QUANTIFICATION OF THE EFFECTIVENESS OF VESSEL TRAFFIC SERVICES

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1 INTRODUCTION

Vessel Traffic Services have been variously defined and exist in a number of configurations, but their fundamental objectives are **"safety of traffic and efficient traffic flow"** achieved by providing information and advice on other traffic and navigational hazards to the vessels participating in the system. In some cases the VTS centre has its own radar coverage of the waterway and directly maintains surveillance of vessel movements with complete communication systems. In other cases the centre will maintain the estimated track of vessels based on VHF communication and vessel reporting.

Categorization of VTS systems (USCG study)

- Level I A Vessel Movement Reporting System
- Level II The VMRS of Level I coupled with basic radar surveillance.
- Level III This system includes complete communication plus an state-of-the-art VTS radar surveillance system
- Level IV : Automatic dependent surveillance based on the use of differential GPS retransmissions.

The candidate VTS level in this study is Level III technology.

The estimation of the effectiveness of Vessel Traffic Services(VTS) is a diverse and complex problem. A review of the VTS effectiveness literature covering U.S.A, Canadian and European research suggests three potential approaches in estimating effectiveness:

- Simulation of a VTS system;
- Collection of opinions from experienced mariners and VTS operators;
- Statistical analysis of casualties in situations "with and without" VTS.

Simulation of a VTS system includes the use of full bridge simulators coupled with a simulation of a VTS centre, as well as various forms of mathematical simulation. Some work of this type has been done in Europe.[1]

Synthesis of expert opinion, to collect the opinions of experienced mariners and VTS operators, has been used in the Canadian Coast Guard Study [2], COST 301 Study [3] and U.S. Coast Guard Study [4] in connection with the estimation of the effectiveness of varying levels of VTS in different waterway types.

Another method is statistical analysis of casualties in situations "with and without" VTS. This method has been used in the COST 301 study.[5] A simplified fault tree analysis was used to indicate the complex relationships between factors. The causal relationships were collected and analyzed using a block scheme.

This study uses a new metnod determining the VTS benefits by multiplying casualty rate reduction factors by the effect level of causal factors. This method is a new approach to quantify the VTS effectiveness unlike any other earlier studies. Combining the casualty rate reduction factors with the effect level of causal factors, it produces more rational index of the effectiveness than the only synthesis opinion of expert or statistical analysis. This approach could reduce the overestimation of the percentage of the benefit by the another filtering process (selection of VTS addressable factors).

The primary objective of the effectiveness analysis in this study is to determine the expected percentage of the "addressable" casualties that could be prevented with the introduction of some form of VTS.

2 LITERATURE SURVEY RELATED TO VTS EFFECTIVENESS

2.1 LIST OF STUDY

(1) Expert's Opinion

- European VTS Project - Problem Area Identifier, 1986 [3]
- National VTS Study- Canadian Coast Guard 1984, 1988, 1991 [2][6][7]
- Port Needs Study(VTS Benefits)- U.S.C.G. 1991 [4]

(2) Assessment of Safety by Historic Performance

- Survey on Vessel Traffic Management Systems- 1984 [8]
- Trends in Navigation Safety in Dover Strait- 1978 [9]
- Safety Assessment of Waterway in Tokyo Bay- 1981, 1990 [10]

(3) Casualty Analysis

- VTS, Analysis of Port Needs- U.S.C.G., 1973 [11]
- Casualty Analysis of Selected Waterways- 1978 [12]

(4) Example of the study [6]

From the questionnaire results (COST 301 project) the study noted three main conclusions related to the effectiveness of VTS on collision rates.

☆ The more complex the shore support facilities become, the less difference there is between the effectiveness ratings.

☆ The results suggest that experienced mariners see little or no benefit in terms of risk reduction in the introduction of a control service rather than an information service.

☆ The maximum benefit to be obtained through the introduction of a VTS system is approximately 60 percent overall.

The results of the potential effectiveness of VTS in reducing stranding rates are estimated using same procedures. The study recognises two points of interest:

☆ The results are consistent with those for collision rates in that the subjects see only a small benefit in terms of risk reduction in the introduction of a control service rather than an information service at either of the VTS levels.

☆ The maximum benefit which is likely to be obtained through the introduction of any VTS system is estimated to be 55 percent.

The report also points out that the potential benefits of VTS for reducing stranding rates is somewhat less than for reducing collision rates.

