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Optimization of shift work in VTS

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Optimization of Shift Work in VTS

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Declaration

I certify that all the material in this dissertation that are not my own work have 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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All the way sweat, all the way fragrance!

Abstract

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Vessel Traffic Services (VTS) provides a significant additional safeguard to vessel navigating in VTS area on a 24/7 basis, which has been proved to be an effective means to guarantee the navigation safety of vessels, improve the navigation efficiency of vessels and prevent marine environmental pollution in the busy and complex waters. As the core element of VTS service, VTS Operators (VTSO) must work on shift work. However, the nature of shift work is contrary to the natural rhythm of human beings, which is the main cause of fatigue of VTSO. Fatigue has a negative impact on both the physical and mental health of the duty personnel and the quality of VTS service. However, any hazards and risks can be eliminated or controlled by taking certain measures. Therefore, it is very important to study how to optimize shift work to eliminate the negative effects of fatigue.

Finding the problem is the premise to solve the problem. At present, the negative impact of VTS shift work has not been fully and accurately realized due to the lack of intuitive and effective way to evaluate the rationality of shift work. Based on the analysis of related factors affecting VTS shift work, an evaluation system of shift work by using Fuzzy Comprehensive Evaluation (FCE) and Analytic Hierarchy Process (AHP) methods was established in this paper. The weight of evaluation factor was determined, which enable the VTS managers to achieve a much more effective adjustment plan when optimizing VTS shift work. In addition, an evaluation system of the rationality of shift work was established. This paper takes Zhuhai VTS Center as an example to make an empirical analysis and verify the established evaluation system. And the results turn to be satisfying. Finally, some suggestions are put forward to improve the risk management of VTS shift work.

KEY WORDS: Shift work, Fatigue, VTS Operator, AHP, FCE, Attribution Degree

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List of Abbreviations

AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
ATC	Air Traffic Controller
CR	Consistency Ratio
ECDIS	Electronic Chart Display and Information System
FCE	Fuzzy Comprehensive Evaluation
HSE	Health and Safety Executive
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ILO	International Labor Organization
MIAVTS	Measures for Internal Administration of Vessel Traffic System of China MSA
MRCC	Maritime Rescue Coordination Center
MSA	Maritime Safety Administration
RI	Random Consistency Index
SAR	Search and Rescue
SOLAS	International Convention for Safety of Life at Sea
VTS	Vessel Traffic Service
VTSO	Vessel Traffic Service Operators

Chapter 1 Introduction

1.1 Background

VTS is recognized internationally as a navigational safety measure and play an increasingly important role in maritime safety and marine pollution prevention from ships. The provisions in SOLAS Chapter V Regulation 12 states that VTS contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment, adjacent shore areas, work sites and offshore installations from possible adverse effects of maritime traffic. VTS is unlike other marine aids to navigation, which is capable of interacting and influencing the decision-making process on board the vessel in a proactive way. For example, VTS might detect the development of a vessel standing into danger, and can thus alert such vessels accordingly (International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) , 2021). As the majority of maritime accidents can be attributed to human factors, the involvement of VTS, and interaction with it, can provide a significant additional safeguard. Where an incident has occurred, VTS can also be used to support other incident mitigation operations. As a result of the improvements in efficiency, safety and the reduction of potential environmental pollution experienced by authorities using a VTS, together with the rapid developments in computer technology, the number of VTS type operations has increased considerably. By now, there are now well over 500 of these services operating worldwide. The main difference between VTS and traditional aids to navigation is the involvement of

VTS operators. Due to the continuous operation of sea transport around the clock, almost all the VTS around the world is available 24/7. It means the VTS officer have to do shift and night work on a regular basis.

Shift work was described as a method of organization of working time in which workers succeed one another at the workplace so that the establishment can operate longer than the hours of work of individual workers at different daily and night hours by the International Labor Organization (ILO) (1990). Shift work has been a public health issue since 1870s(Härmä,2008). In addition, with the development of social economy and the demand of consumers for 24-hour service, shift work has become the main work system in many industries. The prevalence of shift work in the United States is nearly 28%. In China, 30% of the workforce is in shift work, and the number continues to grow rapidly (Yu, 2019). Researches on shift work had never stopped in various sectors where shift work exists, with an aim to mitigate the negative effect caused by shift work. Health and Safety Executive (HSE), an independent regulator of Great Britain with a mission to prevent work-related death, injury and ill health (HSE, 2021), listed in its publication Managing Shift work the undesirable consequences from shift work as follows, Disruption of the internal body clock; Fatigue; Sleeping difficulties; Disturbed appetite and digestion; Reliance on sedatives and/or stimulants; Social and domestic problems. Some researches tried to reveal the reasons why shift works have an impact on the worker performance outcome from a biochemical perspective. Mariana and Claudia (2016) concluded that circadian disruption resulting from irregular sleep-wake cycles and acute melatonin suppression by exposure to light at night are the two reasons explaining the high health risk of diseases for rotating shift worker. Pedram et al. (2019) found the rotating-shift workers on night shifts had greater light exposure and lower urinary melatonin levels during the night compared with day-shift workers. Meanwhile, better alignment of rotating shift work and chronotype appeared to produce less impact on circadian system (Pedram, 2019). In 2007, the International Agency for Research in Cancer (IARC) declared that shift work involving circadian disruption is a probable carcinogen, citing robust evidence from animal studies which have strongly suggested that circadian disruption is associated with faster tumor growth rates. Jessica et al. (2020) emphasized by reviewing plenty of research reports on this issue that the impact of shift work not only negatively impacts their own neurocognitive performance but also pose threat to the public safety by drowsy driving and medical errors.

Meanwhile, some researchers found that the longer you worked in shift work, the more your health suffered. A recent study published in the American Journal of Preventive Medicine reported that female nurses working rotating night shifts for 5 or more years could be at an increased risk of all-cause and cardiovascular disease mortality. In addition, working rotating night shifts for 15 years or more was found to potentially raise the risk of lung cancer mortality (McIntosh, 2016). Accumulating data from epidemiologic studies of humans suggest probable links between people who work rotating night shifts for 20-30 years and increased risk of cancer, most notably breast cancer in females and prostate cancer in males. Shantha et al. (2013) introduced to what extent the shift work increases risk of occupational accidents quantitatively. They stated that risk of occupational accidents was at least 60% higher for non-day shift workers. Road and workplace accidents to which shift work contribute significantly are estimated to cost $71-$93 billion annually in the United States (Shantha, et al., 2013).

All the results of established evidence and reputable researches proved that the disruptions of circadian rhythm resulted from shift work can lead to fatigue and adverse health effects (HSA, 2012). Meanwhile, chronic fatigue is also a contributory factor to some long-term health problems. In addition, all the side effects resulting from shift work in turn can affect shift-workers' performance and increase the likelihood of errors and accidents.

1.2 Significance and Purpose of the Study

On the one hand, shift work has been found to be causal factor to such disasters as *Three Mile Island* (nuclear power station release) in 1979, *Bhopal* (chemical plant explosion) in 1984, *Challenger Space Shuttle* (rocket explosion) in 1986, *Chernobyl* (nuclear power station release) in 1986, *Clapham Junction* (rail crash) in 1988, *Exxon Valdex* (ship oil spill) in 1989 and the *Buncefield* (oil refinery explosion) in 2005. (Yu, 1997; HSE, 2006; HSA, 2012) On the other hand, as the role of VTS is very technical and highly specialized, these undesirable effects from shift work could be exponentially increased where VTS personnel must keep alert and concentrate fully on the traffic monitoring (IALA, 2009). Despite of the damage to VTSO's health as well as maritime safety in VTS Area resulting from shift work, limited researches were conducted on VTS. Two reasons may account for that. First of all, there are no more than 10 thousand VTSO around the world, of which the number is much smaller compared with a number of 28 million nurses worldwide (Jr, 2020). Hence, the profession of VTSO is rarely known because of its low social and life relevance. Furthermore, most of the VTSO around the world are civil servants whose salary and welfare are relatively stable, and resignation rate is in the lower level compared with other professions, and they have to comply with the work arrangement as MSA staff even if they are assigned to do shift work, rather than out of personal preference. In this context, the impact of shift work on VTSO has been ignored easily. However, the gigantic trend of vessels and increasing complexity of traffic at sea caused by continuing exploitation of marine resources led to an increasing application of VTS system. Some casualties happened in VTS area have been reminding us of the negligence of fatigue of VTS operators. *Sewol* ferry sank in Jindo VTS area on April 16 in 2014, VTSO were imprisoned after being claimed to be guilty of not monitoring the passenger ship properly. The public prosecutor found the regulation about watching in which two VTSO are required to be on duty was not complied with, there is only one VTS operator on duty. VTSO complained that working 24 hours including the night shift in three days was too hard. Capsized *Eastern Star* ferry in Yueyang VTS area at the night of June 1 in 2015 caused a death toll of up to 442, the VTS supervisor at night shift was dismissed because of not tracking the ferry continuously (The State Council Investigation Team, 2015). Such Damocles Sword of malfeasance faced by VTSO also exacerbated VTSO's fear of shift work. Research and optimization of shift work is beneficial to eliminate their fear of shift work.

The quality of VTS is highly determined by the performance of the VTSO who are suffering the undesirable impacts from shift work. Therefore, not only is the health of VTSO but also the maritime safety of sea area covered by VTS are affected by the shift work. There are many different shift patterns and each pattern has different features. The diversity of job and workplaces indicates that there is no single one optimal shift system can be used in all industries (Knauth, 1993; HSE, 2006). Therefore, the VTS shift patterns vary a lot worldwide. Research on how to optimize shift arrangement can effectively reduce and control the risks caused by shift work.

VTS is usually established in waters with complicated traffic flow to reduce the safety risk of ship navigation, which means that once an accident happens in VTS Area, it would exert great influence. The performance of VTSO directly determines the quality of VTS. Therefore, it is very important to manage the risks of shift work in VTS to ensure the navigation safety in the VTS area. Meanwhile, with the increasing importance of the role VTS playing in modern maritime supervision, most of VTSO are being stretched to breaking point. However, workload is not the lower the better. VTSO in underload can also be liable to errors as compared with VTSO in overload (Costa, 1995; Komadina, 2011). Due to the workload of VTSO is dynamic with the traffic situation. Periodic review on shift work arrangement in VTS should be kept by VTS authority with an aim not only to reduce the fatigue of VTSO but also to optimize the allocation of human resource in MSA.

