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Research Article

Application of VTS Comprehensive Evaluation Based on Combination Evaluation

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Abstract

Background: Evaluation the operation of vessel traffic service. **Materials and Methods:** Delphi, fuzzy comprehensive evaluation method and information entropy are supplied to comprehensive evaluate 5 VTS centers in Z province respectively, then Kendall is used to test consistency of the results of the three models. The final evaluation result is combined through mean value, Bora, Compeland and fuzzy Borda. **Results:** The five VTS centers in the Z province are ranked according to their service efficiency. **Conclusion:** The combination evaluation method reconciles the differences in the results caused by the evaluations by independent methods and provides a useful reference for the comprehensive and scientific evaluation of VTS.

Key words: Vessel traffic service, combination evaluation, Delphi method, fuzzy, entropy

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

With the development of the shipping industry and the increasing vessel types, quantity and speed accelerate vessel traffic and density, resulting frequent traffic accidents and water traffic safety supervision are confronted with more pressure and the requirements pertaining to dynamic monitoring, data collection, navigation aid and traffic management capacity of Vessel Traffic Service (VTS) centers continue to rise. It is imperative to conduct VTS comprehensive evaluation and fully exploit and develop the functions of VTS.

Existing literature focuses on the evaluation of economic benefits of VTS and the evaluation methods are mostly limited to the cost/benefit analysis provided in the VTS GUIDE by the International Association of Lighthouse Authorities. Lee *et al.*[1] estimates the public value of a VTS facility construction project using the Contingent Valuation (CV) method. Bukhari *et al.*[2] developed RADAR operated intelligent software, which directly gets the required data from RADAR and displays the vessels list based on their degree of collision severity. Oh *et al.*[3] analyzed the statistical near miss data between fishing vessels and non-fishing vessels in the Wando Vessel Traffic Services (VTS) area and assessed the risk of ship collisions. Mou *et al.*[4] evaluated VTS benefits based on a case study of Zhoushan.

A VTS comprehensive evaluation model based on Delphi method, fuzzy comprehensive evaluation method and information entropy was proposed in this study and the evaluation results that passed Kendall conformance test were combined using mean value method, Bora method and fuzzy Borda method to obtain more objective evaluation.

MATERIALS AND METHODS

VTS comprehensive evaluation model based on delphi method

Construction of VTS comprehensive evaluation index system: According to the definition of VTS and user's requirements on the functions of VTS in current actual operation, VTS comprehensive evaluation in this study focuses on the system operation and management capacity and resource service capacity. System operation and management capacity primarily reflect the operational performance and the strength of the basic public functions provided by the system. Only the strong capacity in this regard can give full play to other application functions designed and developed by the whole system; resource service capacity primarily reflects VTS's capacity in regulation, analysis and sharing of its acquired information resources of guiding and supporting shipping service; the stronger the function is the greater the VTS's effect on shipping management[5]. After four rounds of consulting with expert and reaching a consensus, a VTS comprehensive evaluation index system was built (Table 1).

Weighting of analytic hierarchy process: Weighting was made according to the following four steps: Building a hierarchical model, expert judgment matrix and consistency test of judgment matrix, calculating index weight of the indices at all levels and calculating weights of the underlying index to the overall objective. Paired comparisons of the importance of each index were made by a number of maritime experts based on their working and practical experience and the relative weight of each index was calculated by computer program written based on the mathematical model of index weight coefficient (Table 2).

Design of ranking rules of VTS comprehensive evaluation: The ranking rules should be designed based on the characteristics of the index factors to be evaluated in the whole operation of the VTS system and combined with the management methods of administrations to determine specific implementation standards and guidelines. Complying with the above ideology, the ranking rules of the set four-level indices were made in this study (Table 3) and administrations can determine the specific implementation rules according to their actual requirement on management.

Implementation of VTS comprehensive evaluation: The whole VTS comprehensive capacity evaluation process is mainly comprised of ranking process and system comprehensive calculation process, in which the latter is implemented by AHP algorithm generally through automatic computer calculation. While the former can be implemented according to the above ranking rules and it will be ranked after being reviewed by VTS authorities and industry experts.

The specific evaluation time and evaluation experts for each VTS will be appointed by senior administrations. The users of each VTS can identify the shortcomings, developing programs for improvement and promote the effective application of VTS based on the annual evaluation scores of VTS service capability.

Table 1: VTS comprehensive evaluation index system

First-level index			Second-level indexe			Third-level index			Fourth-level index			
Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Index description
VTS operation and management capacity of system	U_1	W_1	Operation capability of infrastructure	U_{11}	W_{11}	Hardware	U_{111}	W_{111}	Server performance	U_{1111}	W_{1111}	Extent to which servers meet the applications of shared platform
						Software	U_{112}	W_{112}	Mainframe system security	U_{1112}	W_{1112}	Mainframe system security applications
									Reserved function interfaces	U_{1113}	W_{1113}	Whether there are interfaces reserved for VTS development under E navigation
									Input in software development	U_{1121}	W_{1121}	Financial input in software development, reflecting the sophistication and level of software
									Software system stability	U_{1122}	W_{1122}	Software system failure frequency
						Network	U_{113}	W_{113}	Level of network performance	U_{1131}	W_{1131}	Access broadband of shared platform service network
									Network stability	U_{1132}	W_{1132}	Shared platform service network failure frequency
									Network security	U_{1133}	W_{1133}	Shared platform service network security application
			Degree of system function application	U_{12}	W_{12}	Single function subsystem	U_{121}	W_{121}	Radar subsystems	U_{1211}	W_{1211}	Radar equipment of remote control radar stations
									VHF communication subsystem	U_{1212}	W_{1212}	Communication between vessels and broadcasting navigation aid information to the vessels in the coverage area
									Meteorological subsystem	U_{1213}	W_{1213}	Superimposing weather information on VTS system
									Multi-sensor comprehensive processing subsystem	U_{1214}	W_{1214}	Fusing radar video information, AIS information and tracking data information from radar stations
									Multimedia data recording subsystem	U_{1215}	W_{1215}	Recording radar images (digital video and tracking data), voice and other data and instructions
									Management information subsystem	U_{1216}	W_{1216}	Statistics and management of vessels in VTS's administrative zone
									Traffic display and subsystem control	U_{1217}	W_{1217}	Displaying traffic image and object track in administrative zone
									AIS subsystem	U_{1218}	W_{1218}	Receiving AIS information of vessels
									Radar data processing subsystem	U_{1219}	W_{1219}	Processing radar signal and recording and tracking objects

