Intelligent VTS

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ABSTRACT: In this paper the author depicts new approach involving fuzziness in navigational situation assessment. Nowadays operator at maritime traffic monitoring station is assumed to have access to a great amount of data. The data comes from different places and multiple of sensors. Properly associated data enable the operator to approximate congestion for each restricted and considered as vital regions. Ship's presence function within a confined area defines a non-empty bounded closed interval. It can be denoted by the earliest and latest bounds of the closed time interval at a given possibility level. To assess situation within any confined region one should calculate maximal sum of safety factors present within forecast imprecise slots of time. Safety factors themselves are also fuzzy, imprecise values.

1 INTRODUCTION

Vessels traffic is monitored using different appliances. Main monitoring aim is to check that everyone obeys imposed rules and traffic separation is not violated. The measure introduced within Vessels Traffic Systems (VTS), mostly used radar stations, significantly contributed to reduction of risk of collision and improved environment safety standards. Nowadays radar surveillance can be supplemented by other sources of data. AIS (Automated Identification System) which is about to be introduced seems rather limited in its ability. The throughput as well as an overall functionality seems do not meet expectations related to this new technology. For this reason there are attempts to create ad hoc networks to transfer even more data among ships using wireless transceivers. Dynamic schemes could include shore hot spot stations to open access to the internet and transmit data to all interested parties.

Multiple sources of data create new challenge regarding data association. The challenge is met by appropriate but still emerging technology called data fusion. By means of fusion, different sources of information are combined to improve the performances of a whole system. The most obvious illustration of fusion is the use of various sensors to detect objects. Available data could be subject to various processing and the results of different procedures may be further combined. Objectives such as detection, identification and tracking can be achieved thanks to data fusion. Data fusion produces high quality, enriched and reliable sets of data. Such sets are necessary for further processing to create foundations for decision making process.

Data fusion is a process dealing with the association, correlation, and combination of data and information from multiple sources to achieve refined position and identity estimates for observed entities, and to achieve complete and timely assessments of situations and threats, and their significance. These can contribute to further improvement of the safety standards in particularly within restricted waters. It is also assumed that VTS operator is able to have access to these reliable and enriched data, which create foundation for implementation and execution of a policy aimed at prediction and traffic control within the region.

Avoiding local congestion one can reduce number of encounters and furthermore potential risk of collision (Filipowicz et al. 2005). To introduce such measures a few assumptions are to be made. First there must be all data fused with unlimited data flow within wide area sea routes schemes. All local branches of VTSs are to be networked and all available data regarding traffic along with local conditions easily exchanged. Second there is a decision-making body within VTS structures. Databases are to be implemented and decision problems to be formulated and solved. The last comes along with proposal of the set of assessment criteria and delivering necessary tools to decision maker.

In order to take adequate decision one has to compare a handful of parameters of different types.

Basically there are crisp and fuzzy values to be taken into account. For particular vessel and each route, she is assumed to take scheduled traffic is an important factor. For VTS operator traffic encountered within each restricted and considered as crucial regions can usually be foreseen. Quality of the forecast depends on data precision.

To process imprecise inputs one has to introduce interval arithmetic with possibility level selected. Ship's presence within confined area defines a bounded closed interval of time. It can be denoted by the earliest and latest limits of a time slot with a given possibility level. To assess navigational situation within any confined region one should calculate maximal sum of safety factors present within at any moment. Safety factors, which reflect tonnage of a ship as well as carried cargo, are also likely to be fuzzy values. Subjective assessment of a term like "large vessel" should be perceived rather as a range of values than a single, crisp one.

Data fusion technology will be discussed in the next chapter. Fuzzy or interval arithmetic will be shortly presented in the further chapter. In the second part of the paper fuzziness in the vessels traffic engineering will be presented.

2 DATA FUSION

Modern VTS logical structure should integrate of traditional and advanced surveillance appliances, communications means, computer, and other technologies for purposes of improving navigation safety standards at waterways. The overall integration techniques are embraced within data fusion. Data fusion is a scheme of collecting, processing and enrichment of informational aspects of available data. Multiple level model (figure 1) extends from raw sensor data up to situation refinement and final decision making.