2.2 RESULTS OF THE STUDIES

Table 1 VTS Effectiveness Percentage

Study	Collision	Grounding	Ramming	Foundering	Total
J S Park	50	47	36	21	46
COST 301	50	45			
CCG 1984					61(estd.)
CCG 1988					64(estd.)
CCG 1991	48 (P+NP) 64	69	48 (P+NP) 64		(estd.)
USCG 1991	27 (P+NP) 60	37	42		(estd.)
USCG 1973	65				32 (21 ports area)
USCG 1978					32 (5 waterways)
Tokyo Bay	42	45			43 (No. of accidents)
Rotterdam					73 (Accident rate in fog per 1,000 trips) 1.1→0.3
St. Lawrance	75				Av. No. of Collisions per year (12→3)
Elbe					50 (Amount of Loss due to delays in fog) $3M/year → Half
Dover	65				Av. No. of Collisions for 5 years (69→24) by Johnson
Dover	51	58			〃 (Dare/Lewison)

3 VTS ADDRESSABLE CASUALTY AND CAUSAL FACTOR

◆ VTS non-addressable casualties: Fire, explosion, shift of cargo,
Mechanical casualties such as power failure, loss of propulsion or steering,
Ramming tp docks while berthing and docking manoeuvres
Groundings in narrow channels by bank suction and slight heading errors

◆ VTS addressable casualties: Dynamic casualties (i.e., collisions, groundings, and rammings) Open water collisions between two vessels caused by surprise, poor visibility, or simple miscalculation.

An analysis was undertaken of all casualties that occurred in VTS study areas from 1986-1990. Using the selection criteria for a VTS addressable casualty, 381 ship-casualties were identified involving in collision, grounding, ramming and foundering incidents.

Many international studies agree that human error is the primary cause of all casualties. Whether the reason for this error is inattention, fatigue, mistakes in judgement, high-risk manoeuvres, or a lack of knowledge or experience, the underlying cause will be a lack of complete information on the bridge about what is happening around the vessel. Clearly, the mariner stands a better chance of making the correct decision if he has as much information as possible. The fundamental VTS role in reducing risk lies in their ability to provide the mariner with complete, accurate and timely information.[2]

◆ VTS addressable causal factors:

- reduced visibility by fog/mist/snow/etc
- excessive speed under the circumstance
- sailed on wrong side of fairway or in unmarked waters

◆ VTS non-addressable factors: no officer on the bridge or watchkeeper under other tasks, physical/mental health condition of watchkeeper, loss of propulsion or steering and accidental failure including electricity blackout, broken mooring rope and fracture of ship structure.

4 ESTIMATION OF VTS EFFECTIVENESS

In the estimation of VTS effectiveness procedure used in this study the following assumptions and limitations are applied:

(a) Collisions, groundings, rammings and founderings are the only types of casualties considered in this study.

(b) The estimation of VTS effectiveness is based on existing aids including:
- Vessel Movement Reporting System (VMRS);
- Traffic Separation Schemes (TSS); and
- Conventional aids - lights, buoys, ranges and loran.

Therefore the casualties already prevented by existing VTS systems are not considered.

(c) The VTS level and effectiveness in the waters under consideration is assumed to be Level III (Advanced radar surveillance) system

The causal factors of the casualties in the data base have been analysed using the evaluation procedure. As a result, the effect level of the causal factors has been obtained. These results form the basis for the estimation of the effectiveness of VTS.

The perceived importance and effectiveness of VTS activities which have been developed from the questionnaire survey form the risk reduction rates in the following procedure.

1) The possible effect of a VTS on a each activity (10 sub-sets) is expressed with a positive coefficient δ. (value of $\delta = 0$ indicates that VTS would have totally eliminated the causal factors contained in the activity, value of $\delta = 1$ indicates VTS would not have had any effect on the causal factors)

2) The formula $\Sigma n\delta/n$, n is the number of respondents, yields the casualty reduction rate to each of the activity.

The procedure was applied to the all casualties considered in this study, and then estimates the effectiveness. According to these results, the maximum benefit to be obtained through the introduction of a VTS system is approximately 46 percent overall.