Table 1: Continue

First-level index			Second-level indexes			Third-level index			Fourth-level index			
Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Index description
						Comprehensive analysis function	U_{122}	W_{122}	Integrity and accuracy of system information resource	U_{1221}	W_{1221}	Integrity and accuracy description of VTS system information resource by features
									Comprehensive statistical analysis	U_{1222}	W_{1222}	Statistics of the number of navigation aid service and vessel traffic of reporting lines
									Comprehensive decision analysis	U_{1223}	W_{1223}	Assisting VTSO in supervision of vessels
			System management capability	U_{13}	W_{13}	Quality management	U_{131}	W_{131}	Importance attached by leadership	U_{1311}	W_{1311}	Input made by leadership in VTS management
									Employee's quality awareness	U_{1312}	W_{1312}	Employee's involvement in VTS quality management
									Quality system	U_{1313}	W_{1313}	Whether there is available quality system and operation situation
						Personnel training	U_{132}	W_{132}	Professional knowledge training	U_{1321}	W_{1321}	Effect of professional knowledge training
									Management knowledge training	U_{1323}	W_{1322}	Effect of management knowledge training
						Traffic command management	U_{133}	W_{133}	Regulation management	U_{1331}	W_{1331}	Integrity and implementation of VTS regulations
									Information management	U_{1332}	W_{1332}	Integrity of information management system
									Site management	U_{1333}	W_{1333}	Response speed of law enforcement patrol and supervision
						Facility management	U_{134}	W_{134}	Repair and maintenance	U_{1341}	W_{1341}	VTS's repair and maintenance capability
									Operating rules and regulations	U_{1342}	W_{1342}	Integrity of VTS operating procedures
			Operation management capacity of employees	U_{14}	W_{14}	Attendant	U_{141}	W_{141}	Academic attainment	U_{1411}	W_{1411}	Average academic attainment of attendants
									Maritime experience	U_{1412}	W_{1412}	Average maritime experience of attendants
									Oral english	U_{1413}	W_{1413}	Proficiency of attendants in oral English
									Annual performance appraisal	U_{1414}	W_{1414}	Annual performance appraisal of attendants
						Leadership of VTS centers	U_{142}	W_{14}	Management and technology innovation capacity	U_{1421}	W_{1421}	Average annual performance appraisal of leadership of VTS
									Organization and operation management capacity	U_{1422}	W_{1422}	Average organization and operation management capacity of VTS
									Annual performance appraisal	U_{1423}	W_{1423}	Capacity of management and technological innovation representatives

Table 1: Continue

First-level index			Second-level indexes			Third-level index			Fourth-level index			
Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Name	Mark	Weight	Index description
Resource service capacity of VTS	U_2	W_2	Service mode	U_{21}	W_{21}	VHF communication service	U_{211}	W_{211}	VHF communication service	U_{2111}	W_{2111}	VHF is primarily used in communication between vessels within the jurisdiction
						Telephone communication service	U_{212}	W_{212}	Telephone communication service	U_{2121}	W_{2121}	Whether there is available telephone communication service
						Online service	U_{213}	W_{213}	Online service	U_{2131}	W_{2131}	Whether there is available online service
			Degree of function service application	U_{22}	W_{22}	Classified information service	U_{221}	W_{221}	Information service	U_{2211}	W_{2211}	A service to guarantee vessels' access to the necessary information when navigation decisions are made
									Navigation aid service	U_{2212}	W_{2212}	A service to guarantee vessels' access to the necessary information when navigation decisions are made
									Traffic organization service	U_{2213}	W_{2213}	Effective organization of vessel traffic flow within the jurisdiction and ensuring navigation safety
									Supporting joint actions	U_{2214}	W_{2214}	Supporting the joint actions relating to maritime safety, pollution prevention and control, search and rescue conducted by VTS authorities and the interested parties
									Other service	U_{2215}	W_{2215}	Others services helpful to navigation safety
						Comprehensive information service	U_{222}	W_{222}	Information resource retrieval service	U_{2221}	W_{2221}	Whether there is available information retrieval function in VTS system
									Anchor analysis induction	U_{2222}	W_{2222}	Whether there is available sorting and guiding anchoring
									Berth analysis induction	U_{2223}	W_{2223}	Whether there is available service of arranging vessels for berthing after entering port in a specified order
									Other decision analysis service	U_{2224}	W_{2224}	Assisting VTSO in decision making