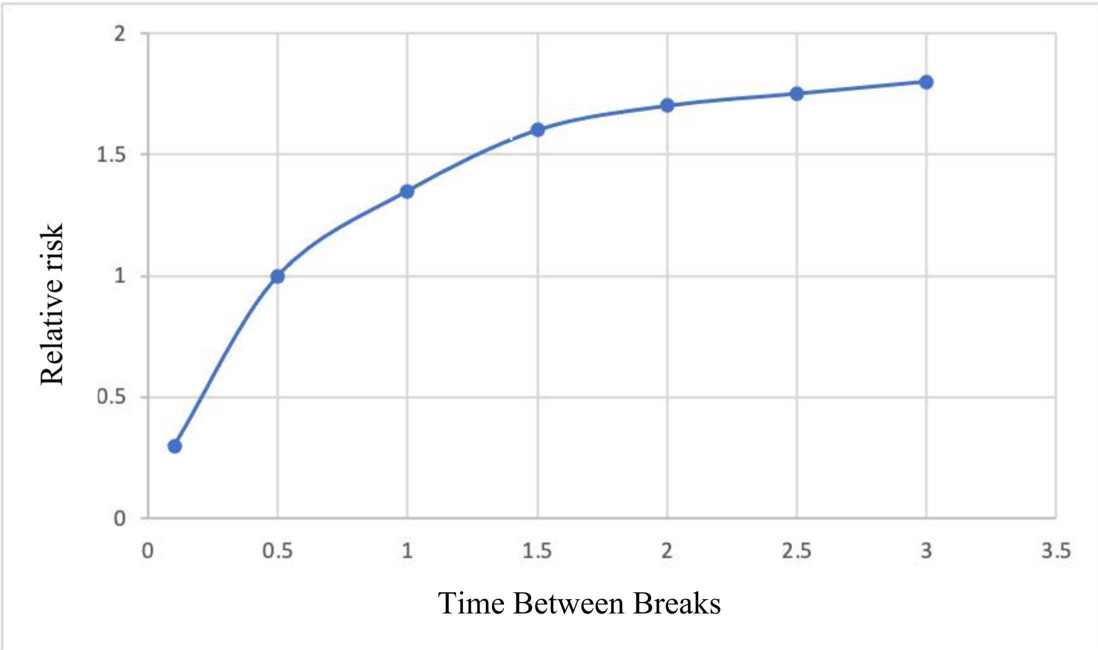

Figure 1.1: **Relative Risk of Continuous Periods Between Breaks.**

Source from: HSE (2006)

According to the formation mechanism of fatigue, some fatigue will disappear after a period of rest, this physiological fatigue can be restored. There is no strict boundary between pathological fatigue and physiological fatigue. One biochemical explanation for fatigue is that our metabolism activity would produce lactic acid, and non-protein nitrogen, and the productivity speed of such fatigue materials is always higher than the absorbing speed except when we are having a rest. When accumulation of such lactic acid reaches to the threshold of fatigue, the body will feel tired. In addition, if the fatigue materials are constantly higher than the threshold, the time to absorb them is greatly extended. Figure 1.1 also shows it is important to have rest to avoid fatigue. This rule suggests that people should not rest when they feel tired (Liu, 2015). In the case of high working intensity, substances such as lactic acid are produced at a faster rate in terms of energy consumption per unit time. VTSO is generally considered one of the working groups dealing with highly demanding jobs. The provision of VTS consumes the VTSO's energy resources quickly, while rest is the most important way to restore and supplement resources. In this context, the fast shift mode is more suitable for the high-intensive VTS center. However, fast shifts affect the frequency of commuting and utilization of VTSO's free time. On the one hand, commuting is also a factor in increasing the fatigue of VTSO. On the other hand, many duty workers prefer to save up their rest time in order to leave earlier and have a long period break. The HSE study (2006) also confirms this. However, this will not only aggravate their own fatigue, but also affect the VTS safety supervision work. A balance should therefore be found between opposing influences. So, a balance must be clinched between competing scientific inferences and the subjective wishes of the VTSO.

Due to circadian rhythms, people have significantly more energy resource during the day than at night. In addition, the workload of night shift for the VTSO is at least the same as day shift because the traffic is continuing and the higher possibility of accident due to poor visibility at night and fatigue of seafarers. Statistics show the probability of maritime accident at night accounts for 2/3 of the total, which makes the shift work in VTS different from other sectors in terms of the workload distribution among shifts. Therefore, the duration of a night shift should be shorter than that of a morning shift and an afternoon shift. At present, night shift in most domestic VTS Centers is even longer than the morning shift and day shift. Shipowner or shipmaster think there is less likely for VTSO to stop their delinquent behaviors at night than at day. Therefore, it is very common that these ships who are committing illegal acts such as overloading, switching off AIS or tampering with AIS information etc. prefer to pass through the VTS area at night in order to avoid maritime supervision. Illegal acts such as switching off AIS not only affect their own safety, but also increases the difficulty of collision prevention for ships nearby.

1.3 Research Status About Shift Work

Much of the current research tried to corelate the Eye Movements, Heart Rate as well as other physiological factors with the fatigue level of VTSO. For example, Serdar and Masao (2014) and Fan et al. (2020) developed approach to assessing the mental workload of VTSO through observation of their eye movement. Serdar and Masao (2014) concluded the effects of different factors on VTSO's workload through a combining measurement of VTSO's eye movement and heart rate as well as the fatigue level of VTSO by utilizing land NASA Task Load Index which is a popular subjective measure used in Air Traffic Controller. All the research identified the major factors affecting the VTSO's fatigue, and recommendations on how to manage fatigue risks were proposed based on their findings.

HSE (2006) systematically studied the elements of shift patterns and proposed systematic approach to assess and better organize your shift work schedules (Table1.1). Moreover, plenty of good practices are shared to optimize the arrangement of shift work. For example, working hours per shift as well as the break between shifts should be controlled to reduce the accumulation of fatigue (International Labor Office, 2004). It was recommended that quickly rotating shift systems are preferable to slowly rotating ones, and permanent night shift work should be avoided (Peter,1993; HSE, 2012; International Labor Office, 2004).

Table 1.1: ***A Systematic Approach to Assessing and Managing Risks of Shift Work***

Step 1	Consider the risks of shift work and the benefits of effective management.	• What are the undesirable effects of shift work? • Consider the costs and benefits of effective management of shift work arrangements.
Step 2	Establish systems to manage the risks of shift work.	• Seek management commitment to control the risks of shift work. • Identify individuals responsible for shift-working arrangements. • Involve safety representatives and workers.
Step 3	Assess the risks associated with shift work in your workplace.	• Consider the risks that workers may be exposed to. • Establish who might be harmed by shift work. • Consult workers and their safety representatives.
Step 4	Take action to reduce these risks.	• Assess how severe the risks are and identify where improvements need to be made. • Improve the shift-work schedule. • Improve the workplace environment. • Apply good practice guidelines.
Step 5	Check and review your shift-work arrangements regularly.	• Implement a system for early reporting of problems associated with shift work. • Monitor alterations to shift-work

		schedules and/or work conditions. • Periodically review the effectiveness of your shift- working arrangements.
Source from: HSE (2006)		

Wiersma and Mastenbroek (1997) introduced situation awareness and a scoring system to measure the VTSO performance. Chen (2013) utilized AHP method to evaluate the relative weights of all standards used to assess whether the candidate is qualified as VTSO. However, training assessment standards are mainly focused on the instantaneous performance of the VTSO, and the assessment system established based on this analysis aims to assess whether the candidate is qualified as a VTS Operator or not after having completed the required courses. In this system, dynamic working conditions and cumulative fatigue that need to be considered, which have not been taken into consideration in actual shift work. Komadina(2011) hold methods developed for the aviation industry which can be useful for testing the VTS operators due to some relative similarities between the workload of the air traffic controllers and the VTS operators. Costa(1995) proposed an Air Traffic Controllers'(ATC) stress attenuation strategy aiming at managing the causes and consequences of stress according to the model of stress development process. Stress intervention at different levels were examined and recommended. Fan et al.(2020) also proposed a context-aware machine learning approach to reducing the average fatigue level of the team rather than the individuals. Moreover, an adaptive work arrangement algorithm and a novel fatigue prediction algorithm were designed to reduce risk of human fatigue.

Based on the causal factors found in different studies, a series of countermeasures are proposed to control the risks of shift work. ILO prescribes regular health-assessments and access to medical advice on work-related health concerns and rate of compensation that accounts for the peculiar nature of night work as well as adequate consultation with workers' representatives on matters relevant to night workers which should be complied with (ILO, 2004). Jaradat's findings suggest that several modifications should be undertaken to improve work facilities, limit working hours, and raise awareness among post-graduate resident physicians. Both Liu (2003), Amit as well as Mariana suggested to limit the secretion of melatonin by controlling ambient lighting in working places to reduce the effect of shift work. The National Institute for Occupational Safety and Health (2020) proposed the advice on the substance use for improving the sleep of shift workers. However, those substance like caffeine, alcohol, and other drugs would bring side effects on their health. Knauth (1993) recommended regular occupational training was helpful, and Centers for Disease Control and Prevention in US initiated an online training program to improve both the employer and employee awareness of the shift work. Many shift systems were also developed in different industries. ILO shared a shift system from American multinational chemical corporation for case study in its column for shift work. Bruce Oliver (2021) analyzed the 10-hour shifts are particularly well-suited to the variable workloads found in law enforcement agencies. Wu (2020) compared the existing duty arrangement of seafarers and analyzed their advantages and disadvantages. Some companies are engaged in provision of shift work solution and consultation services (Shiftwork Solutions, 2021). Those case studies need to be taken into consideration before proposing suggestions to improve occupational health of VTS operators.

1.4 Main Contents of the Study.

The rationality of VTS shift work is affected by many factors. The establishment of an evaluation model for the rationality of VTS shift work is conducive to the optimization of shift work. At the same time, the effects of various influencing factors on VTS shift work is quantitatively analyzed and evaluated in the model, which is helpful to determine the focus of shift work optimization. The main research contents of this paper are divided into five parts:

- Analysis of the adverse impacts of shift work in VTS and related research.
- Current status of VTS shift system and relevant regulations of domestic and abroad.
- Analysis of factors affecting VTS shift work.
- Comprehensive evaluation of influencing factors of VTS shift work based on relevant theories.
- The empirical analysis of the established comprehensive evaluation model was carried out to put forward relevant suggestions on the VTS shift work and the optimization of the evaluation model.

1.5 Research Methods

- Various factors affecting shift work of VTS were collected and classified through literature study.
- Interview the experts to confirm the collected factors affecting VTS shift work for analysis.
- Using the theory of AHP and FCE method to establish the evaluation model of VTS shift work.
- A case study was conducted through a questionnaire survey to verify the evaluation model constructed.
- Analyze the rationality evaluation model for VTS shift work, and put forward suggestions for improvement.

Chapter 2 Current Status of VTS Shift Work and Related Legislation

2.1 International Legislation and VTS Shift Work Abroad.

IALA have been responsible for developing the technical standards and recommendations of VTS, which is a kind of aids to navigation. Two instruments for VTS staffing were formulated. Guidelines on the Recruitment, Qualifications and Training of VTSO which was adopted by IMO through Resolution A.857(20) states that in planning and establishing a VTS (IMO, 1997), the Contracting Government(s) or the Competent Authority should ensure that the VTS Authority is provided with sufficient staff, appropriately qualified, suitably trained and capable of performing the tasks required. Guideline 1045 provides guidance to assist authorities in determining appropriate staffing levels for a VTS Center to ensure that the VTS operations can be carried out efficiently and safely under all conditions(IALA, 2018). Guideline 1045 analyzed the factors which would affect the workload of the VTSO and shared two formulas enable VTS competent authorities to calculate the number of the VTSO required for a VTS. However, the formulas were premised on the same working hours no matter they work in shifts or not. In other words, both the formulas did not take the impact of shift work into consideration appropriately. In addition, there is no recommendation on how to rotate the shifts in those guidelines. Shift systems are commonly regulated by collective agreements in many countries. For example, US department of Labor(2021) Fair Labor Standards stipulates that extra pay for working night shifts is a matter of agreement between the employer and the employee. However, dealing with the issue in a marketed-based way is not good solution as the human rights of.

