangerous cargoes pass through Wuhan Port every year. With the developments in the Chinese economy, especially the littoral zones of the Yangtze River, the total freight volume in the Yangtze River ports has risen very rapidly. Figures 31 and 32 illustrate the change in the distribution of the main cargoes in Yangtze River ports in 1984 and in 2003 (Xinhuanet, 2005). It is shown that in 2003, petroleum and chemical materials possessed a maximum proportion of the total freight volume instead of coal which got the largest share in 1984. Undoubtedly, Wuhan Port also has to confront the increased risks imposed by the sharply growing waterborne dangerous cargo transport along the Yangtze River.

distribution of main cargoes in Yangtze River ports in 1984

others 32%
coal 22%
steel 3%
petroleum 19%
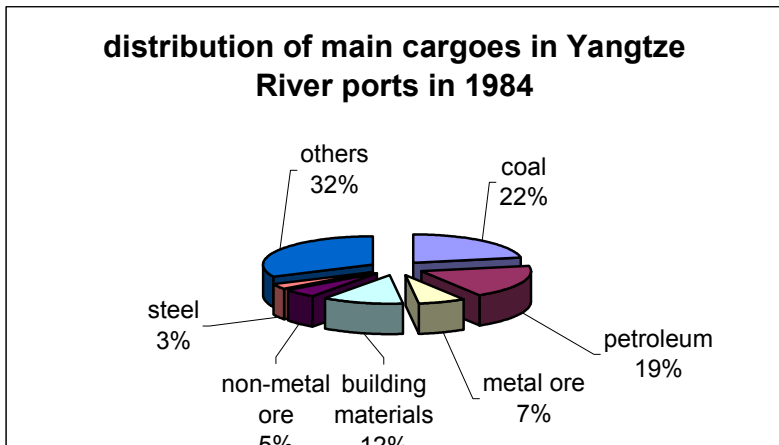non-metal ore 5%
building materials 12%
metal ore 7%

Figure 31: Distribution of main cargoes in Yangtze River ports in 1984

Source: Xinhuanet. (2005, January 12). *Fast Increase in Freight Volume in Yangtze River's Main Ports in the Recent Twenty Years*. From the World Wide Web: http://www.hb.xinhuanet.com/zhuanti/2005-01/12/content_3555086.htm

distribution of main cargoes in Yangtze River ports in 2003

chemical materials 4%
others 16%
coal 19%
steel 9%
petroleum 22%
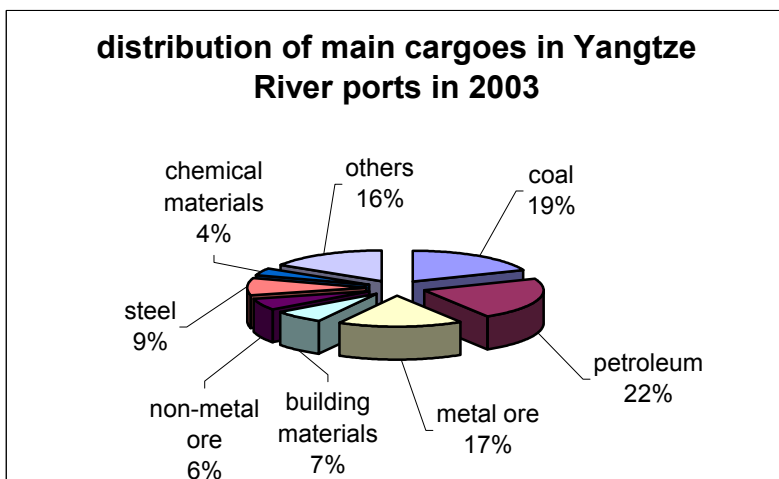non-metal ore 6%
building materials 7%
metal ore 17%

Figure 32: Distribution of main cargoes in Yangtze River ports in 2003

Source: Xinhuanet. (2005, January 12). *Fast Increase in Freight Volume in Yangtze River's Main Ports in the Recent Twenty Years*. From the World Wide Web: http://www.hb.xinhuanet.com/zhuanti/2005-01/12/content_3555086.htm

Wuhan Port is a river harbour along the Yangtze River, the biggest river in China, which is regarded as having very high sensitivity in terms of marine environment pollution. China has promulgated strict laws and regulations to prohibit any discharge of oil and oily mixtures from ships into the Yangtze River.

The port is attached to Wuhan City with more than 8 million residents, along the banks of which there are densely inhabited districts. The River is the main water source for drinking and industrial production in Wuhan. Many bird species build their nests on the beaches, while others regularly wander the shoreline searching for food. Aquatic mammals, such as white-fin dolphins, river suckling pigs and Chinese sturgeons, live in the River but they are close to extinction. Among them, white-fin dolphins are called living fossils and their total number is not beyond ten now in the world. In addition, the River and its shorelines also provide public recreation, such as fishing activities, swimming, boating, tourism and sightseeing.

5. Local geographical conditions

Wuhan Port is located on the Yangtze River in the province of Hubei, 917 km from Wusong. The port's location on the river means there is an extensive network of river transport links. The average width of channels in Wuhan Port is 570 m, where the maximum breadth is 1060 m and the minimum is 80 m in the Yangtze River section while the width of the Hanjiang River is about 60 m and the mouth to the Yangtze River is around 200 m. There are totally four bridges with 32 abutments in water crossing the Yangtze River and seven crossing the Hanjiang River in Wuhan port. The water level in the Yangtze River varies obviously according to the season. The draft limitation in the main channel is 4.5 m with a clean height of 26 m in the dry season and 8.0 m with a clean height of 24 m in the flood season.