Table 2: VTS comprehensive evaluation index weight

	First-level index	Relative weight	Second-level index	Relative weight	Third-level index	Relative weight	Fourth-level index	Relative weight
U	U_1	0.5000	U_{11}	0.2963	U_{111}	0.3333	U_{1111}	0.6437
							U_{1112}	0.2834
							U_{1113}	0.0729
					U_{112}	0.3333	U_{1121}	0.2510
							U_{1122}	0.7490
					U_{113}	0.3333	U_{1131}	0.2308
							U_{1132}	0.6478
							U_{1133}	0.1215
			U_{12}	0.2110	U_{121}	0.8332	U_{1211}	0.1104
							U_{1212}	0.1820
							U_{1213}	0.0239
							U_{1214}	0.1104
							U_{1215}	0.0239
							U_{1216}	0.0432
							U_{1217}	0.2855
							U_{1218}	0.1104
							U_{1219}	0.1104
					U_{122}	0.1668	U_{1221}	0.5909
							U_{1222}	0.0739
							U_{1223}	0.3352
			U_{13}	0.2464	U_{131}	0.2500	U_{1311}	0.3994
							U_{1312}	0.2013
							U_{1313}	0.3994
					U_{132}	0.1250	U_{1321}	0.5000
							U_{1322}	0.5000
					U_{133}	0.5000	U_{1331}	0.5000
							U_{1332}	0.2500
							U_{1333}	0.2500
					U_{134}	0.1250	U_{1341}	0.2468
							U_{1342}	0.7532
			U_{14}	0.2464	U_{141}	0.3333	U_{1411}	0.0714
							U_{1412}	0.2175
							U_{1413}	0.1234
							U_{1414}	0.5877
					U_{142}	0.6667	U_{1421}	0.2000
							U_{1422}	0.2000
							U_{1423}	0.6000
	U_2	0.5000	U_{21}	0.1666	U_{211}	0.6339	U_{2111}	1
					U_{212}	0.2605	U_{2121}	1
					U_{213}	0.1056	U_{2131}	1
			U_{22}	0.8334	U_{221}	0.6666	U_{2211}	0.1847
							U_{2212}	0.1844
							U_{2213}	0.3486
							U_{2214}	0.1844
							U_{2215}	0.0979
					U_{222}	0.3334	U_{2221}	0.1613
							U_{2222}	0.4658
							U_{2223}	0.2772
							U_{2224}	0.0958

Table 3: VTS comprehensive assessment scoring criteria

Fourth-level index	Index description	Scoring criteria	Scores
Server performance	Extent to which servers meet the applications of shared platform	The configuration of the server is lower than the current mainstream configuration of portal services (2U/4G)	0-50
		The current mainstream or higher configuration of portal services is adopted in the server	50-100
Mainframe system security security	Mainframe system security applications	10 scores for each of mainframe security protection measures, including mainframe login control, mainframe system backup and disk partition management, virus and Trojan horse prevention, vulnerability scanning, patch update and mainframe logs (a maximum of 100 scores)	0-100
Reserved function interfaces	Whether there are interfaces reserved for VTS development under E navigation	No interface is reserved	0
		Some interfaces are reserved but they are not available without improvement and adjustment	0-30
		Some interfaces are reserved and they are available subject to the conformance with E navigation criteria	30-50
		Most interfaces are reserved and they are available subject to the conformance with E navigation criteria	50-80
		All interfaces are reserved and they are available subject to the conformance with E navigation criteria	80-100
Input in software development	Financial input in software development, reflecting the sophistication and level of software	Input in software development<300,000	0-20
		300,000≤input in software development<500,000	20-50
		500,000≤input in software development<800,000	50-80
		Input in software development≥800,000	80-100
Software system stability	Software system failure frequency	Frequency of application software system failures≥15 times year^{-1}	0-10
		10 times year^{-1}≤Frequency of application software system failures<15 times year^{-1}	10-30
		5 times year^{-1}≤Frequency of application software system failures<10 times year^{-1}	30-50
		3 times year^{-1}≤Frequency of application software system failures<5 times year^{-1}	50-70
		1 times year^{-1}≤Frequency of application software system failures<3 times year^{-1}	70-90
		No failure occurs in application system all year	90-100
Level of network performance	Access broadband of shared platform service network	Network access broadband<1 M	0-10
		1 M<network access broadband≤5 M	10-30
		5 M<network access broadband≤10 M	30-50
		10 M<network access broadband≤50 M	50-80
		Network access broadband>50 M	80-100
Network stability	Shared platform service network failure frequency	Frequency of network software and hardware failures≥ 20 times year^{-1}	0-10
		15 times year^{-1}≤frequency of network software and hardware failures<20 times year^{-1}	10-30
		10 times year^{-1}≤frequency of network software and hardware failures<15 times year^{-1}	30-50
		5 times year^{-1}≤frequency of network software and hardware failures<10 times year^{-1}	50-70
		3 times year^{-1}≤frequency of network software and hardware failures<5 times year^{-1}	70-90
		Frequency of network software and hardware failures<3 times year^{-1}	90-100
Network security	Shared platform service network security application	No guarantee for network security	0
		40 scores for software or hardware firewall, 30 scores for restricting access to gateway, router and proxy server to the users that pass authentication and 30 scores for other network security applications (a maximum of 100 scores)	30-100
Radar subsystems	Radar equipment of remote control radar stations	20 scores when radar transceiver or antenna motor can automatically stop transmitting and alarm VTS centers in case of failure; 10 scores for each of the radar parameter setting functions, including pulse width, pulse repetition frequency, antenna rotation speed and fan-shaped emitter (a maximum of 100 scores)	0-100