Table 2.1: ***Shift Pattern in Bulgaria***

VTSO A	Day 1	Day2	Day 3	Day 4
Day shift (0700-1900)	A			
Night Shift (1900-0700)		A		
Rest			A	A
Source: the Author				

Table 2.2: ***Shift Pattern in Singapore***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Morning shift	A	A							
Afternoon shift			A	A					
Night Shift						A	A		
Rest					A			A	A
Source: the Author									

Information about the shift system in foreign VTS is hardly available in the Internet or in the reports and meeting proceeding of VTS committee of IALA. To collect the VTS shift systems of other countries, I had written 34 letters to the representatives of VTS symposiums and meetings, and the emails of those attendants can be obtained from the reports of meetings. And all the letters were sent on 20 April, as of today, I received 4 replying letters. Besides, I also collect such information from my colleagues and friends. Based on the information I collected, the shift patterns in different VTS Centers across the world varies a lot. For example, the shift patterns in Bulgaria(Table 2.1), Saudi Arabia and Brazil divided 24 hours evenly into two work shifts including Day shift and Night shift. VTSO works in rotating shift with a break of 24 hours between shifts. However, rotating shift cycles are different. Shift pattern for Bulgaria is on four days basis while Saudi Arabia on 3 days. While VTSO works twice in the night shift every week. Shift pattern in Singapore is a little complicated. Every 24 hours is evenly divided into Morning Shift, Afternoon Shift and Night Shift respectively, and during every shift, VTSO rotate among different work stations(Xu, 2020). VTSO in Singapore VTS work on a 9 days basis(Table 2.2). Fixed shift systems are applied in some countries, which is based on seniority. In other words, new hires often work the night shift (or the least desirable shift) and eventually work the afternoon or morning shift after they have stayed in the company for years(HSE, 2006). In addition, rotating among different workstations of which the workload vary a lot to reduce the fatigue of VTSO is widely applied in VTS Centers with multiple consoles. For example, VTSO in the Dover Strait as well as Singapore hands over operations to another operator frequently, where they have a worldwide reputation for being two of the busiest waterways in the world(Schuett, 2014).

2.2 VTS Shift Work Institutional Framework in China and Current Status.

In China, it is required that VTS Competent authorities should at least operate VTS in Five Working Groups, Three Shifts Pattern (Table 2.3) in Measures for Internal Administration of Vessel Traffic System of China MSA (MIAVTS) ratified in 2012. Consequently, on a no less than five-day basis, VTSO work 3 shifts including one Morning Shift, one Afternoon Shift and one Night Shift respectively. For VTS areas where the traffic flow are complex and heavy, Six Rotating Teams, Three Shifts Pattern (Table 2.4)or Six Rotating Teams, Four Shifts Pattern (Table 2.5) are recommended. The Shift Timing and shift rotation direction is now explicated in

MIAVTS. Some VTS Center rotate shifts in Forward-Rotating while some adopt Backward-Rotating. Although there is limited evidence for which one is the better, Knauth (1993), ILO (2004) and HSE (2006) all recommended Forward-rotating schedule in rotating shifts. With great change in maritime industry like the gigantic and high-speed trends of ships, more sea waters are exploited for other purpose, the traffic density and complexity are changing greater today than any other period of history. The side effects of recommended shift patterns in some VTS centers came to the fore with ages. Thus, shift work in VTS should be adjusted appropriately. Although the MIAVTS was still in force, Guidelines for VTS Watching was adopted by China MSA in 2017. In the Guidelines, no shift patterns were recommended, and VTS competent authority is responsible to design the shift system according to its situation. However, there are more principles should be complied with when VTS competent authorities arrange their shift systems. Those principles include continuous duty time of VTSO should not exceed 4 hours, and the cumulative duty time per day should not exceed 10 hours, and VTSO shall have no less than 10 hours of rest in any 24-hour period. Meanwhile, the Guidelines also set requirements on staffing level. Each shift should staff with VTS supervisor, VTS operator and VTS Information officer who is responsible for information collection, management, statistics, analysis and archiving. In addition, six VTSO should be provided for each workstation in the VTS center. For those VTS Centers composed of less than 4 workstations, at least 1 information officer shall be staffed in the shift; If a VTS center is equipped with 4 or more workstations, each shift shall have at least 2 information clerks, and the number of information officers can be increased according to the need of actual work. Generally, VTS information officer enable VTSO a rest break within shift without violating the requirement of no more than 4 consecutive hours.

Table 2.3: ***Five Rotating Teams, Three Shifts***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5
Morning shift	A				
Afternoon shift		A			
Night Shift			A		
Rest				A	A
Source: the author					

Table 2.4: ***Six Rotating Teams, Three Shifts***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Morning Shift	A					
Afternoon Shift		A				
Night Shift			A			
Rest				A	A	A
Source: the author						

Table 2.5: ***Six Rotating Teams, Four Shifts Pattern***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Morning Shift	A					
Afternoon Shift		A				
Evening Shift			A			
Night Shift				A		
Rest					A	A
Source: the author						

In China, more than 50 VTS centers were established in the past four decades which cover almost all the coastal area of the mainland. Today there are 1100 VTSO working in shifts to provide vessel traffic services. The VTS shift patterns in China also vary a lot. Most big VTS centers with multiple VTS workstations do not apply the shift pattern recommended in the MIAVTS, and the shift patterns are also very complex. Guangzhou VTS are considered as one of the busiest VTS in China, there are six shifts within 24 hours and a total of five rotating teams, each of which consists of eight VTSO (Table 2.6). The VTSO in Guangzhou VTS works 24 hours every eight days. Shanghai VTS is also providing vessel traffic services in high traffic density water, and their shift pattern is a combination of fixed shift and rotating shift. VTSO always rotate shift on a 3 days basis. In other words, they work eight hours on Day 1 and have two days for rest. However, VTSO work at the same shift within a month, next month VTSO rotates to another shift and the shift cycles every three months (Table 2.7). Some VTS Centers along Yangtze River like Zhangjiagang operate in Six Teams, Six shifts. VTSO works 24 hours in four days followed with 2 days break (Table 2.8).

Table 2.6: ***Shift Pattern in Guangzhou VTS***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
2340-0340	A							
0340-0740				A				
0740-1200			A					
1200-1600	A							
1600-2000			A					
2000-2340		A						
Rest					A	A	A	A
Source: the author								

Table 2.7: ***Shift Pattern in Shanghai VTS***

	Month 1			Month 2			Month 3		
VTSO A	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3

0000-0400	A								
0400-0800				A					
0800-1200							A		
1200-1600	A								
1600-2000				A					
2000-2400							A		
Rest		A	A		A	A		A	A
Source: the author									

Table 2.8: ***Shift Pattern in Zhangjiagang VTS***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
0000-0730				A		
0730-1030		A				
1030-1400	A					
1400-1730			A			
1730-2100	A					
2100-2400		A				
Rest					A	A
Source: the author						

2.3 Problems Existing in the Current Shift System.

First, it is common that staffing level are lower than requirement. On the one hand, some VTS centers are staffed with insufficient VTSO. Statistics show that there were 907 VTSO as of the beginning of 2021with the VTS manager, VTS Supervisor as well as VTS Information Officer. Currently, there are 174 VTS workstations in China, excluding Hong Kong, Macao and Taiwan. There is a shortfall of 137 VTSO in China VTS Centers according to the requirements of MIAVTS that at least 6 VTSO for each workstation. On the other hand, VTSO are required to be certificated after completing a series of training courses. However, not all the VTSO in China received VTSO Certificates. 753 VTSO are certified, taking up 83.02% of the total VTSO in China. There are 284 VTS Supervisors in China and 248 of them hold the certificate for VTS Supervisor, with a certificate rate of 87.32%. In addition, most of the VTS centers in China also assume the responsibility of Search and Rescue coordination, and Search and Rescue (SAR) coordination is very highly demanding work. VTSO have to conduct SAR coordination while providing vessel traffic service. SAR coordination carried by VTSO turns to be more efficient and effective because they have a better picture of the available SAR Units and more reasonable SAR route. However, the SAR coordination significantly increases the fatigue of the personnel on duty. Although many MSAs have allocated full-time SAR coordination staffs, they do not participate in shift work and can only assist or take over the SAR coordination when emergencies happened during the normal working hours (0900-1700) in workdays. Distress situations occurring outside the working hours are generally handled by VTSO in shift work.

Secondly, fatigue of VTSO in China was not fully considered. On the one hand, there is scarce research on risk management of VTS shift work, and VTS managers who are responsible for shift work arrangement have limited information about fatigue to refer to when designing shift patterns. Either imitating the shift work with similar background or adopting the recommended shift patterns in MIAVTS directly without any adjustments. That is why shift pattern of Three shifts Five Rotating Teams are still the most popular shift patterns. On the other hand, traditional Chinese culture encourages hard work and dedication. As a result, VTSO would force themselves to continue their tasks rather than ask for a leave even if they feel exhausted, because they worry that such a leave would impress their leader with poor flexibility which is a vital criterion for promotion, which makes the fatigue even worse. VTS as a division of MSA in China, compared with other departments, the turnover rate in VTS is much lower than other departments (Hu, 2008). Statistics in 2018 (Figure 2.1) showed that 42% of VTSO have been working more than 5 years. Hu (2008), Qiu (2016) and Ning (2019) concluded that most of the staffs in MSA are unwilling to work in VTS because of the shift work.

