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Original article

Evaluate VTS benefits: A case study of Zhoushan Port *

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Abstract

It has been well acknowledged that Vessel Traffic Services (VTS) has played a growing important role to ensure the safety of navigation in the busy ports and waterways. However, the benefits produced by VTS are usually ignored by the public and private sectors. Besides, the previous evaluations generally exist following problems: (1) It is difficult to collect the data for the parameters in the evaluation models and/or the parameters are designed illogically; (2) Those models did not take the following factors into consideration such as reducing the frequency of coastal vessel patrolling and saving human and material resources; (3) It is difficult to clearly discriminate the benefits derived from VTS and non-VTS. In this paper, a framework is presented to calculate the benefits of VTS in China. Four key indicators (safety, traffic efficiency, environmental protection and reducing supervising cost) and quantitative methods have been introduced into the framework. When calculating the benefits quantitatively, the traffic condition before the construction (expansion) of the VTS has acted as a benchmark. For a case study, the project of the expansion of VTS in Zhoushan Port, East China was evaluated with 10-year data. According to the results, the largest contribution is from the benefit of environmental protection. Via Cost-benefit analysis the benefit cost ratio (B/C) of the VTS is up to 5.248, which shows the benefits produced by VTS are considerable. The research could provide references for VTS benefits evaluation and investment optimizing.

Keywords: VTS, quantitative analysis, economic benefit, cost-benefit analysis

I. Introduction

From 1978 to the end of 2011, since the first Chinese VTS center in Ningbo Port was constructed, more than 30 VTS centers have been established and put into service, becoming the top in the world with one-third of global amounts. So "Is it worthy in comparison to the high cost of construction, operation and maintenance?" "What benefits can a VTS bring about to the port, which drove the government to establish VTS centers in the past 30 years? Obviously, the answers of the questions depend on the economic and social benefits produced by the VTS. However, the specific research related to establishing a scientific, reasonable and integrated evaluation system to assess the benefits of the VTS remains very sparse.

In view of engineering evaluation, Fan & Wang (2008) systematically analyzed the planning of VTS applying Formal Safety Assessment (FSA); For qualitative analysis, Shi(2004) established a VTS benefit evaluation model based on risk assessment method; Zhu et al (2008) indicated that the VTS was conducive to the safety and efficiency of navigation, protection of maritime environment and safeguarding of state sovereignty and maritime rights; Yang et al(2010), Zhang (2011) all tried to use a fuzzy comprehensive evaluation method to evaluate the effectiveness of the VTS. It is noted that quantitative analysis is a symbol of high quality of any research. IALA (2013) proposed a VTS cost-benefit analysis framework, in which the quantitative method to weigh the cost and benefits of VTS is thoroughly discussed; Lehn (2014) presented a general method for evaluating the effect of a VTS based on incident reports from Great Belt VTS; combining theoretical calculation and questionnaire survey method, Xu (2008) analyzed the ship navigation benefit of the Kaohsiung harbor produced by VTS; Li (2010) calculated the direct/indirect social and economic contribution of the Guang Zhou VTS based on quantitative economic data. Since Zhao et al (1998) firstly indicated that VTS could bring about safety, efficiency and environmental protection benefit, Shao et al (2002), Lu (2004), and Zhang (2006) kept working on these three aspects and put forward a quantitative method respectively. Other relevant research, such as Arild et al (2008) analyze the economic and social benefits produced by VTS in the arctic and other environmental sensitive areas. Generally, the benefits of VTS are divided into direct and indirect or value-added and loss-reduced benefits. Many scholars believed VTS can bring safety, efficiency and environmental protection benefit to the water and had proposed quantitative methods to calculate these three aspects of benefits. However, the methods generally exist following problems: (1) It is difficult to collect the data for the parameters in the previous evaluation models and/or the parameters are designed illogically; (2) Those models did not take the following factors into consideration such as reducing the frequency of coastal vessel patrolling and saving human and material resources; (3) It is difficult to clearly discriminate the benefits derived from VTS and non-VTS.