Table 3: Continue

Fourth-level index	Index description	Scoring criteria	Scores
VHF communication subsystem	For communication between vessels and broadcasting navigation aid information to the vessels in the coverage area	20 scores when the requirement for VHF call functions are basically met; 40 scores for regularly broadcasting navigation warnings, weather forecasts and other emergent information related to navigation safety to the vessels in the coverage area; 20 scores for broadcast, hook-up broadband or selected broadband of automatic communication language; 20 scores when the communication needs are met in search and rescue (a maximum of 100 scores)	0-100
Meteorological subsystem	Superimposing weather information on VTS system	30 scores for the display of real-time meteorological data, graphics, variation curve, etc.; 20 scores for the storage and retrieval of meteorological data of every day in previous years; 30 scores for the auto-alarm of wind speed and other data affecting navigation safety; 20 scores for the display of meteorological data on the traffic monitor window (a maximum of 100 scores)	0-100
Multi-sensor comprehensive processing subsystem	Fusing radar video information, AIS information and tracking data information from radar stations	40 scores for a total tracking capacity of multi-sensor integrated processor that is not less than 10,000; 40 scores for the ability to fuse digital video, radar tracking data, AIS data and other information; 20 scores for the ability to process the video information from two radar stations to minimize false echoes caused by the repeated emission by radar housing (a maximum of 100 scores)	0-100
Multimedia data recording subsystem	Recording radar images (digital video and tracking data), voice and other data and instructions	30 scores when data recording duration is 30 successive days, the old data are overwritten by new ones in looping records and the important data can be rewritten in CD for permanent preservation; 40 scores for multimedia recording and playback to ensure the synchronization of radar video recording and VHF voice recording playback; 30 scores for manual record, fast forward and slow playback (a maximum of 100 scores)	0-100
Management information subsystem	Statistics and management of vessels in VTS's administrative zone	30 scores for the ability to manage the data such as vessel files, port facility management, navigation plans, endorsements and accidents; 20 scores for a data management information database with a capacity of 3 years of navigation data; 50 scores when the database structure can exchange data with the internal and external data of the maritime administration and make two-way data link to the multi-sensor comprehensive processors (a maximum of 100 scores)	0-100
Traffic display and subsystem control	Displaying traffic image and object track in administrative zone	10 scores for each of the abilities to display the followings: electronic marine charts, video radar images, object tracking, tracking measurement and statistics, AIS data, vessel label data and other information of subsystems (a maximum of 100 scores)	0-100
AIS subsystem	Receiving AIS information of vessels	10 scores for each of the followings: ability to receiving AIS information for vessels, available data communication interface and stable tracking performance (a maximum of 100 scores)	0-100
Radar data processing subsystem	Processing radar signal and recording and tracking objects	10 scores for each of the followings: available radar video processor, digital video, PLOT video, radar target acquisition and tracker, tracking stability (a maximum of 100 scores)	0-100
Integrity and accuracy rate of information resource description	Integrity and accuracy description of VTS system information resource by features	Scores = Integrity and accuracy rate of information resource description x100	0-100
Comprehensive statistical analysis	Statistics of the number of navigation aid service and vessel traffic of reporting lines	Available statistical analysis function and having the ability to export related statistics reports (a maximum of 100 scores)	0-100
Comprehensive decision analysis	Assisting VTSO in supervision of vessels	Available regulating system for anchoring in anchorage and berthing in port and assistant functions, such as decision assistant system for dealing with dangerous situations (a maximum of 100 scores)	0-100
Importance attached by leadership	Input made by leadership in VTS management	Leaders pay no attention to or make no substantive action for VTS quality management	0-60
		Leaders attach importance to VTS management and provide manpower, financial and material support	60-80
		Leaders attach great importance to VTS management and provide manpower, financial and material support	80-90
		Leaders attach great importance to VTS management and take command	90-100

Table 3: Continue

Fourth-level index	Index description	Scoring criteria	Scores
Employee's quality awareness	Employee's involvement in VTS quality management	Employees never get involved in quality management and have no awareness of VTS quality management	0-60
		Employees are involved in quality management but they have insufficient awareness of VTS quality management	60-80
		Most employees are actively involved in quality management and have strong awareness of VTS management	80-90
		All the employees are actively involved in quality management and have very strong awareness of VTS management	90-100
Quality system	Whether there is available quality system and operation situation	No available quality system	0
		A less complete quality system, great improvement in operation is needed	0-60
		A basically complete quality system, no major problems in operation	60-80
		A scientific and complete quality system, functioning well	80-100
Professional knowledge training	Effect of professional knowledge training	No professional knowledge training	0
		Average test scores of all the employees involved in professional training	0-100
Management knowledge training	Effect of management knowledge training	No management-related knowledge training	0
		Average test scores of all the employees involved in management training	0-100
Regulation management	Integrity and implementation of VTS regulations	The traffic management regulations of VTS waters are far from scientific or complete and failing to be well implemented	0-20
		The traffic management regulations of VTS waters are less scientific or complete and failing to be well implemented	20-60
		The traffic management regulations of VTS waters are fairly scientific and complete and well implemented on the whole	60-80
		The traffic management regulations of VTS waters are scientific or complete and well implemented	80-100
Information management	Integrity of information management system	No available management information system or database and failing to effectively provide information support for vessels or ports	0-20
		Management information systems and databases are fragmentary, information processing technologies are less advanced or awkward for operators	20-60
		Management information systems and databases are less complete, information processing technologies are less advanced or awkward for operators	60-80
		Effective management information system and complete database, information processing technology is very advanced and easy to operate	80-100
Site management	Response speed of law enforcement patrol and supervision	Response time of oversight stations and enforcement speed-boats or patrol boats >15 min on receipt of the notification of VTS	0
		10 min≤Response time of oversight stations and enforcement speed-boats or patrol boats <15 min on receipt of the notification of VTS	20-60
		5 min≤response time of oversight stations and enforcement speed-boats or patrol boats <10 min on receipt of the notification of VTS	60-80
		Response time of oversight stations and enforcement speed-boats or patrol boats <5 min on receipt of the notification of VTS	80-100
Repair and maintenance	VTS's repair and maintenance capability	Sum of VTS failure time >20 min	0
		10 min≤sum of VTS failure time <20 min	0-60
		5 min≤sum of VTS failure time <10 min	60-90
		10 min≤sum of VTS failure time<5 min	90-100