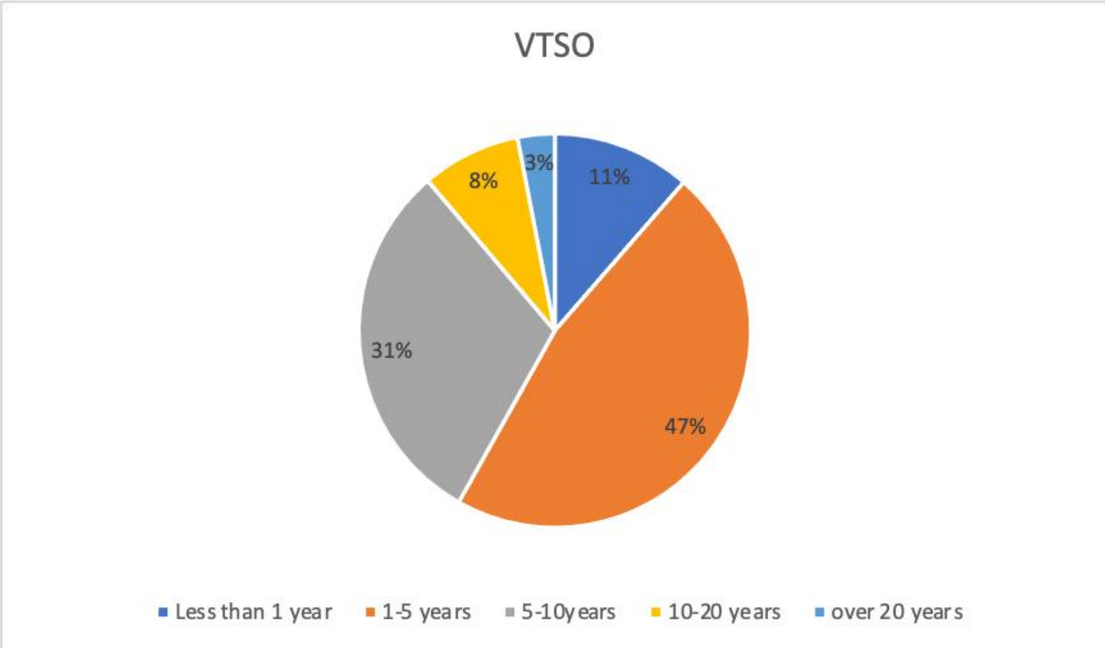

Figure 2.1: **Distribution of VTSO Based on Working Years in VTS.**

Source: the author

Thirdly, there are no effective internal assessment mechanism in most VTS Centers. On the one hand, intuitively, it is the ship master who should always be responsible for the safety of ship. Even if the accident happened in VTS area, VTSO should not be held responsible due to the nature of VTSO's work. Zhao (2014) and Liu (2019) were of the view that the VTSO should not be claimed to be liable for accidents in VTS area. Wiersma and Mastenbroek (1997) also reckoned that the role of the VTSO in traffic was more of informing and advising rather than controlling, as ships had a large freedom to accept or reject orders from the VTSO. Zhao and Sui (2012) conducted a nomological analysis of functional crime of negligence in VTS and concluded that the VTSO functional negligence indirectly results in the causal outcome, so it cannot be attributed to the crime of dereliction owing to the objective capacity. On the other hand, the VTS Centers are required to investigate accidents occurring in the VTS area. In this process, whether the VTSO performed correctly at the time of accident and the operation of VTS complied with regulations should be assessed. However, the investigation was usually conducted by staffs in VTS Center. They tend to focus on external causes rather than internal ones. Because they can do little to improve the performance of VTSO who are always in fatigue. From the 7 internal investigation reports of accidents in Guangdong VTS Area (including 6 VTS centers and 18 VTS workstations) in the past 3 years we can see, human factors of VTSO were not assessed properly.

Chapter 3 Introduction of AHP and FCE

To conclude, shift work is the main cause of fatigue in VTSO. Shift work is influenced by many factors, and these factors can interact and interfere with each other, giving rise to not only possible additive, but also subtractive effects (Costa, 1995). However, Certain factors can be relatively controlled because they are of an organizational nature (Komadina, 2011) Although there are many studies on shift work, there are limited research on managing the risk of shift work in VTS. Being aware of the risks of VTS shift work and being able to identify the main causes of these risks are the prerequisites for reducing the adverse impacts of VTS shift work. The factors affecting VTS shift work are analyzed and the effects of these factors are assessed through AHP and FCE methods in this dissertation.

3.1 Principle of AHP.

AHP is a systematic analysis method combining qualitative and quantitative analysis proposed by Prof. Thomas Saaty in the 1970s. AHP can determine the relative weight of a series of factors by hierarchizing mathematically the process of human subjective judgment, which provides a simple decision-making method for multi-attribute decision-making problems (Satty, 2012). Therefore, it is widely used in multi - objective decision - making problems. However, the AHP cannot fully take into account the uncertainty and inaccuracy of the decision maker in the analysis (Gong, 2021). At the same time, the fuzzy nature of qualitative evaluation indicators and the tendency of human evaluation were ignored in the implementation process, which affected the judgment results to a certain extent. The steps of AHP are as follows:

3.1.1 Analyze the Correlation and Attribution of Each Factor, and Establish the Hierarchical Structure Model. AHP attempts to decompose it layer by layer and deconstruct it layer by layer in a hierarchical form, which is often divided into target layer, criterion layer, index layer and so on.

3.1.2 Construct a Judgment Matrix for Pairwise Comparison. All factors under a same layer are compared pairwise to construct a judgment matrix. Values indicating comparative importance between two factors are generally assigned on a 1-9 scale (Table 3.1). If factor A1 is threefold important than factor A2, we mark A12 = 3 in the judgement matrix, while A2 is threefold important than A1 we mark A12 = 1/3 (Table 3.2). Judgment matrix is usually constructed by pairwise comparison by experts based on their mutual importance to the goal.

Table 3.1: ***The Fundamental Scale for Pair-wise Comparisons***

Intensity of importance	**Definition**	**Explanation**
1	Same	Neither of the two alternatives is preferable over the other
3	Weak	One alternative is preferred slightly over the other
5	Clear	One alternative is preferred clearly over the other
7	Strong	One alternative is preferred strongly over the other
9	Very Strong	One alternative is preferred very strongly over the other

2, 4, 6, 8	Compromise	Can be used for graduation between evaluation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit
Source: Saaty, 2012		

Table 3.2: ***An Example of Pairwise Comparison in Judgement Matrix***

	A1	**A2**	**A3**
A1	1	1/3	
A2	3	1	
A3			1
Source: The Author			

3.1.3 Consistency Test of Matrix. As the judgment matrix involves the mutual comparison of multiple factors, experts are prone to make mistakes in grading. For example, in the grading process, they define that A1 is more important than A2, and A2 is more important than A3, while A3 was labeled more important than A1. Such logical error will directly lead to the discredit of assessment results. Therefore, it is necessary to test whether the constructed judgment matrix is seriously inconsistent in order to determine whether to accept the judgment matrix. Consistency test is usually carried out in the following steps:

3.1.3.1 Calculate Consistency Index (CI) through formula 3.1. In this formula, n represents the number of factors in the judgment matrix. λmax is the maximum eigenvalue of the matrix.

$$CI = \frac{\lambda max - n}{n-1} \quad (3.1)$$

3.1.3.2 Find the corresponding Random Consistency Index (RI) in Table 3.3. RI is a constant varies with n.

Table 3.3: ***Average Random Consistency Index (RI)***

Size of matrix (n)	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45
Source: Saaty, 2012									

3.1.3.3 Calculate the Consistency Ratio (CR), which is a comparison between CI and RI. If the value of CR is smaller than 0.1, the result is acceptable. If CR is bigger than 0.1, the subjective judgement should be revised.

$$CR = \frac{CI}{RI} \quad (3.2)$$

3.1.4 Calculate λmax. Sum-product method was adopted in this dissertation, and the specific steps are as follows:

3.1.4.1 The judgment matrix is normalized according to columns through formula 3.3.

$$\overline{U}_{ij} = \frac{U_{ij}}{\sum_{i=1}^{n} U_{kj}}, i, j = 1,2\ldots, n \quad (3.3)$$

3.1.4.2 The judgment matrix after normalization of each column is added according to rows through formula 3.4.

$$\overline{W}_i = \sum_{j=1}^{n} \overline{U}_{ij}, j = 1,2\ldots, n \quad (3.4)$$

3.1.4.3 Normalize the vector Wi through formula 3.5.

$$W = \frac{\overline{W}_i}{\sum_{j=1}^{n} \overline{W}_j}, j = 1,2\ldots, n \quad (3.5)$$

3.1.4.4 λmax was calculated through formula 3.6.

$$\lambda max = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}, i = 1,2\ldots, n \quad (3.6)$$

3.2 Principle of AHP-FCE.

FCE is a commonly used quantitative Evaluation method in the field of Fuzzy mathematics. It is able to make a reasonable comprehensive evaluation of the overall quality of things affected by a variety of factors. FCE takes full account of the subjective judgment, decision and ambiguity of preference itself, which makes the final decision more objective and reasonable (Ge, Fu, 2015). It is more consistent with people's conventional thinking habits and reasoning logic, so that when there are fuzzy phenomena and fuzzy concepts in the process of judgment, this method will be readily solved.

AHP-PCE method organically integrates the quantitative and objective advantages of AHP with the inclusiveness of FCE method. It can not only consider more comprehensive factors and minimize the subjective influence degree, but also better integrate expert's opinions into the decision-making process (Zhu, et al. 2006). The specific operation principle is firstly to calculate corresponding weights of factors through AHP method. This process is to compare the relative importance of factor in pairwise according to experts' expertise, and then combine the qualitative description results with AHP method to get the weight of each factor. Evaluation of the VTS shift work through a combination AHP-FCE method not only examines all the factors that affect the VTS shift work comprehensively and systematically, but also solves the fuzzy bottleneck in the evaluation process, and gives precise quantitative calculation to the factors. The basic steps of AHP-PCE method are as follows:

3.2.1 Identification of Factors Set.

The objectives to be evaluated should be determined based on our goals at first. Then, the factors that affecting the objectives should also be determined. If we mark the objective as U, supposing there are n factors under U, the indicators set could be expressed as $U = (U_1, U_2, \ldots U_n)$.

3.2.2 Establishment of Reviews Set.

We need to determine to which level the evaluation factors belong to. The levels of evaluation are generally an integer between 3 and 7. The level in specific research can be confirmed by experts according to the contents of the evaluation object and described in appropriate language. Five levels of evaluation set and three levels of evaluation set are commonly used. The reviews set with m levels can be expressed as $V = (V_1, V_2, \ldots V_m)$

3.2.3 Evaluate the Attribution Degree of Factors and Establish Fuzzy Matrix.

Attribution degree is to which level the factors to be evaluated conforms to a certain standard. Based on previously constructed factors set, review sets to carry on quantitative evaluation, evaluated factors is quantitatively determined one by one. Only if the evaluation standards of attribution degree for different levels were established, the attribution degree of evaluated factors can be determined. When all the attribution degree of all factors are determined, the fuzzy matrix is expressed as formula 3.7. r_{ij} in the fuzzy matrix R represents the attribution degree of the factor U_i to the fuzzy set of the V_j level.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (3.7)$$

3.2.4 Determine the Weight of Factors to Be Evaluated by AHP Method.

Determine the weight vector of all factors. The weight vector can reflect the importance of evaluated factors, that is, the attribution degree of each factor to the evaluated object. Generally, each evaluation factor is not equally important to the evaluated object. Determining the weight of all factors is one of the key steps of AHP-FCE model before comprehensive evaluation. AHP method was used in this evaluation model to determine the weight.