According to the analysis of construction and running of VTSs in China, a framework is presented to calculate the benefits produced by VTS. Four key indicators (safety, traffic efficiency, environmental protection and reducing supervising cost) and quantitative methods are introduced into the framework. For a case study, the project of expansion of VTS in Zhoushan Port was evaluated and the Cost-benefit analysis are also conducted.

II. A Generic Methodology

The ultimate aim of VTS is to improve the safety, efficiency of the traffic and protect maritime environment. It is a truth in 30-year practice of Chinese VTSs. For instance, through supervising ships dynamically, close quarters situation between ships can be detected timely, which could effectively prevent the occurrences of accident and avoid risks turning into fatal traffic accidents. By organizing the traffic, the capacity of transit, navigability at night/in fog can be greatly improved. Besides, via implementing intensive monitoring on oil tankers, oil spill accidents can be reduced, as well as the damage to fisheries and natural environment. In addition, when consulting VTS operators and coastal patrol personnel, it is found that VTS operators can schedule the use of coastal patrol vessels more effectively by integrating the latest traffic information, thus reducing the patrol cost, relevant personnel expenses and maintenance cost, etc. In conclusion, it is considered that VTS can bring about four aspects of benefits, as shown in figure 1. In addition, in order to discriminate the benefits derived from VTS and non-VTS, the traffic condition before the construction of the VTS acts as a benchmark. All benefits are transformed into monetary value.

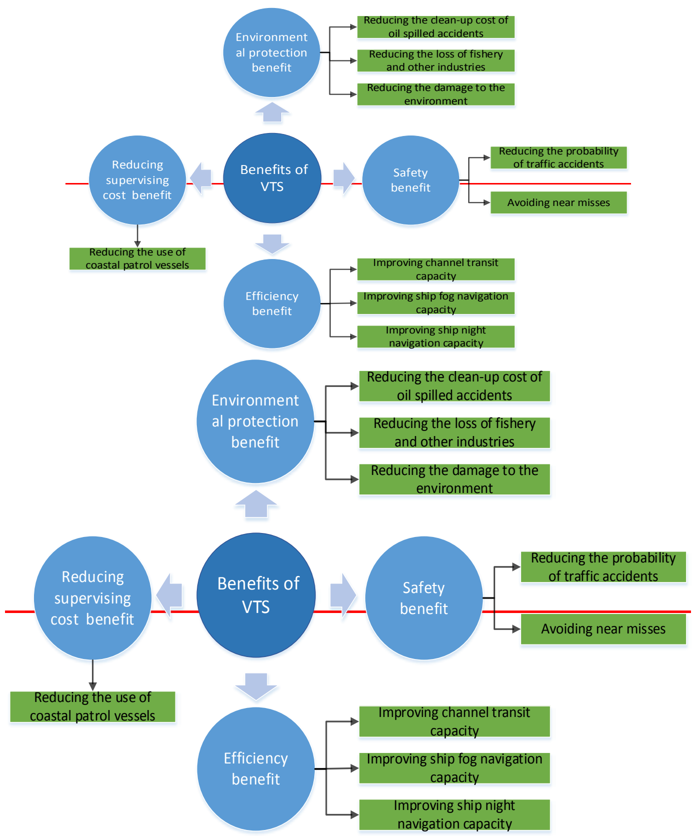


Figure 1: The Framework of Benefit of VTS

2.1. Establishment of Rule-Based with belief structure

2.1.1st Reducing traffic accidents

Through monitoring and tracking ships dynamically, the frequency of accidents (collision et al) in the supervised water can be reduced, thus the loss of the reduced accidents which should happen (excluding oil spilled accidents) can represent the safety benefit of the VTS. In the paper, the accident reduction benefit per year is a product of the annual accident reduction rate with the average accident loss per year before the construction of VTS (assuming VTS was not constructed, the loss of accidents would remain the same), as shown in equation (1). To strip the influence of traffic flow to traffic accidents and to distinguish the loss degree of different ranks of accidents, traffic flow and the weight of the difference in accidents are introduced in the equation.

$$E_s = \left\{ 1 - \frac{\sum_{a=1}^{a} w_{ma} \cdot k_a / Q_m}{\frac{1}{n} \sum_{n=1}^{n} \sum_{a=1}^{a} \left(w_{na}^{'} \cdot k_a \right) / Q_n^{'}} \right\} \times \left(\frac{1}{n} \sum_{n=1}^{n} C_n \right) \quad (1)$$