Table 3: Continue

Fourth-level index	Index description	Scoring criteria	Scores
Operating rules and regulations	Integrity of VTS operating procedures	VTS operating procedures are incomplete and unclear and not fully implemented	0-30
		VTS procedures are basically complete and clear and implemented on the whole	30-60
		VTS procedures are complete and clear and effectively implemented	60-80
		VTS operating procedures are very complete and clear and quite effectively implemented	80-100
Academic attainment of attendants	Average academic attainment of attendants	Master or above	100
		Undergraduate	80
		College	60
		Vocational secondary school or below	0
Maritime experience of attendants	Average maritime experience of attendants	Captain or above	100
		Chief officer or second pilot (with an occupation of over 6 months)	80
		Second or third mate or third pilot (with an occupation of over 6 months)	60
		Over 1 year of maritime experience	20
		Less than 1 year of maritime experience	0
Oral English of attendants	Proficiency of attendants in oral English	Average scores of oral english exam of attendants	0-100
Performance appraisal of attendants	Annual performance appraisal of attendants	Average scores of annual performance appraisal of all attendants	0-100
Profession capability of VTS leadership	Average annual performance appraisal of VTS leadership	Average scores of annual performance appraisal of VTS leadership	0-100
Management capability of VTS leadership	Average organization and operation management capacity of VTS (a maximum reduction of 40 scores for accidents and 60 scores for other capacity)	A reduction of 5 scores for every extremely serious accident	0-40
		A reduction of 2 scores for every serious accident	0-40
		A reduction of 1 score for every ordinary accident	0-40
		A reduction of 0.5 scores for every minor accident	0-40
Innovative capacity of VTS leadership	Capacity of management and technological innovation representatives (sum of person item, a maximum of 100 scores)	20 scores for every general policy reform	0-100
		80 scores for every major policy reform	0-100
		80 scores for preparing or participating in every local industrial standard or scientific research	0-100
		90 scores for preparing or participating in every national industrial standard or scientific research	0-100
		100 scores for preparing or participating in every international industrial standard or scientific research	0-100
VHF communication service	VHF is primarily used in communication between vessels within the jurisdiction	Evaluation based on VHF coverage, scores = coveragex100	20-100
Telephone communication service	Whether there is an available telephone communication service	This service is unavailable	0
		This service is available	0-100
Online system	Whether there is an available online service	This service is unavailable	0
		This service is available	0-100
Information service	A service to guarantee vessels' access to the necessary information when navigation decisions are made	Unable to fully provide essential information required for vessels in a timely manner	0-60
		Able to provide essential information required for vessels but not timely (such as failing to broadcast navigational warnings in a timely manner)	60-80
		Able to provide essential information required for vessels	80-100
Navigation aid service	Providing aid service in case of navigational difficulties	Unable to provide timely and effective navigation aid service	0-60
		Providing adequate navigation aid service in case of navigational difficulties	60-80
		Providing effective navigation aid service in case of navigational difficulties	80-100

Table 3: Continue

Fourth-level index	Index description	Scoring criteria	Scores
Traffic organization service	Effective organization of vessel traffic flow within the jurisdiction and guaranteeing navigation safety	No available related traffic organization system or failing to implement efficiently the available related traffic organization system	0-20
		There is available traffic organization system but there are difficulties in implementation due to insufficient support facility	20-60
		There are available traffic organization system and support anchorage facility, which can basically guarantee the smooth and efficient vessel traffic within the jurisdiction	60-80
		There are available sophisticated traffic organization system and support anchorage facility, which can well guarantee the smooth and efficient vessel traffic within the jurisdiction	80-100
Supporting joint actions	Supporting the joint actions relating to maritime safety, pollution prevention and control, search and rescue conducted by VTS authorities and the interested parties	Unable to effectively coordinate with other departments to successfully complete joint actions	0-60
		Able to basically complete joint actions, such as search and rescue, through cooperation with other departments	60-80
		Able to efficiently complete joint actions, such as search and rescue, through coordination with other departments	80-100
Other services	Others services helpful to navigation safety	This service is unavailable	0
		10 scores for the ability to provide services related to navigation safety and guide vessels safely through the jurisdiction (a maximum of 100 scores)	10-100
Information resource retrieval service	Whether there is available information retrieval function in VTS system	This service is unavailable	0
		This service is available	10-100
Anchor analysis Induction	Whether there is available sorting and guiding for anchoring	This service is unavailable	0
		This service is available	10-100
Berth analysis induction	Whether there is available service of arranging vessels for berthing after entering port in a specified order	This service is unavailable	0
		This service is available	10-100
Other decision analysis services	Assisting VTSO in decision making	This service is unavailable	0
		10 scores for each of the services helpful to VTSO's decision making (a maximum of 100 scores)	10-100

VTS comprehensive evaluation model based on fuzzy comprehensive evaluation method: Fuzzy comprehensive evaluation is a method to build multi-level fuzzy subsets based on an overall analysis of various factors affecting fuzzy objects in a fuzzy environment according to the basic theory of fuzzy mathematics, build evaluation sets for all the possible results and establish appropriate membership functions, make quantitative analysis of the affecting factors that have indistinct borders and have problems in quantitative analysis according to the fuzzy indexes and then make comprehensive evaluation for the fuzzy objects according to the fuzzy transformation principle[6]. Characterized by several affecting factors, complex structures and powerful fuzziness, VTS comprehensive evaluation fuzzy is suitable for the analysis and quantification of VTS fuzziness via fuzzy comprehensive evaluation method.