3.2.5 Calculate FCE Result.

To synthesize the factors weight "W" with their attribution degree "R", Comprehensive evaluation result was expressed as “B” which is the product of “W” multiplying “R” (Formula 3.8). In practice, the most commonly used method is the principle of maximum attribution degree, but the disadvantage of this method is that it is not suitable for use in some cases, a lot of information is lost, and even unreasonable evaluation results are obtained.

$$B = W \odot R = (W_1, W_2, W_3, \ldots W_n) \odot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = (b_1, b_2, \ldots b_m) \quad (3.8)$$

Chapter 4 Establishment of VTS Shift Work Rationality Assessment System

4.1 Identification of Factors Set of VTS Shift Work.

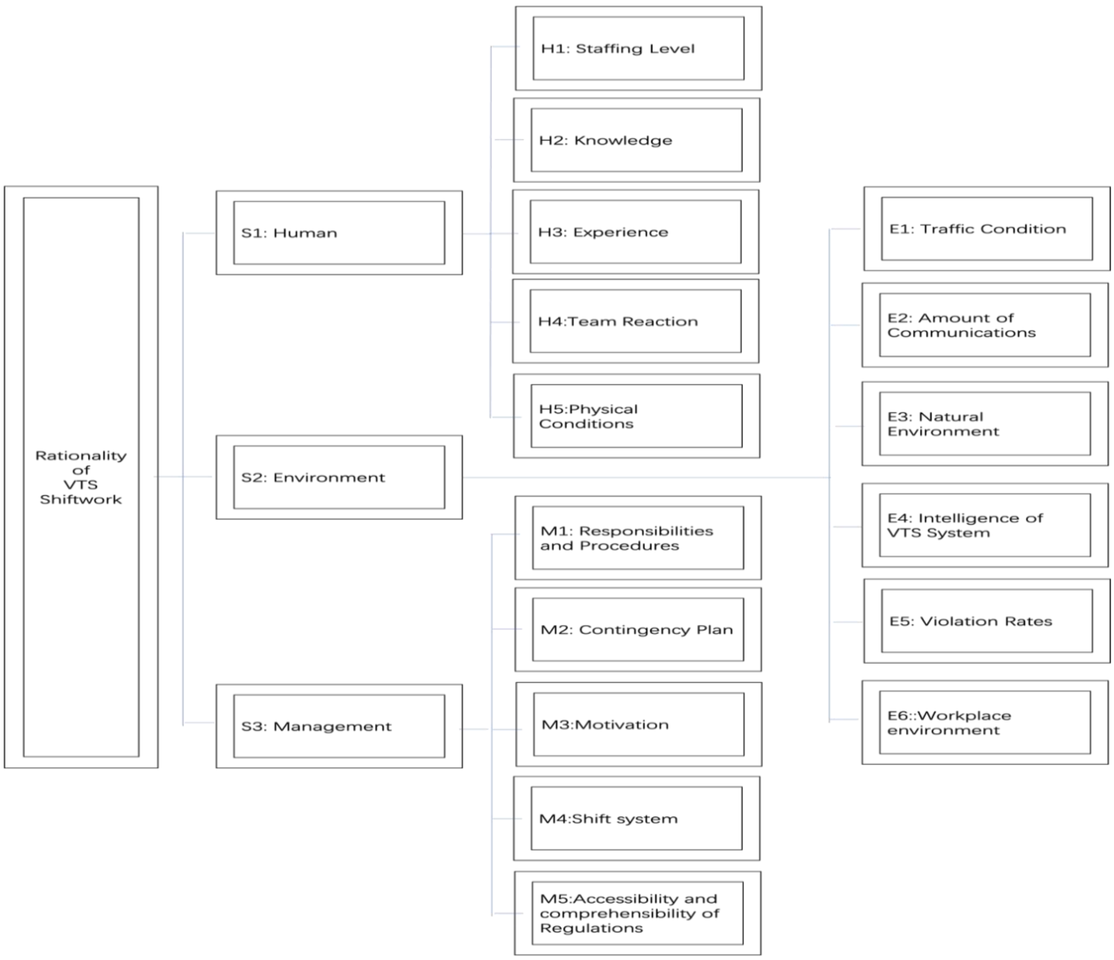

Figure 4.1 **Factors Set of VTS Shift Work.**

Source: the author

Whether the VTS shift work is reasonable or not is affected by many factors. Through literature research and consulting experts in the form of questionnaires, a total of six questionnaires were issued and six were withdrawn. Consistency tests were carried out for all questionnaires, and the results of consistency test were satisfactory. This dissertation proposes that the main factors affecting the shift mode can be divided into three parts: human, environment and management (Figure 4.1).

4.1.1 Human Factors.

Human factors are associated with staffing level in VTS center, knowledge, experience, teamwork and physical condition of VTSO. Workload and stress from work can vary from VTSO to VTSO.

4.1.1.1 Staffing Level.

Staffing level in the VTS plays a decisive role in VTS shift work design. IALA who is responsible for provision of the guidelines for operation of VTS only recommended one Possible Formula for Determining the Number of VTSO Required for Staffing a VTS Center in G1045(2018). However, the staffing level of VTS Centers in China were highly dependent on to what extent the emphasis was put on VTS by leadership of MSA, while emphasis degree was determined by how well they know about VTS. Statistics show only 40 % of VTS centers in China are staffed with sufficient VTSO as required. Even for those VTS centers with sufficient VTSO currently had experienced understaffing for a long time before they have sufficient staffing, as there is no effective periodic staffing level adjustment for most VTS centers. Such adjustment of staffing level is often triggered by marine accidents in VTS Area.

4.1.1.2 Knowledge.

VTS System consists of the latest technological equipment like radar, AIS, ECDIS, VHF and Meteorological equipment. Those devices enable VTSO to provide vessel traffic service to ships in VTS area. In other words, VTSO should have the basic knowledge of the equipment so that they can perceive the potential risk among ships, then they are capable of informing or warning or instructing the related ship to take consideration of the information they provided and take actions appropriately. To maintain the whole picture of dynamic traffic and respond immediately and correctly is a quite demanding job for the VTSO. Thus, sufficient knowledge is a necessity for a qualified VTSO. In order to ensure the qualification of the VTSO, IALA issued model courses like V-103 for the training and certification of VTS personnel in 1998.

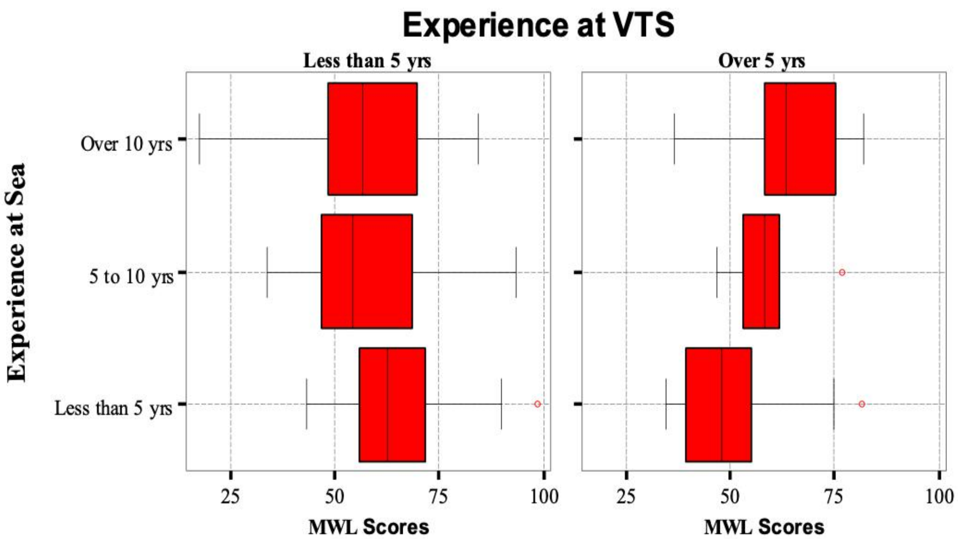

Figure 4.2: **Levels of VTSO Mental Workload Based on VTS Experience and Sea Experience.**

Source from Serdar Kum, 2014

4.1.1.3 Experience.

Both sea experience and experience at VTS make the VTSO have better situational awareness. Good situational awareness can improve the performance of VTSO and reduce their stress. Since VTSO works in teams, other team members can quickly learn and accumulate relevant experience if there is an experienced VTSO in their team. Some countries like China and Turkey require sea experience for VTSO to be employed because people with sea experience are reckoned to have better ability to predict the potential risk in their responsibility area. In addition, results from study conducted by Serdar and Masao (2014) showed that the VTSO with less experience had higher mental workload than those with more experience (Figure 4.2).

4.1.1.4 Teamwork.

Good team interaction can enhance understanding and trust among the teammates, as well as the sense of collective honor and belonging, and also reduce the stress of individual VTSO to a large extent. VTSO usually works on a team basis. It is hard for people with different professional knowledge background, personality, work experience and age etc. to work together in the most effective way. Reasonable personnel allocation can be a relatively stable state of organic connection. Academics generally believe that people who are homogeneous tend to have friction in the process of getting along, which makes it difficult to form complementary advantages to maintain the efficient operation of the team (Tang, 2020). Therefore, such an unscientific allocation of human resources should be avoided as possible. Teamwork has an impact on the effectiveness of shift work.

4.1.1.5 Physical Condition.

Keeping physically fit can resist the stress and illness (Roger, 1997). Physical conditions vary widely from person to person, and some people adapt well to shift work, while it is difficult for some others to adapt to it. However, individual personality is not taken into consideration in the recruitment of VTSO. In addition, the mental workload of VTSO might increase with age as Figure 4.2 shows that the mental workload of VTSO who have more than ten years sea experience as well as five years VTS experience have greater mental workload than others.

4.1.2 Environmental Factors.

Environmental factors in this dissertation not only relate to the physical environment of VTSO but also include the navigation environment in the VTS area where the VTSO interact through VTS system. Environmental factors consist of traffic condition, amount of communication, natural environment, intelligent level of VTS system, violation rate and workplace environment.

4.1.2.1 Traffic Condition.

It is common for VTSO to have a heavy workload due to the complexity of traffic conditions in their area of responsibility. Traffic speed, density, direction, and composition etc. all contribute to the stress of VTSO. Pylyshyn(2006) proposed the concept of Multiple Object Tracking (MOT) and found human was only able to track up to five moving objects simultaneously in the presence of distractors (Wang, 2013). VTSO are always tracking more than 5 objects despite the fact that the speed of target on the display was slow. However, there are always much more objects needing to be tracked. Traffic monitoring in area where the traffic condition is complex is physically and mentally demanding for VTSO.

4.1.2.2 Amount of Communication.

The vessel traffic services provided by VTSO are mainly delivered through VHF. They have to respond quickly to calls from ships and provide timely warning to the potential risks. VTSO often works close to the limits of their information processing capacity (Fan, 2020). In addition, the continuous noise from the radio telecommunication is very annoying. VTSO with higher amount of communication are prone to fatigue than others.

4.1.2.3 Natural Environment.

Natural environment has a huge impact on the safety navigation, which includes Aids to Navigation, waterway crossing points, shallow waters, reefs, and curvature radius of channel etc. In other words, the workload of VTSO is closely associated with the natural environment. In addition, the frequency of adverse climate such as poor visibility and wind also corelates with the workload of VTSO.

4.1.2.4 Intelligence of VTS System.

With the development of technology, more and more VTS systems have been upgraded with more intelligent risk analysis capabilities. By setting certain rules in the system, visual alarm or audio alarm will be activated when the vessel in VTS area violates the set rules, so as to remind VTSO to take timely measures to deal with the potential risks. For example, collision risks can be predicted by setting parameters such as CPA and TCPA. However, due to the existence of many tugs in VTS area, especially port VTS, and the high density of traffic flow, some combination of rules like tug exemption and area exemption should be set together with parameters like CPA and TCPA. Especially in the water area with high traffic density, the intelligent assistance of the system plays a very important role in traffic monitoring. Whether VTS system enable VTSO to adjust the rules fit for purpose is an important criterion of the intelligent level of VTS. However, most of the VTS systems equipped in China VTS Centers were imported from abroad, which made the upgrading and maintenance of the system difficult to meet regulatory requirements. At present, more and more VTS centers tend to replace the old VTS system with domestic VTS system when upgrading. In addition, the VTSO also assumes the responsibility of data collection. The higher intelligent VTS center enables data recording, storage and analysis of data automatically, while some VTS systems need a lot of manual input work. Therefore, the intelligence level of VTS system directly determines the workload of the VTSO on duty.