Where, Es is the accident reduction benefit of the VTS (ten thousand yuan/year), $Q_n^{'}$ is annual vessel traffic flow before the running of the VTS (ten thousand/year), Q_m is annual vessel traffic flow after the running of the VTS (ten thousand/year), $w_{na}^{'}$ is the number of "A" kind of accidents happened per year without VTS, k_a is the weight of "A" kind of accident, referring to table 1, w_{ma} is the number of "A" kind of accidents happened per year with the running of VTS, C_n is the annual loss of the accident per year without VTS (ten thousand yuan/year), which mainly includes salvage costs, accident investigation fees, cargo damage, repair and inspection fees. According to "Statistic method for the traffic accident in the water" promulgated by Ministry Transportation of China, corresponding weight to different rank of accident is given.

2.1.2st Avoiding potential accidents

VTS could interact with the traffic. Through VHF or other communication equipment, VTS operators can communicate with ships and warn them of the dangerous situations (such as course deviation, illegally overtaking, dragging anchor et al) online which may turn into fatal accidents. So the potential loss of the risks which were effectively eliminated with the assistance of VTS can represent the safety benefits as well.

In 1969, Bird analysed 1753498 accidents reported by 297 companies (involving 21 industries and 1750 thousand personnel). The result indicated that when there are 600 hidden dangers or illegal behaviours in a system, 30 property loss accidents, 10 minor-injuries and 1 accident with serious property and human life losses are bound to happen.

Figure 2: Bird's severity distribution of accidents

Applying the result, the probability of different rank of accidents which may develop from the risks could be calculated: the ratio of serious/major injury accident (with serious life and property loss) $P_1 = 1/600$, the probability of minor-injury accident (with casualties) $P_{II} = 10/600$, and the probability of property damage accident (with property loss) $P_{III} = 30/600$. So the benefit of avoiding near misses E_{aviod} can be calculated by equation (2):

$$E_{avoid} = \sum_{i=I}^{III} W \times (P_i - P_{i-1}) \times C_i \qquad (2)$$

Where Ci（i= Ⅰ 、Ⅱ 、Ⅲ）is the average losses of the serious/major injury accident, minor-injury accident and property damage accident (ten thousand yuan/year); W is the number of risks avoided per year.

2.2. Traffic efficiency benefit

When monitoring the water, VTS operators could organize the traffic, assist navigation under unfavorable circumstances (fog, night) and mitigate traffic congestion in a timely manner. Therefore the waiting time in and out of the ports or waterways can be reduced and the efficiency of ship navigation can be improved. The cost of time-reduced navigation in the water can represent the traffic efficiency benefit. The benefit of improving transit capacity and navigability at night/in fog can be obtained with the equation (3).

$$E_I = \left(Q_m - \frac{1}{n} \sum_{n=1}^{n} Q_n^{'} \right) B \cdot T \qquad (3)$$

Where, $Q_n^{'}$ is the vessel traffic (fog/night navigation) flow per year before the construction of the VTS; Q_m is vessel traffic (fog/night navigation) flow per year with the running of the VTS; B is average sailing cost (or demurrage charge) of a ship per day; T is the average time reduced (or demurrage time) of a ship sailing in the water with the running of the VTS.

2.3. Environmental protection benefit

It is usually accidents involving oil tankers that would cause catastrophic pollution to the environment. Therefore oil tankers are paid special attention by VTS operators. Under the strict and scientific supervision of the oil tankers, the frequency of oil spill accidents can be reduced, thus the reduction of clean-up cost, damage to fisheries et al. and natural environment can represent environmental protection benefit. In 2010, Kontovas et al carried out a regression analysis of total cost with the quantity of oil spilled in each accident with the data assembled by the International Oil Pollution Compensation Fund (IOPCF). The square of correlation coefficient of the fitting equation is R2=0.738, showing the equation is pretty reliable. Therefore, we apply the result to calculate the environmental protection benefit as shown in the equation (4).