Determination of evaluation set of VTS comprehensive evaluation: Evaluation set, also known as comment set or evaluation rating is made up of all the evaluation results of fuzzy objects in fuzzy evaluation and can be expressed as: $V = \{v_1,..., v_j,..., v_n\}$, where, v_j is several possible evaluation results in evaluation, $j = 1, 2,..., n$.

The objective of fuzzy comprehensive evaluation is to make an overall analysis of all the factors affecting objects, analyze the possible results obtained in evaluation to build evaluation set, make quantitative analysis of affecting factors according to the fuzzy indexes, carry out comprehensive evaluation based on the fuzzy transformation principle and obtain the optimal results from the evaluation ratings. Refinement degree of evaluation scale will affect the accuracy of evaluation results, the higher the degree, the greater the discrimination between individual index for objects and the more accurate the fuzzy evaluation results, but which will lead to more complex and difficult evaluation process. So it is necessary to select a proper evaluation scale. The selection of evaluation scale involves evaluation scale classification and evaluation scale setting[6].

As for VTS fuzzy comprehensive evaluation, the percentage system was adopted in this study, so the evaluation sets were divided into 5 scales in VTS fuzzy comprehensive evaluation model, that is, $v = \{v_1, v_2,..., v_5\}$, where, the corresponding percentage interval is v_1: Perfect, with scores of 90-100, v_2 good with scores of 80-89, v_3 medium with scores of 70-79, v_4 poor with scores of 60-69, v_5 bad with scores of 0-59, as shown in Table 4.

Table 4: Percentage of VTS evaluation scale

Evaluation scale	v_1	v_2	v_3	v_4	v_5
Comment	Perfect	Good	Medium	Poor	Bad
Scores	90-100	80-89	70-79	60-69	0-59
Mean scores	95	85	75	65	30

The fuzzy evaluation vectors of fuzzy comprehensive evaluation are obtained through the determination of evaluation sets. Membership of evaluation objects in evaluation scales is represented by fuzzy vectors to reflect the fuzziness of evaluation.

Determination of fuzzy membership matrix of VTS comprehensive evaluation: Given the five evaluation scales and the mean scores of VTS comprehensive evaluation (Table 4), the membership functions for the comprehensive evaluation index data x_{ij} are as follows:

- Membership function of the VTS comprehensive grade of "Perfect":

$$f_1(x) = \begin{cases} 1 & x \geq 95 \\ \dfrac{x-85}{10} & 85 < x < 95 \\ 0 & x \leq 85 \end{cases}$$

- Membership function of the VTS comprehensive grade of "Good":

$$f_2(x) = \begin{cases} 0 & x \leq 75,\ x \geq 95 \\ \dfrac{x-75}{10} & 75 < x \leq 85 \\ \dfrac{95-x}{10} & 85 < x < 95 \end{cases}$$

- Membership function of the VTS comprehensive grade of "Medium":

$$f_3(x) = \begin{cases} 0 & x \leq 65,\ x \geq 85 \\ \dfrac{x-65}{10} & 65 < x \leq 75 \\ \dfrac{85-x}{10} & 75 < x < 85 \end{cases}$$

- Membership function of the VTS comprehensive grade of "Poor":

$$f_4(x)=\begin{cases}0 & x\le 30,\ x\ge 75\\ \dfrac{x-30}{35} & 30<x\le 65\\ \dfrac{75-x}{10} & 65<x<75\end{cases}$$

- Membership function of the VTS comprehensive grade of "Bad":

$$f_5(x)=\begin{cases}1 & x\le 30\\ \dfrac{65-x}{35} & 30<x<65\\ 0 & x\ge 65\end{cases}$$

Fuzzy synthesis of VTS comprehensive evaluation: The fuzzy comprehensive evaluation results C of factor set U are obtained by fuzzy synthesis of the fuzzy evaluation membership matrix R and the corresponding weight vector W, that is:

$$C = W\bullet R = (w_1, w_2,..., w_m)\begin{bmatrix} r_{11} & r_{12} & ... & r_{1n}\\ r_{21} & r_{22} & ... & r_{2n}\\ ... & .... & .... & ...\\ r_{m1} & r_{m2} & ... & r_{mn}\end{bmatrix} = (b_1, b_2,..., b_n)$$

VTS comprehensive evaluation model based on information entropy-unascertained measure evaluation method: Entropy is the probability of variable uncertainty and can be used to indicate the degree of information orderliness. Information entropy is introduced to measure the average size of information in information sources and thereby represent the average degree of the uncertainty of the entire information system and the more orderly the information, the lower the information entropy, the more uncertain the information source and the greater the information entropy. Information entropy can quantify VTS evaluation data that involve many aspects and have a lot of uncertainties and it can provide decision-makers with more useful information.

Establishment of VTS evaluation index system: According to the index system in Table 1, the marks were re-numbered, as shown in Table 5.

Determination of evaluation matrix and selection of evaluation index: When s objects are evaluated through r evaluation indices and when evaluation object vector is $T = \{t_1, t_2,..., t_s\}$ and evaluation index vector is $I = \{I_1, I_2,..., I_r\}$, then $t_i = \{t_{i1}, t_{i2},..., t_{ir}\}$, where t_{ij} is the evaluation value i = 1, 2,..., s of evaluation object t_i against index I_j and the evaluation matrix is:

$$A_{ij} = \begin{bmatrix} I_1 & I_2 & ... & I_r & \\ t_{11} & t_{12} & ... & t_{1r} & t_1\\ t_{21} & t_{22} & ... & t_{2r} & t_2\\ & ... & & ... & \\ t_{s1} & t_{s2} & ... & t_{sr} & t_s\end{bmatrix}$$

The entropy value and entropy weight of the index are calculated using the concept formula of information entropy (that is index discrimination) and the indices that have no discrimination for evaluation objects are deleted and the index system is reintegrated after reduction.