4.1.2.5 Violation Rates.

Violation in VTS area is usually a time-consuming task for VTSO, especially for violations like AIS switch-offs deliberately and not maintaining a watch on assigned VHF. In general, VTSO relies heavily on the AIS to identify the vessel's activity at sea, VTSO would spend much time to track and identify by dispatching the patrol vessel or asking the passing by vessel once the ship switch off the AIS. Those ships who don't maintain a VHF watch also cost VTSO lots of time. Because the AIS and VHF are the eyes and hands of VTSO which enable them to respond to the traffic timely. Violation rates in different VTS areas vary with how strictly and effectively the regulations are enforced. Those VTS centers which can correct the violations effectively always have a lower violation rate. In this context, VTSO won't spend more resources on violation corrections. Therefore, the violation rate also affects the workload of VTSO.

4.1.2.6 Workplace Environment.

Poor working environment adds to the strain of shift work (Roger, 1997). Workplace environment proves important to the fatigue of VTSO who have to sit in front of the operating consoles for hours. How are the equipment ergonomics, layout, temperature, lighting, humidity, cleanliness of the workplace etc. designed and noise control have a significant impact on VTSO’s fatigue. Workplace environment should also enable VTSO to have a good rest during the break within shifts.

4.1.3 Management Factors.

How a VTS center and VTS-related organization are managed can have both positive and negative impact on the overall work environment. These factors may potentially lead to increased stress and workload, uncertainty in job expectations and job security (IALA, 2009). Management factors include the Responsibilities and Procedures of the VTS, Contingency plans, Motivations, Shift patterns, and Accessibility and Comprehensibility of Regulations.

4.1.3.1 Responsibilities and Procedures.

Clear responsibilities of VTSO and working procedures for various tasks can make VTSO have a good picture of their work. As long as VTSO do what they should do stipulated in the instrument, they can avoid the risk of not performing their duties properly, and eliminate their anxiety from work. The focus of regulatory work should be regularly adjusted due to the changing maritime traffic. Timely optimization and updating of VTSO's responsibilities and related working procedures can not only ensure the effectiveness of VTS services, but also provide timely guidance for VTSO to deal with new problems and reduce VTSO's anxiety about unexpected situations.

4.1.3.2 Contingency Plan.

Due to the fact that the VTS center also bear the responsibility as Maritime Rescue Coordination Center (MRCC) besides the provision of vessel traffic service, SAR usually lasts several hours even several days. As we all know, it is a quite demanding job to coordinate the SAR operation. Whether there is a contingency plan in which additional manpower are allocated to take over the SAR coordination from VTSO is important to alleviate the burden of VTSO.

4.1.3.3 Motivation.

All VTS centers in China are required to establish an assessment and reward and punishment system to motivate VTSO who perform well in the assessment in terms of promotion as well as honor award. A good motivation system can improve the performance of VTSO greatly, and maintain a much higher safety level in VTS area. However, the motivation systems in practice do not always work well. Some VTSO complain that the motivation system is so unreasonable that cannot achieve the goal of motivation. In addition, they have to spend time on the paperwork related to the motivation system. Some other reckon that even if their work can be assessed in a reasonable way, no incentive mechanism or the incentive measures are not enough to achieve the desired management purpose. Therefore, whether the incentive mechanism is reasonable can have either positive or negative effects on the performance of VTSO.

4.1.3.4 Shift System.

There are various shift systems in use all over the world. All shift systems have advantages and drawbacks despite the fact that it is designed to minimize the accumulation of fatigue. However, shift system which is more favorable in this sector while it is less favorable in the other domain. The shift system should be designed according to its features. A good shift system is able to minimize the accumulation of fatigue (Knauth, 1993). However, there is no shift system recommended in IALA Guidelines. Nevertheless, a Brochure (IALA, 2009) released by IALA listed some tips about shift work arrangement. In the Brochure, no detail information on to what extent those factors should be considered when designing the shift patterns.

4.1.3.5 Accessibility and Comprehensibility of Regulations.

The effectiveness of the VTS service is directly affected by the crew's understanding of the regulatory requirements in the VTS area. Sometimes the regulatory requirements are available in the VTS User Guide, however the format of the guide varies worldwide, which causes confusion to seafarers when they look up the detail requirements of the destination VTS Center. Although a uniform template for VTS User Guide have been adopted at 69th IALA Council conference in 2019, some seafarers still mistake the requirements of VTS due to the language barrier or not updating information. For example, the duty officer on the *Sewol* Ferry tried to ask Jeju VTS for help while the passenger ship was actually in the Jindo VTS area when it began to capsize. It wasted a lot of time to relay the distress warning. *Sewol* Ferry finally capsized and caused a death toll of 304.

4.2 Establishment of Reviews Set.

In this dissertation, the attribution degree of reviews on corresponding factors is determined by carrying out a questionnaire survey. When the respondents fill in the questionnaire, each factor is evaluated according to the judgment standards set for different levels of review. Finally, the attribution degree of this factor to different review is determined according to the statistical results of all the questionnaire survey.

4.2.1 Staffing Level (Table 4.1).

Table 4.1: ***Review Set for Staffing Level***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Serious insufficient, VTSO works longer hours than required.
2	Bad	Insufficient. When there is VTSO on leave or business trip or training program VTSO has to work longer hours than required.
3	Average	Redundant, VTSO are often in the underload state within shifts.
4	Good	Relatively sufficient. All the related requirements about staffing are met. However, VTSO are always in stress due to high workload.
5	Very Good	Sufficient. Workload is reasonable.
Source: the author		

4.2.2 Knowledge (Table 4.2).

Table 4.2: ***Review Set for Knowledge***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Not qualified, with insufficient knowledge on VTS
2	Bad	Qualified, but knowledge on VTS is

		insufficient.
3	Average	Qualified, with basic knowledge on VTS. Processing information slowly.
4	Good	With sufficient knowledge on VTS to handle most complex situations.
5	Very Good	Very professional.
Source: the author		

4.2.3 Experience (Table 4.3).

Table 4.3: ***Review Set for Experience***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Lack of experience, feel difficult in VTS provision.
2	Bad	Capable of provision VTS with the supervision of experienced VTSO or VTS Supervisor.
3	Average	Capable of provision VTS independently for most time.
4	Good	Experienced.
5	Very Good	Expert.
Source: the author		

4.2.4 Team Reaction (Table 4.4).

Table 4.4: ***Review Set for Team Reaction***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Disharmonious, often in conflict.
2	Bad	Work independently with little interaction.
3	Average	Reluctant to correct teammates' mistakes out of

		politeness.
4	Good	Respect each other, and dare to correct teammates' mistakes.
5	Very Good	Work harmoniously and communicate well.
Source: the author		

4.2.5 Physical Condition (Table 4.5).

Table 4.5: ***Review Set for Physical Condition***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Very bad. Application for transfer to another department was not approved.
2	Bad	Little bad. Very likely to get sick if shift work continues.
3	Average	No problem. In spite of constant fatigue.
4	Good	Healthy, fit for shift work for the time being.
5	Very Good	Healthy and willing to work in shift work for a few more years.
Source: the author		

4.2.6 Traffic Condition (Table 4.6).

Table 4.6: ***Review Set for Traffic Condition***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Extreme complex
2	Bad	complex
3	Average	General
4	Good	Simple
5	Very Good	Very Simple

Source: the author

4.2.7 Amount of Communication (Table 4.7).

Table 4.7: ***Review Set for Amount of Communication***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Very heavy.
2	Bad	Heavy.
3	Average	Moderate.
4	Good	Few.
5	Very Good	Very few.
Source: the author		

4.2.8 Natural Environment (Table 4.8).

Table 4.8: ***Review Set for Natural Environment***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Extremely complex
2	Bad	complex
3	Average	General
4	Good	Simple
5	Very Good	Very Simple
Source: the author		

4.2.9 Intelligence of VTS System (Table 4.9).

Table 4.9: ***Review Set for Natural Environment***

Attribution Degree	Review Set	Description of the level

1	Very Bad	VTS system is old and unable to detect danger automatically.
2	Bad	Able to detect simple hazards, but with low reliability.
3	Average	Able to detect simple hazards, with high reliability.
4	Good	Able to detect multiple hazards, strong reliability.
5	Very Good	Equipped with very advanced function, enable VTSO to set up rules for hazards identification in the system and work well.
Source: the author		

4.2.10 Violation Rates (Table 4.10).

Table 4.10: ***Review Set for Violation Rates***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Violations occur frequently, and it is difficult for VTSO to correct.
2	Bad	Violations occur frequently, and correcting the violations is a high time-consuming task for VTSO.
3	Average	Violations occur occasionally, and correcting the violations is a high time-consuming task for VTSO.
4	Good	Violations occur occasionally, and VTSO can stop the violations easily.
5	Very Good	Violations occur rarely, and VTSO can stop the violations easily.

Source: the author

4.2.11 Workplace Environment (Table 4.11).

Table 4.11: ***Review Set for Workplace Environment***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Very bad
2	Bad	Bad
3	Average	Average
4	Good	Good
5	Very Good	Very Comfortable
Source: the author		

4.2.12 Responsibilities and Procedures (Table 4.12).

Table 4.12: ***Review Set for Responsibilities and Procedures***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Both responsibilities and procedures are confused.
2	Bad	Responsibilities are vague, but procedures are clear.
3	Average	Responsibilities are clear, but procedures are vague.
4	Good	Responsibilities and procedures are clear, but not updated in a timely manner.
5	Very Good	Responsibilities and procedures are clear and up to date.
Source: the author		

4.2.13 Contingency Plan (Table 4.13).

Table 4.13: ***Review Set for Contingency Plan***

Attribution Degree	Review Set	Description of the level
1	Very Bad	No full-time personnel appointed in the contingency plan to take over the emergency coordination from VTSO.
2	Bad	Full-time personnel were appointed in the contingency plan to take over the emergency coordination from VTSO. However, this appointment is non-substantive. Actually, they help little with VTSO in an emergency.
3	Average	Only for those major emergency events happened at normal working hours, full-time personnel are assigned to take over the emergency coordination from VTSO.
4	Good	Full-time personnel are only assigned to take over coordination of major emergency from VTSO.
5	Very Good	Full-time personnel are assigned to take over any emergency coordination from VTSO.
Source: the author		

4.2.14 Motivation (Table 4.14).

Table 4.14: ***Review Set for Motivation***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Motivation mechanism is not well designed, and

		VTSO were not incentivized to a better performance, moreover, it increases the workload of VTSO.
2	Bad	No motivation mechanism.
3	Average	VTSO were assessed regularly, but no substantial incentive.
4	Good	Most of VTSO are incentivized to a better performance.
5	Very Good	All are incentivized to a better performance.
Source: the author		

4.2.15 Shift system (Table 4.15).

Table 4.15: ***Review Set for Shift System***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Very dissatisfied, but it is hard to compromise a new one.
2	Bad	Dissatisfied, but already got accustomed.
3	Average	So-so.
4	Good	Satisfied, but there is room for improvement.
5	Very Good	Very satisfied, it seems to be tailor-made.
Source: the author		

4.2.16 Accessibility and Comprehensibility of Regulations (Table 4.16).

Table 4.16: ***Review Set for Accessibility and Comprehensibility of Regulations***