$$E_e = 51432\left(\frac{1}{n}\sum_{u=1}^{u} V_u^{0.728} - \sum_{k=1}^{k} V_k^{0.728}\right) D + \left(\frac{1}{n}\sum_{u=1}^{u} V_u - \sum_{k=1}^{k} V_k\right) M$$

$$E_e = 51432\left(\frac{1}{n}\sum_{u=1}^{u} V_u^{0.728} - \sum_{k=1}^{k} V_k^{0.728}\right) D + \left(\frac{1}{n}\sum_{u=1}^{u} V_u - \sum_{k=1}^{k} V_k\right) M \qquad (4)$$

Where, Vu is the quantity of oil spilled in each accident without VTS (tons); D is the dollar exchange rate before the construction of the VTS; Vk is the quantity of oil spilled in each accident after the running of the VTS (tons); M is the cost of spilled oil per ton without VTS (ten thousand yuan/ ton).

2.4. Reducing Supervising cost

Before the running of VTS, the main approach to correct the illegal behavior of ships (such as course deviation, dragging of anchor et al) was by cruise on site which was usually lagging behind and had limited effects. However, through dynamically monitoring, VTS operators can correct the illegal behavior immediately on the VTS center, thus the time and amount of cruising can be reduced and the on-site management of ships would be performed more effectively and efficiently. The costs of reducing the use of coastal patrol vessels and relevant manpower/material resources can represent the reducing supervising cost benefit of the VTS, which can be calculated with equation (5).

$$E_c = \left(\frac{C_m}{\square L_n}\right) T \cdot B + M_1 + M_2 + M_3$$

$$E_c = \left(\frac{C_m}{\Delta L_n}\right) \mathrm{T} \cdot B + M_1 + M_2 + M_3 \qquad (5)$$

Where, Cm is the number of illegal acts corrected by the VTS operators per year; $\square L_n$ ΔL_n is the average number of illegal acts corrected in each on-site cruise; T is average time cost in each cruise (hours); B is the average fuel fee of each cruise (ten thousand yuan/ hour); M_1, M_2, M_3 represents the reduction of labor cost, maintenance cost and material cost respectively (ten thousand yuan/year).

III. Case Study of Zhoushan Port

3.1. Brief introduction

Zhoushan VTS has been in service since 2003. However, with the expansion of terminals /waterways and the construction of national major transport infrastructures in the water of Zhejiang province, such as Jintang Bridge, the supervision to improve the safety of the traffic has become increasingly difficult. To solve this problem, Zhejiang Maritime Safety Administration had expanded the Zhoushan VTS and the expanded VTS has been in service since 2010. To calculate the benefit of the expanded VTS, an investigation was performed in the Zhoushan Maritime Safety Administration during July and August in 2013. Much data before (2003-2009) and after (2010-2012) the expansion of the VTS had been collected, such as the traffic flow and cargo throughput per year(figure 3), the number of accidents and loss of accidents per year (figure 4), the number of risks effectively avoided per year, the quantity of spilled oil in each accident (table 1) et al. Besides, the circumstances of ship night/fog navigation capacity and the use of coastal patrol vessels were also consulted with the VTS operators and coastal patrol personnel.

3.2. Data Description

3.1.1st Traffic flow, cargo throughput, accidents and spilled oil

As shown in figure 3, the traffic flow and cargo throughput of the Zhoushan port have increased rapidly in the 10 year period. In figure 4, before the expansion of VTS, the total amount of traffic accidents per year fluctuated around 50 and there was an upward trend in the annual loss of the accidents. After reconstructing, both total amount of accidents and loss of accident per year is indicating a downward trend. Besides, according to the monthly running assessment report of Zhoushan VTS, the average number of risks effectively increased by 464 per year and the average loss of each serious/major injury accident, minor-injury accident, and property damage accident is about 500 thousand yuan, 200 thousand yuan and 10 thousand yuan. In addition, after the running of the reconstructed VTS, no oil spill accident has occurred.