Unascertained measure of single index: Unascertained measure of single index is to calculate the measure u_{ijk} of each index by identifying the evaluation scale Q of index and single index measure function U (t) and thus obtain the measure spaces matrix $(u_{ijk})_{s\times p}$ of index t_{ij}. The details are follows:

Setting p evaluation scales $q_1, q_2,..., q_p$ for t_{ij} and then the evaluation vector $Q = \{q_1, q_2,..., q_p\}$ and Q is an ordered vector, that is, $q_k > q_{k+1}$, then:

Classification criterion matrix:

$$A(t_i) = \begin{bmatrix} q_1 & q_2 & ... & q_p & \\ u_{i11} & u_{i12} & ... & u_{i1p} & I_1\\ u_{i21} & u_{i22} & ... & u_{i2p} & I_2\\ & ... & & ... & \\ u_{ir1} & a_{ir2} & ... & a_{irp} & I_r\end{bmatrix}$$

and $u_{ijk} = u(t_{ij}\in q_k)$ is the degree of unascertain of t_{ij} that is obtained via unascertained measure model and belongs to level q_k; in addition, single index measure u_{ijk} should have the following characteristics:

Nonnegative boundedness : $0\le u(t_{ij}\in q_k)\le 1$

Additivity : $u(t_{ij}\in U) = 1$

Normalization : $u\left(t_{ij}\in\bigcup_{1}^{k} q_l\right) = \sum_{l=1}^{k} u\left(t_{ij}\in q_l\right)$

Determination of index weight: According to the definition of information entropy, the peak value of index I_j is:

$$V_{ij} = 1 + 1/\log_2 p\bullet\sum_{k=1}^{p} u_{ijk}\ \log_2 u_{ijk} \qquad (1)$$

where, p is the number of level, u_{ijk} is the single index measure; the importance of index I_j can be indicated by V_{ij}, then the weight of I_j is:

Table 5: VTS comprehensive evaluation index system

Operation capability of infrastructure		Degree of system function application		System management capability		Operation management capacity of employees		Service mode		Degree of function service application	
Name	Mark	Name	Mark	Name	Mark	Name	Mark	Name	Mark	Name	Mark
Server performance U_{1111}	I_1	Radar subsystems U_{1211}	I_9	Importance attached by leadership U_{1311}	I_{21}	Academic attainment U_{1311}	I_{31}	VHF communication service U_{2111}	I_{38}	Information service U_{2211}	I_{41}
Mainframe system security U_{1112}	I_2	VHF communication subsystem U_{1212}	I_{10}	Employee's quality awareness U_{1312}	I_{22}	Maritime experience U_{1412}	I_{32}	Telephone communication service U_{2121}	I_{39}	Navigation aid service U_{2212}	I_{42}
Reserved function interfaces U_{1113}	I_3	Meteorological subsystem U_{1213}	I_{11}	Quality system U_{1313}	I_{23}	Oral english U_{1413}	I_{33}	Online service U_{2131}	I_{40}	Traffic organization service U_{2213}	I_{43}
Input in software development U_{1121}	I_4	Multi-sensor comprehensive processing system U_{1214}	I_{12}	Professional knowledge training U_{1321}	I_{24}	Annual performance appraisal U_{1414}	I_{34}			Supporting joint actions U_{2214}	I_{44}
Software system stability U_{1122}	I_5	Multimedia data recording subsystem U_{1215}	I_{13}	Management knowledge training U_{1322}	I_{25}	Management and technology innovation capacity U_{1421}	I_{35}			Other services U_{2215}	I_{45}
Level of network performance U_{1131}	I_6	Management information subsystem U_{1216}	I_{14}	Regulation management U_{1331}	I_{26}	Organization and operation management capacity U_{1422}	I_{36}			Information resource retrieval service U_{2221}	I_{46}
Network stability U_{1132}	I_7	Traffic display and control subsystem U_{1217}	I_{15}	Information management U_{1332}	I_{27}	Annual performance appraisal U_{1423}	I_{37}			Anchor analysis induction U_{2222}	I_{47}
Network security U_{1133}	I_8	AIS subsystem U_{1218}	I_{16}	Site management U_{1333}	I_{28}					Berth analysis induction U_{2223}	I_{47}
		Radar data processing subsystem U_{1219}	I_{17}	Maintenance U_{1341}	I_{29}					Other decision analysis services U_{2224}	I_{48}
		Integrity and accuracy of system information resource U_{1221}	I_{18}							Operating rules and regulations U_{1342}	I_{30}
		Comprehensive statistical analysis U_{1222}	I_{19}								
		Comprehensive decision analysis U_{1223}	I_{20}								

$$w_{ij} = v_{ij} / \sum_{j=1}^{r} v_{ij} \quad (2)$$

Where:

$$i = 1, 2, ..., s, \ j = 1, 2, ..., r, \ \sum_{j=1}^{r} w_{ij} = 1$$

Unascertained measure of multi-index: The synthetic unascertained measure:

$$u_{ik} = \sum_{j=1}^{r} w_{ij} u_{ijk}, \ i = 1, 2, ..., s; \ k = 1, 2, ..., p$$

of object t_i can be obtained based on the weight. Multi-index unascertained measure matrix is as follows:

$$(u_{ik})_{s\times p} = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1p} \\ u_{21} & u_{22} & \cdots & u_{2p} \\ & \vdots & & \vdots \\ u_{s1} & u_{s2} & \cdots & u_{sp} \end{bmatrix} \quad (3)$$