Attribution Degree	Review Set	Description of the level
1	Very Bad	Regulatory requirements change frequently, due to poor accessibility and comprehensibility of

		regulations, VTSO has to do lots of explaining.
2	Bad	Regulatory requirements change frequently. The accessibility of regulations is poor, VTSO has to do lots of explaining too.
3	Average	Regulatory requirements change frequently, however, comprehensibility of regulations is poor, even though some ships have access to the new regulations, they are often confused with the content.
4	Good	Regulatory requirements remain rarely changed, with explanations only for first-time calling ships, and accessibility and comprehensibility of regulations are good.
5	Very Good	Regulatory requirements are constant, and accessibility and comprehensibility of regulations are good.
Source: the author		

4.3 Evaluate the Attribution Degree of Factors and Establish Fuzzy Matrix.

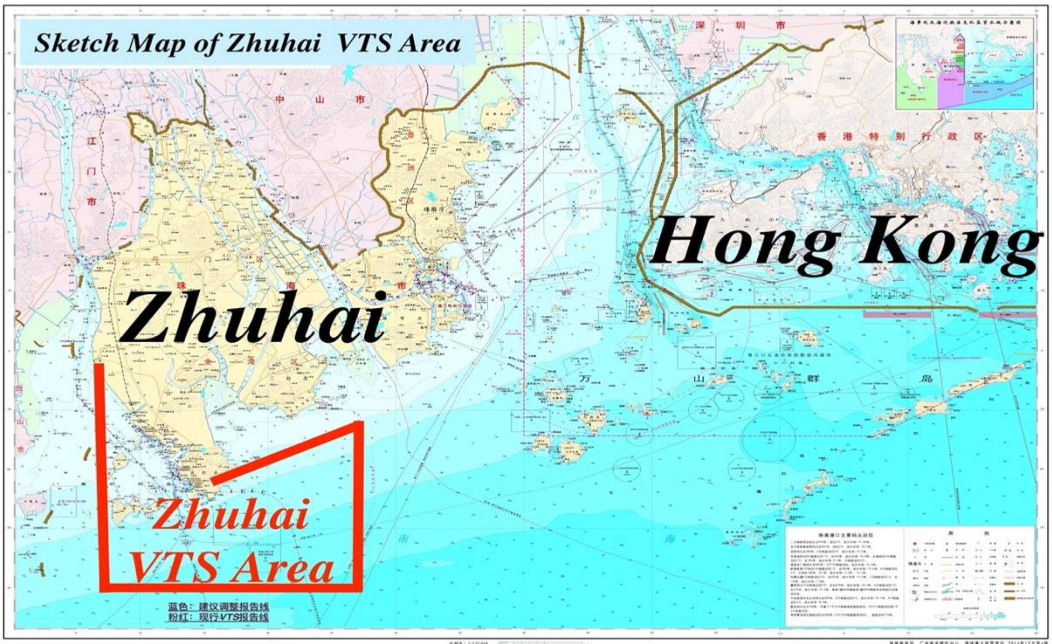

Figure 4.3: **Sketch Map OF Zhuhai VTS Area.**

Source: the author

Zhuhai is one of the central cities of the Pearl River Delta and an important node city of the Guangdong-Hong Kong-Macao Greater Bay Area. It is located in the central and southern part of Guangdong Province, facing Hong Kong and Shenzhen across the sea to the east, connecting with Macao on land, and facing Macao across the river on the island. Zhuhai Port is an important hub of the national comprehensive transportation system and one of the main coastal ports. Zhuhai VTS Center covers a water area from 21° 45.0'N to 22° 05.0'N and from 113° 05.0'E to 113°27.0'E, covering an area of 750 square kilometers (Figure 4.3).

As for Zhuhai VTS Center, this dissertation calculates the attribution degree between evaluation factors and reviews set through questionnaire survey. There were 25 people in Zhuhai VTS Center, 25 questionnaires were sent out and 24 were received back, all of which were valid. The attribution degree of each factor was determined according to the evaluation ratio of respondents to each factor. See Table 4.17 for the statistical results of the questionnaire:

Table 4.17: ***Attribution Degree of All Evaluated Factors***

No	Factors	1	2	3	4	5
1	E1: Traffic Condition	0.0833	0.7083	0.2083	0.0000	0.0000
2	E2: Communication	0.1250	0.7083	0.1667	0.0000	0.0000
3	E3: Navigation Environment	0.0833	0.5833	0.3333	0.0000	0.0000
4	E4: Intelligence of VTS System	0.6250	0.2083	0.1667	0.0000	0.0000
5	E5: Violation Rates	0.0833	0.2083	0.4167	0.2917	0.0000
6	E6: Workplace Environment	0.0417	0.1667	0.3750	0.2917	0.1250
7	H1: Staffing Level	0.0417	0.4167	0.0000	0.0000	0.5417
8	H2: Knowledge	0.0417	0.2083	0.5000	0.1667	0.0833
9	H3: Experience	0.0417	0.5000	0.2500	0.2083	0.0000
10	H4: Team Reaction	0.0000	0.0833	0.0000	0.7500	0.1667
11	H5: Physical Condition	0.1250	0.2917	0.3333	0.2500	0.0000
12	M1: Responsibilities and Procedures	0.0417	0.0833	0.1250	0.4583	0.2917
13	M2: Enforcement	0.0000	0.0000	0.4167	0.2917	0.2917
14	M3: Motivation	0.0417	0.4167	0.3750	0.1250	0.0417
15	M4: Shift System	0.0417	0.1250	0.1667	0.6250	0.0417
16	M5: Accessibility and Comprehensibility of Regulations	0.0000	0.1667	0.0417	0.6250	0.1667

Source: the author

The fuzzy matrix R could be expressed as Formula 4.1.

$$R = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \\ r6 \\ r7 \\ r8 \\ r9 \\ r10 \\ r11 \\ r12 \\ r13 \\ r14 \\ r15 \\ r16 \end{bmatrix} = \begin{bmatrix} 0.0833 & 0.7083 & 0.2083 & 0.0000 & 0.0000 \\ 0.1250 & 0.7083 & 0.1667 & 0.0000 & 0.0000 \\ 0.0833 & 0.5833 & 0.3333 & 0.0000 & 0.0000 \\ 0.6250 & 0.2083 & 0.1667 & 0.0000 & 0.0000 \\ 0.0833 & 0.2083 & 0.4167 & 0.2917 & 0.0000 \\ 0.0417 & 0.1667 & 0.3750 & 0.2917 & 0.1250 \\ 0.0417 & 0.4167 & 0.0000 & 0.0000 & 0.5417 \\ 0.0417 & 0.2083 & 0.5000 & 0.1667 & 0.0833 \\ 0.0417 & 0.5000 & 0.2500 & 0.2083 & 0.0000 \\ 0.0000 & 0.0833 & 0.0000 & 0.7500 & 0.1667 \\ 0.1250 & 0.2917 & 0.3333 & 0.2500 & 0.0000 \\ 0.0417 & 0.0833 & 0.1250 & 0.4583 & 0.2917 \\ 0.0000 & 0.0000 & 0.4167 & 0.2917 & 0.2917 \\ 0.0417 & 0.4167 & 0.3750 & 0.1250 & 0.0417 \\ 0.0417 & 0.1250 & 0.1667 & 0.6250 & 0.0417 \\ 0.0000 & 0.1667 & 0.0417 & 0.6250 & 0.1667 \end{bmatrix} \quad (4.1)$$

4.4 Determine the Weight of Factors to Be Evaluated by AHP Method.

This dissertation designed a questionnaire to determine the weight of each factor and sent it to 6 experts. A total of 6 questionnaires were collected. The judgment matrix feedback from each expert meets the requirements of consistency test. After calculating the arithmetic mean of the original data from the questionnaires of 6 experts, the weight of each element was calculated with the arithmetic mean. The process is as follows.

4.4.1 Determine the Weight of Factors in the First Floor.

The judgement matrix for the factors in the first floor was established in Table 4.18. According to the AHP principle and Formulas aforementioned in Chapter 3, the weight and consistency test can be calculated.

Table 4.18: ***Judgement Matrix for Evaluation Index of Factors in the First Floor***

	S1: Environment	S2: Human	S3: Management

S1: Environment	1	0.439	0.632
S2: Human	2.278	1	1.565
S3: Management	1.583	0.639	1
Source: the author			

The weight vectors for Environment, Human and Management are 0.205, 0.480 and 0.315 respectively.

$$\lambda max = 3.001$$

$$CI = \frac{\lambda max - n}{n - 1} = 0.0005$$

$$RI = 0.58$$

$$CR = \frac{CI}{RI} = 0.001 < 0.1$$

Therefore, it meets the requirements of consistency test.

4.4.2 Determine the Weight of Environment Factors.

The judgement matrix for environment factors was established in Table 4.19.

Table 4.19: ***Judgement Matrix for Evaluation Index of Environment Factors***

	E1: Traffic Condition	E2: Amount of Communication	E3: Natural environment	E4: Intelligence of VTS System	E5: Violation Rates	E6: Workplace environment

E1: Traffic Condition	1	1.675	0.818	0.923	1	2.326
E2: Amount of Communication	0.597	1	0.576	0.40	0.581	1.637
E3: Natural environment	1.222	1.736	1	1.17	1.029	2.183
E4: Intelligence of VTS System	1.083	1.695	0.986	1	1.029	2.252
E5: Violation Rates	1	1.722	0.972	0.50	1	2.033
E6: Workplace Environment	0.43	0.611	0.458	0.33	0.492	1
Source: the author						

The weight vectors for Traffic Condition, Amount of Communication, Natural environment, Intelligence of VTS System, Violation Rates, Workplace environment are 0.190, 0.121, 0.207,0.201,0.194 and 0.087 respectively.

$$\lambda max = 6.012$$

$$CI = \frac{\lambda max - n}{n - 1} = 0.002$$

$$RI = 1.24$$

$$CR = \frac{CI}{RI} = 0.002 < 0.1$$

Therefore, it meets the requirements of consistency test.

4.4.3 Determine the Weight of Human Factors.

The judgement matrix for the human factors was established in Table 4.20.

Table 4.20: ***Judgement Matrix for Evaluation Index of Human Factors***

	H1: Staffing level	H2: Knowledge	H3: Experience	H4: Team Reaction	H5: Physical Condition
H1: Staffing level	1	0.439	0.383	0.621	0.800
H2: Knowledge	2.278	1	0.735	0.947	1.441
H3: Experience	2.611	1.361	1	0.837	1.637
H4: Team Reaction	1.611	1.056	1.195	1	1.250
H5: Physical Condition	1.25	0.694	0.611	0.800	1
Source: the author					

The weight vectors for Staffing level, Knowledge, Experience, Team Reaction and Physical Condition are 0.117, 0.225, 0.264, 0.233 and 0.161 respectively.

$$\lambda max = 5.048$$

$$CI = \frac{\lambda max - n}{n - 1} = 0.012$$

$$RI = 1.12$$

$$CR = \frac{CI}{RI} = 0.011 < 0.1$$

Therefore, it meets the requirements of consistency test.

4.4.4 Determine the Weight of Management Factors.

The judgement matrix for the management factors was established in Table 4.21.