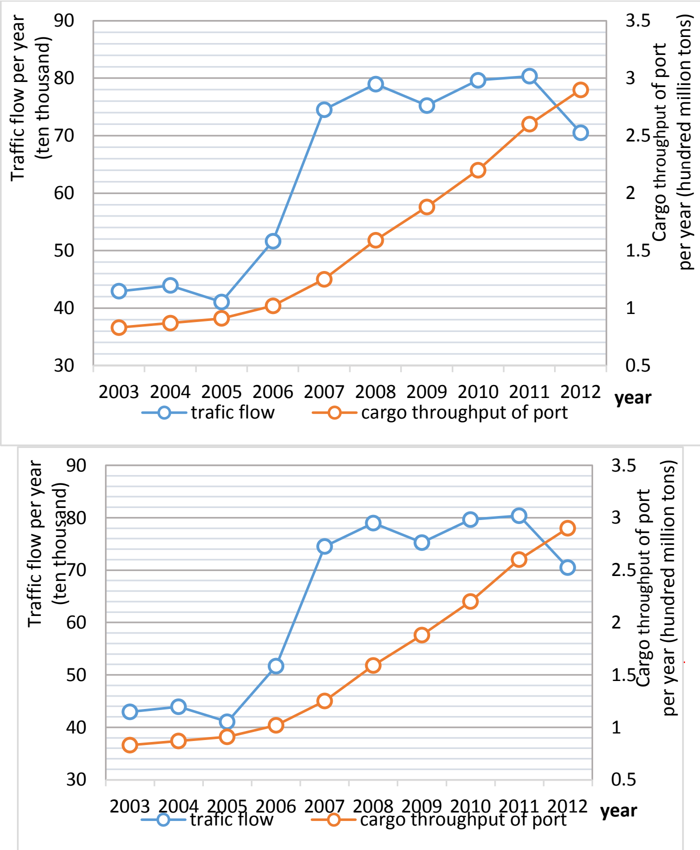
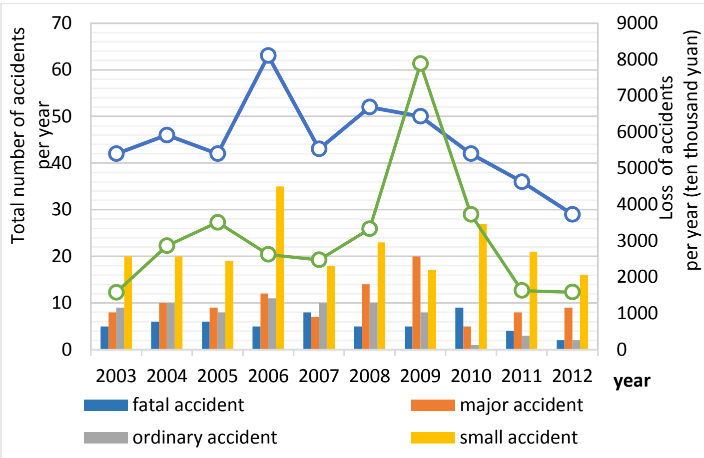