Table 2 Estimated VTS Effectiveness Percentage by Casualty type

Sub-area	Tonghae	Pohang	Ulsan	Pusan	Masan
Percentage	30%	41%	53%	47%	49%
Sub-area	Yosu	Cheju	Mokpo	Kunsan	Inchon
Percentage	49%	40%	48%	50%	46%

Table 3 Estimated VTS Effectiveness Percentage by Sub-area

Type of casualty	Causal Factor Group	Sum of Weight Coefficient		Reduction Rate
		Without VTS	With VTS	
Collision	Environment	185.25	59.43	-0.679
	Human	326.75	195.85	-0.401
	Technical	10.25	6.71	-0.345
	Total	**522.25**	**261.99**	**-0.498**
Grounding	Environmental	61.25	27.74	-0.547
	Human	122.50	68.69	-0.439
	Technical	19.75	11.94	-0.395
	Total	**203.50**	**108.37**	**-0.467**
Ramming (Striking)	Environmental	18.00	11.79	-0.345
	Human	28.00	16.34	-0.416
	Technical	6.25	5.37	-0.141
	Total	**52.25**	**33.50**	**-0.359**
Foundering	Environmental	18.75	14.12	-0.247
	Human	26.50	16.36	-0.383
	Technical	29.50	28.67	-0.028
	Total	**74.75**	**59.15**	**-0.209**
Total	Environmental	282.75	113.08	-0.600
	Human	504.75	297.24	-0.411
	Technical	65.75	52.69	-0.199
	Total	**852.75**	**463.01**	**-0.457**

The percentages shown in the above table correspond closely with the other quantitative results. For example: the collision reduction rate (50%) obtained from the estimation procedure is below the values obtained by the experts' group in the U.S.A and Canadian study, but same as the estimates of European study (COST 301). The grounding reduction percentage (47%) is also very close to the value of COST 301 and Japan, but higher than the estimates of U.S.A. study(1991), and lower than the value of Canada.

5 SENSITIVITY ANALYSIS

Sensitivity analysis shows how the value of the criterion changes with changes in the value of any variable. This method is popularly used in project appraisal (Cost Benefit Analysis) and in optimization process. This consists essentially of varying key parameter values, usually one at a time but sometimes in combination, and assessing the effect of such changes on the outcome of the study.
This can be useful if information about key parameters is such that some common yardstick can be used to assess how far each parameter should be varied; it is common to vary primary parameters by a fixed percentage (e.g. 10%).[13]

One or more of the key variable inputs of this study may be somewhat uncertain and therefore subject to sensitivity analysis. The key variable of the VTS effectiveness percentage is the value of weight coefficient δ. Consequently, differing values for this input are derived in this section and the impact that these variations have on the VTS effectiveness noted.
In this sensitivity analysis, the weight coefficient have been varied by +10 percent and by -10 percent.

Table 4 Sensitivity Analysis of VTS Effectiveness by Casualty type

	Collision	Grounding	Ramming	Foundering	Total
Base	49.9	46.7	35.9	20.9	45.7
+ 10 %	57.0	53.5	41.1	23.9	52.5
- 10 %	42.7	39.9	30.6	18.0	39.1

6 SUMMARY

The methods of estimation of VTS effectiveness are compared and the worldwide literature related to the VTS effectiveness is reviewed. The review suggests three potential approaches: simulation; synthesis of expert opinion and statistical analysis of casualties. This study adopted dissimilar approaches to estimate the VTS effectiveness to the earlier studies; the combination of synthesis of expert opinion and causal analysis of casualty.

The VTS effectiveness is derived by multiplying casualty rate reduction factors by the effect level of causal factors. The development of casualty rate reduction factors was based on the questionnaire survey, and the evolution of effect levels was based on the causal analysis using functional block diagram.

According to these procedures, the maximum benefit to be obtained through the introduction of a VTS system was approximately 46 percent overall. The collision reduction rate was estimated to be approximately 50 percent for a VTS system with advanced radar surveillance. And 47 percent of groundings, 36 percent of rammings and 21 percent of founderings could be reduced by the introduction of VTS. These figures are more or less the same to the earlier studies.

The VTS effectiveness by the different causal factor groups was examined. VTS may reduce about 68 percent of causal factors classified as environmental conditions, 40 percent of human factors and 35 percent of technical factors in collision accidents. As a whole 60 percent of environmental factors, 41 percent of human factors and 20 percent of technical factors may be prevented by a VTS.

The key variable of the VTS effectiveness percentage is the value of weight coefficient δ. Therefore differing values for this input was discussed and the impact that these variations have on the VTS effectiveness noted. As the results of sensitivity analysis of VTS effectiveness by ± 10 percent, the effectiveness is varied approximately three to seven percent by casualty type. And the value is changed roughly four to eight percent by a ± 10 percent variation by different sub-areas.

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