Table 4.21: ***Judgement Matrix for Evaluation Index of Management Factors***

	M1: Responsibilities and Procedures	M2: Contingency Plan	M3: Motivation	M4: Shift System	M5: Accessibility and comprehensibility of Regulations
M1: Responsibilities and Procedures	1	0.632	1.262	0.654	1.220
M2: Contingency Plan	1.583	1	1.333	0.546	1.181
M3: Motivation	0.792	0.750	1	0.461	0.857
M4: Shift System	1.528	1.833	2.167	1	1.008
M5: Accessibility and Comprehensibility of Regulations	0.820	0.847	1.167	0.992	1
Source: the author					

The weight vectors for Responsibilities and Procedures, Contingency Plan, Motivation, Shift System and Accessibility and comprehensibility of Regulations are 0.179, 0.208, 0.144,0.281 and 0.188 respectively.

$$\lambda max = 5.089$$

$$CI = \frac{\lambda max - n}{n - 1} = 0.022$$

$$RI = 1.12$$

$$CR = \frac{CI}{RI} = 0.02 < 0.1$$

Therefore, it meets the requirements of consistency test.

4.4.5 Determine the Overall Weight of All Second Floor Factors and Their Rankings.

The overall weight of each second-floor factor is determined by the weight of the factor to its superior indicator and the weight of the superior indicator to the overall goal. For example, the overall weight of Traffic Condition is 0.039 that is the product of 0.190 and 0.205. The overall weight of all factors and their rankings can be seen in Table 4.22.

Table 4.22: ***Overall Weight of All Factors and Their Rankings***

	Environment W=0.205	Human W=0.480	Management W=0.315	Overall Weight	Ranking
E1: Traffic Condition	0.190			0.039	14
E2: Amount of Communication	0.121			0.025	15
E3: Natural Environment	0.207			0.042	11
E4: Intelligence of	0.201			0.041	12

VTS System					
E5: Violation Rates	0.194			0.040	13
E6: Workplace Environment	0.087			0.018	16
H1: Staffing Level		0.117		0.056	9
H2: Knowledge		0.225		0.108	3
H3: Experience		0.264		0.127	1
H4: Team Reaction		0.233		0.112	2
H5: Physical Condition		0.161		0.077	5
M1: Responsibilities and Procedures			0.179	0.056	8
M2: Contingency Plan			0.208	0.066	6
M3: Motivation			0.144	0.045	10
M4: Shift System			0.281	0.089	4
M5: Accessibility and Comprehensibility of Regulations			0.188	0.059	7
Source: the author					

An overall consistency test is needed according to the AHP method. The overall consistency test should be calculated as follows.

$$CI = \sum_{i=1}^{n} CI(i)Si = 0.002 \times 0.205 + 0.012 \times 0.480 + 0.022 \times 0.315 = 0.0131$$

$$RI=\sum_{i=1}^{n} RI(i)Si = 1.24\times 0.205 + 1.12\times 0.480 + 1.12\times 0.315 = 1.1446$$

$$CR=\frac{\sum_{i=1}^{n} CI(i)Si}{\sum_{i=1}^{n} RI(i)Si}=\frac{0.0131}{1.1446}=0.0114<0.1$$

Therefore, it meets the requirements of consistency test.

4.5 Calculate FCE Result.

$W = (W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, W_{13}, W_{14}, W_{15}, W_{16}) =$

$(0.039, 0.025, 0.042, 0.041, 0.040, 0.018, 0.056, 0.108, 0.127, 0.112, 0.077, 0.056,$

$0.066, 0.045, 0.089, 0.059)$

$B = W \odot R$

$$= (W_1, W_2, W_3, \ldots W_{16}) \odot \begin{bmatrix} 0.0833 & 0.7083 & 0.2083 & 0.0000 & 0.0000 \\ 0.1250 & 0.7083 & 0.1667 & 0.0000 & 0.0000 \\ 0.0833 & 0.5833 & 0.3333 & 0.0000 & 0.0000 \\ 0.6250 & 0.2083 & 0.1667 & 0.0000 & 0.0000 \\ 0.0833 & 0.2083 & 0.4167 & 0.2917 & 0.0000 \\ 0.0417 & 0.1667 & 0.3750 & 0.2917 & 0.1250 \\ 0.0417 & 0.4167 & 0.0000 & 0.0000 & 0.5417 \\ 0.0417 & 0.2083 & 0.5000 & 0.1667 & 0.0833 \\ 0.0417 & 0.5000 & 0.2500 & 0.2083 & 0.0000 \\ 0.0000 & 0.0833 & 0.0000 & 0.7500 & 0.1667 \\ 0.1250 & 0.2917 & 0.3333 & 0.2500 & 0.0000 \\ 0.0417 & 0.0833 & 0.1250 & 0.4583 & 0.2917 \\ 0.0000 & 0.0000 & 0.4167 & 0.2917 & 0.2917 \\ 0.0417 & 0.4167 & 0.3750 & 0.1250 & 0.0417 \\ 0.0417 & 0.1250 & 0.1667 & 0.6250 & 0.0417 \\ 0.0000 & 0.1667 & 0.0417 & 0.6250 & 0.1667 \end{bmatrix}$$

$$= (0.0693, 0.2752, 0.2366, \mathbf{0.3077}, 0.1113)$$

According to the principle of maximum degree of attribution of the fuzzy comprehensive vector, the rationality of shift work in Zhuhai VTS can be considered to be good in level 4.

4.6 Empirical Analysis of the Result Calculated From the Evaluation System.

This result is closely related to the shift work adjustment recently implemented in Zhuhai VTS Center. At the beginning of this year, China MSA put forward the goal of building all-factor comprehensive vessel traffic management, aiming to consolidate the leading role of VTS in maritime supervision and promote the continuous upgrading of the efficiency of maritime supervision. Zhuhai MSA organized research and formulated a reform plan to actively promote the implementation of the goal set by China MSA, and the reform plan was put into effect in April this year. According to the requirements of the program, VTS shift work has been adjusted in the following two aspects.

First, shift system was changed. After many discussions between the VTS managers and the VTSO, several shift systems were proposed, and the adopted shift system was voted (Table 4.23). There is a great change from the previous shift system (Table 4.24). The new shift system enables the staff to get more rest, so it can effectively avoid accumulation of fatigue. In order to adapt to the adjustment of shift system, other factors like VTS staffing level and the teammate matching have been adjusted accordingly. The number of VTSO increased by six, and all of them are certified as VTSO. In recent years, Zhuhai VTS Center dispatches new employees to participate in VTSO certification training every year to prepare for staff changeover. Therefore, after a short period training and evaluation, those freshmen with VTS knowledge can provide vessel traffic services independently. Besides, various factors such as personality, hobbies, language ability, age composition and experience level of each VTSO have been fully considered in the team members' matching with an aim to improve team interaction.

Table 4.23: ***Previous Shift Pattern in Zhuhai VTS***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5
Morning shift	A				
Afternoon shift		A			
Night Shift			A		
Rest				A	A
Source: the author					

Table 4.24: ***New Shift Pattern in Zhuhai VTS***

VTSO A	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
2340-0340	A							
0340-0740				A				
0740-1200			A					
1200-1600	A							
1600-2000			A					
2000-2340		A						
Rest					A	A	A	A
Source: the author								

Second, the responsibilities of VTSO, procedures of VTS business as well as Contingency Plan of Zhuhai VTS Center were redefined appropriately. In addition, a series of training specified on those adjustments were carried out to ensure that VTSO can fully understand and master before implementation of new shift system.

Chapter 5 Conclusion and Suggestions

5.1 Conclusion

In conclusion, we can find from this adjustment of Zhuhai VTS shift work that the adjustment factors include Shift system, Staffing Level, Team Reaction, Knowledge, Contingency Plan, Responsibilities and Procedures. These factors are generally ranked highly on the list of all 16 factors (Table 5.1). It must be noted that although some factors have more effect on VTS shift work, significant effect cannot be achieved in a short period of time. For example, although Experience proved to be the most important influence on VTS shift work, it cannot be effectively improved in a short period of time. Therefore, from the perspective of effectiveness, the adjustment strategy of this adjustment is basically consistent with the weight of each element determined by the evaluation system. For example, there are generally two ways to reduce the workload of VTSO, one is to reduce VTSO's responsibility area through splitting the VTS Area, the other one is to shorten the shift duration. According to the evaluation results, the influence factors of Shift System are greater than the weight of all factors in the environment, it means shift system has better effectiveness in reducing the VTSO's workload as compared with changing the environment factors.

Table 5.1: ***Factors Involved in Shift Work Adjustment and Their Weight Rankings***

Factors	Weight Ranking
Team Reaction	2
Knowledge	3
Shift System	4
Contingency Plan	6
Responsibilities and Procedures	8
Staffing level	9
Source: the author	

Moreover, in the attribution degree questionnaire survey which was conducted a month later than the shift work adjustment of Zhuhai VTS Center, it can be clearly seen that the adjusted factors tend to have better reviews, which directly affect the comprehensive evaluation results of current shift work of Zhuhai VTS. Therefore, we can conclude that the established evaluation system is comparatively scientific and is meaningful for reference.

5.2 Suggestions

First, VTS manager should have the basic knowledge of VTS and shift work. Leadership attention is critical to promoting shift work optimization in VTS because leadership has more resources at its disposal. Shift work should be devised by people who are familiar with fatigue and good practices in managing fatigue (ORR, 2012). VTS manager should also be aware of shift work in VTS. Although in almost every workplace, including VTS Centers, there may be occasional increase or decrease in workload, which can generally be handled relatively easily by well-trained workers (Komadina, 2011). However, VTS managers need to judge whether this fluctuation in workload is normal fluctuation. Therefore, VTS managers should have the management ability to evaluate the rationality of VTS shift work which enable them to optimize shift work in advance rather than to be forced to adjust the shift work after some unexpected accidents in VTS Area.

Second, a healthy professional ethic should be established. In the established evaluation system, the related experience of VTSO has a great influence on the VTS shift work. However, the longer VTSO work in shift work, the greater the impact on their physical and mental health is. Humanized management would be the key to solve this problem. On the one hand, the ceiling on promotion and compensation in VTSO as a career for life should be lifted. On the other hand, a scientific and reasonable shift system should be adopted to control health damage to VTSO who work in shifts for a long time. For example, good practice like shift workers with higher seniority are free of night shifts could be referenced. Only a healthy work ethic is established can we get a win-win solution for this dilemma in VTS shift work.

Thirdly, the intelligence of VTS system can undoubtedly help VTSO to detect potential risks timely. However, there are also certain threats. On the one hand, the intelligent algorithm is based on the authenticity of the data collected. However, the current technique for data collection and transmission are not 100% reliable. On the other hand, intelligent applications may make VTS work much boring, which would contribute to VTSO fatigue (Ryan, 2016). Maybe that is why the weight of the intelligence level of VTS system on shift work rank 12 out of 16 in the proposed evaluation system. However, it is inevitable for VTS system to become even smarter in the future. We should take care to avoid falling into the intelligent trap.

In addition, the weight of all factors in the evaluation model established in this paper only consulted the opinions of some experts in China, and it is not necessarily suitable for foreign VTS due to differences of culture, institution, habit and other factors. However, the AHP-FCE method adopted can be used to analyze the composition of influencing factors and their relative weights.

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