Figure 3: The statistic of traffic flow and cargo throughput per year



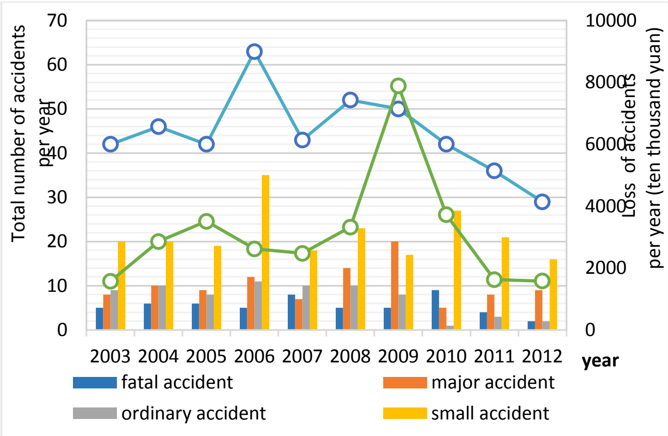


Figure 4: The statistic of accidents and the loss per year

3.2. 2nd Transit capacity and supervising cost

There are on average 60 foggy days per year with visibility less than 1 kilometer in the Zhoushan Port and the fog lasts about 2.5 hours each time. After the running of reconstructed VTS, about 0.1% of vessels can be navigated normally on each foggy day. Besides, only after the expansion of the VTS, 10 thousand-tons and above ships are allowed to navigate at night. Consulting with Zhoushan VTS operators, there are on average 350 large-scale ships (10 thousand-ton or above) passing through Zhoushan port. In addition, by providing information services, navigational assistance services and traffic organization services, the time of 10% goods passing through the port can be reduced by 30 min per ten thousand tons. According to cruise records of Zhoushan Maritime Safety Administration, each cruise costs about 3.37h and can correct approximate 0.38 illegal acts of ships. The fuel fee, labor cost and material expense et al in each cruise was 1.02 thousand yuan per hour and the average maintenance cost of patrolling vessels was 0.17 thousand yuan in each cruise. Based on the running effect report of Zhoushan VTS, the number of illegal acts corrected has increased by 684.67 per year after the expansion of the VTS.

3.3. Calculation and Cost benefit analysis

The demurrage cost of one ton goods is one dollar per day (consulting the agents) and 1 dollar is equal to 7.91 yuan (according to the dollar exchange rate announced by the bank of China before the expansion of VTS). Putting all this data into equations (1)-(3) and (5)-(6), the average benefit of expansion of VTS per year in 2010-2012 is shown in table 2. Cost benefit analysis is a method to evaluate the efficiency of projects with its resource allocation by using the discounted value of the costs and benefits. Since firstly applied by USA in 1936, the method has been accepted by governments and played an important role in decision-making in developing countries (Chen, 2014). Cost benefit analysis has many evaluation indicators, considering the long-term influence of the VTS, benefit-cost ratio (B/C) is chosen as the evaluation basis to judging the economic feasibility of the expansion of Zhou Shan VTS. In the process of system decision, if B/C>1, the program is considered to be feasible. Table 10 shows the summarization of the average benefits of Zhoushan expanded VTS per year.

The total investment of the expansion of Zhoushan VTS is 24.9455 million yuan and the average maintenance costs per year is 2.93505 million yuan. According to the cost benefit analysis, the benefit-cost ratio (B/C) is equal to 5.248>1, indicating that the expansion benefit of the VTS is considerable.

Table 1: Average Benefit of Expansion of VTS per year in 2010-2012

category of benefits	sub-benefits	benefits(ten thousand yuan/year)		Percentage
Safety benefit	reducing accidents	1428.627	1761.160	29.83%
	avoiding potential accidents	332.533		
Efficiency benefit	improving channel transit capacity	226.392	1597.694	27.06%
	improving ship fog navigation capacity	679.177		
	improving ship night navigation capacity	692.125		
Environmental benefit	reducing loss of oil spill accidents	1895.091		32.10%
Reducing supervising cost benefit	reducing the use of patrol vessels	649.965		11.01%
total	——	5903.910		100%

IV. Discussion

As can be seen in table 10, the environmental protection benefit produced by the expansion of VTS is maximum, which occupied 32.10%, the safety benefit comes second (29.83%), followed by efficiency benefit (27.06%). The reducing supervising cost is lowest, reaching 11.01%.

When calculating the benefits quantitatively, the traffic condition before the construction (expansion) of the VTS acts as a benchmark. What should be pointed out is that the framework is on the premise that there is no significant changes in other department of the Maritime Safety Administration which also have an influence on the traffic in the water. If big adjustments have occurred during the running of the VTS, which leads to the great changes of influence to the water traffic, the effect of other departments should be taken into consideration. Besides, the indicators of the benefits in the framework can basically represent the direct benefits produced by VTS. However, the indirect benefits (such as the promotion for the waterway transportation, which further drives the development of other industries) need further analysis as they involve a number of different industries.

V. Conclusion

In this paper, we present a framework to calculate the benefits of VTS in China. Four key indicators (safety, traffic efficiency, environmental protection and reducing supervising cost) and quantitative methods have been introduced into the framework. For case study, the project of expansion of VTS in Zhoushan Port, East China was evaluated with the 10-year data. According to the results, the following conclusions are made: (1) The expansion of VTS contributes most to the protection of the environment; (2) Cost-benefit analysis indicates the benefits of the expansion of VTS are considerable. The research could provide references for VTS benefits evaluation and investment optimizing.

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