Confidence Identification: If $q_k > q_{k+1}$ in $Q = \{q_1, q_2, ..., q_p\}$, the calculation of confidence λ ($0.2 < \lambda \leq 1$) leads to:

$$k(t_i) = \min_k (k : \sum_{l=1}^{k} u_{ij}(q_k) \geq \lambda), \ k = 1, 2, ..., p \quad (4)$$

then t_i is considered to belong to level q_k. Ranking t_i and:

$$g(t_i) = \sum_{l=1}^{p} n_l \bullet u_{ik}(q_k) \quad (5)$$

As the ranking rule calculation, where n_l is set as a value in an arithmetic progression with a difference of -2 and the comparison and ranking analysis of t_i are made according to $g(t_i)$.

RESULTS

Evaluation application: With the subjects of 5 Vessel Traffic Service (VTS) centers in Z province, the results of VTS evaluation based on three independent methods and ranking of 5 VTS centers are shown in Table 6. Obviously the ranking results differ from three methods and it is prima facie difficult to judge, which is right or wrong, so consistency testing is made using KENDALL-W concord coefficient, m = 3, n = 5, so $3 \leq m \leq 20$, $3 \leq n \leq 7$ and:

$$\frac{\delta_{R_i}^2}{m} = \frac{\sum R_i^2 - \frac{1}{4} m^2 n (n+1)^2}{n} = \frac{\sum R_i^2 - \frac{1}{4} m^2 n (n+1)^2}{mn}$$

is required to be calculated and then checked according to the v alue of table W of Kendall coordination coefficient. Then w = 0.9111 and $\delta_{R_i}^2 / 3 = 5.46$, check the "cheat sheet of significantly critical value" (n = 3), 5.46 is greater than the critical value 4.75 of 0.05 level in the sheet, then $p < 0.05$, so with a confidence degree of 95%, the results of VTS comprehensive evaluation based on Delphi method, fuzzy comprehensive evaluation method and entropy value method are roughly the same. Three evaluation results can therefore be used for combination evaluation.

Evaluation result combination of the evaluation results was made in this study using the mean value, Bora method, Compeland method and fuzzy Borda method based on three evaluation methods and the combination evaluation results were calculated, as shown in Table 7.

Table 6: Results of VTS evaluation and ranking based on Delphi, fuzzy comprehensive evaluation method and information entropy, respectively

VTS	Delphi method	Ranking	Fuzzy comprehensive evaluation method	Ranking	Information entropy method	Ranking
A	76.4807	5	0.2957	4	3.085763	4
B	92.5477	1	0.7161	1	5.942322	1
C	78.0456	4	0.2641	5	2.42076	5
D	79.7875	3	0.3917	3	5.441135	2
E	80.428	2	0.4546	2	3.37411	3

Table 7: Combination evaluation results

VTS	Mean value	Ranking	Borda method	Ranking	Compeland method	Ranking	Fuzzy Borda method	Ranking	Standard deviation
A	1.666667	4	1	4	-2	4	0	4	0
B	5	1	4	1	4	1	7.50732	1	0
C	1.333333	5	0	5	-4	5	0	5	0
D	3.333333	3	2	3	0	3	0	3	0
E	3.666667	2	3	2	2	2	2.46571	2	0

DISCUSSION

So far, a few academic studies have been made on the comprehensive evaluation of VTS and there are very few quantitative evaluation methods, including the commonly used Delphi method, analytic hierarchy process and fuzzy comprehensive evaluation method. Due to varied principles and evaluation properties of single evaluation methods, the evaluation results of the same object vary with evaluation methods. In order to reconcile the differences between evaluation results, comprehensive evaluation was made in this study, taking 5 VTS centers in Z province for example, based on the combination evaluation method.

The study of combination evaluation method has been conducted from weight combination, evaluation method combination and combination of single method results. In terms of weight, the subjective weighting methods, such as analytic hierarchy process and fuzzy analytic process, were adopted in this study and moreover, entropy weight information method that uses objective weighting was combined to guarantee scientific and objective target weighting.

So, through the combination of the evaluation results, the rankings of operation effects of 5 VTS centers (A-E) are roughly the same, reconciling the differences in the results caused by the evaluations by independent methods.

CONCLUSION AND RECOMMENDATIONS

A systematic evaluation of the effectiveness of the operation and the implementation of software and management of VTS in Z province was made in this study and an in-depth evaluation was made from VTS structure, function, construction operation and personnel supervision model and combined with many factors, such as personnel and management mode. Study results show that the combination evaluation method is practical and suitable for VTS comprehensive evaluation and provides methods and guidance for the comprehensive and scientific evaluation of the comprehensive operation effects of VTS and can be used as a reference for VTS construction and development.

Specific recommendations include the following two aspects:

- With regard to the final evaluation results, VTS (B) present the best operation effect, followed by VTS (D) and (E) and then VTS (A) and (C). When hardware facilities are roughly the same, VTS operation effects depend on the innovation and management capacity of marine attendants and leadership of marine centers, so VTS centers should attach importance to the training and improvement of personnel quality
- There is a space for development and improvement of the comprehensive capacity of VTS centers, which is mainly manifested in the development and exploitation of VTS function application and value-added functions. For instance, there is no available advanced anchor aid inductive analysis or berth aid inductive analysis function in any VTS centers and they fail to make full use of the application of existing data analysis features to navigation decision analyses. Therefore, importance should be attached to the development of value-added services of the existing VTS data

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