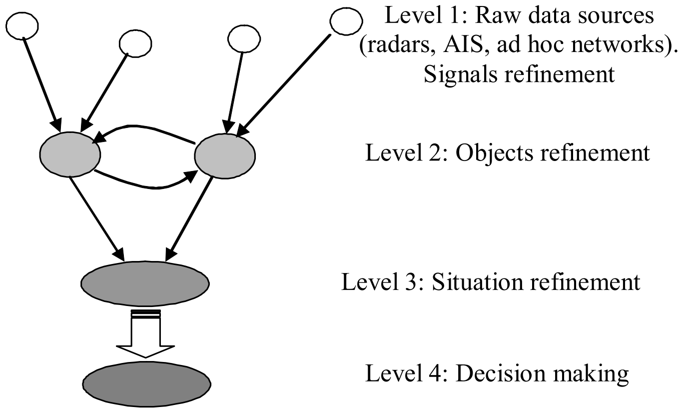

Fig. 1. General scheme of data fusion in maritime traffic engineering

Multi-source data fusion enables deliver information that is characterized by (Sarma et al. 1991):

– increased confidence - more than one sensor can detect the same object
– reduced ambiguity - joint information from multiple sensors reduces the set of hypotheses about the target
– improved detection - integration of multiple measurements of the same target increases possibility of detection
– extended coverage and reliability - one sensor can work when or where another sensor is out of order or remains beyond the range

Data fusion comprises four levels. Signal, object and situation refinement are carried out at the lower levels. Situation recognition and identification deliver reliable and adequate set of information for the highest level where decisions are made and recommendations issued. Table 1 shows main fusion levels, their methods and techniques.

Table 1. Main fusion levels, their methods and techniques.

Fusion level	Methods and main tasks	Techniques
Level one	signal refinement, position estimation	Kalman filtering
Level two	object refinement, pattern recognition	Bayesian methods, Dempster-Shafer reasoning
Level three	situation refinement	fuzzy logic, modeling
Level four	artificial intelligence, optimization, best passage recommendation	MADM Decision Making (TOPSIS, AHP)

2.1 *Level One Fusion*

Association of multi-sensor raw data is the main task for the first level of data fusion. It is supposed to correlate sets of sensor outputs. As a result the data can be used to estimate a target's position, course and velocity. In order to remove noise from sensor signals many systems employ Kalman filtering technique.

Kalman filtering produces data that estimate the targets positions. Consequently smoothed positions coordinates values enable better estimates of velocity and course (Linn et al. 1991). The accuracy, the tolerance of each sensor's output accuracy can be estimated and assigned. In such case object's approximate position can be roughly forecast. Kalman filtering delivers ability to define limits within which an object will be located.

2.2 *Level Two Fusion*

It is said that at level one sensor signals are refined. Level two data fusion is considered to be an object refinement level. It delivers more processed and meaningful data. To create a model of uncertain system states by consolidating and interpreting overlapping data delivered by different sensors Bayesian decision theory is widely used. Dempster-Shafer Evidential Reasoning (DSER) is an alternative to Bayesian approach. It is known as a generalization of Bayesian method that offers a way to combine uncertain information from various and unreliable sources. It works with fuzzy data, perceived as intervals of confidence instead of unique probability value.

Neural network technology can be also used at the second level of data fusion. Neural networks produce results that incorporate input from various information sources. A neural network consists of processing nodes that collect and compare data. Nodes also called neurons are interconnected and weights and applied to their outputs, which are then forwarded to the successor nodes. Usually a neuron has many inputs, but it has only a single output. It has attributed equations that define what the output would be like for given inputs. For neural network there must be learning scheme. During the learning period weights are adjusted according to the stimulation the neurons receive. During the learning process each neuron must be taught establishing the proper relation between their inputs and generated output. The network is taught through the observations of discrepancies between expected and achieved results which cause modified weights assigned to each neuron until an expected behaviour is obtained.

2.3 *Level Three Fusion*

The third fusion level is supposed to refine situations which result from detected objects movement. In the discussed navigation field it should create picture of what will take place within particular areas. In restricted waters with heavy traffic it is important to avoid local congestions in routes crossing regions.

It is quite often that values cannot be categorized using strict range limits. For example it is not practical to expect that a vessel will be crossing an area starting at time t_1 and ending at t_2. Instead one must specify that she will arrive sometime around t_1 and depart from the area at about t_2. Fuzzy logic is a type of theory that mathematically describes imprecision and is widely used at data fusion process.

This level also employs artificial intelligence methods. Computer Expert Systems emulate the behavior of a human expert. They consist of two components: inference engine and the knowledge base. The inference engine performs search through available possibilities in order to arrive at appropriate conclusions. The knowledge base is the set of facts and rules. These rules are usually in the form of “IF-THEN” statements. Modern expert systems are able to cooperate with knowledge bases using fuzzy logic.

2.4 *Level Four Fusion*

Level four should be discussed taking into account specificity of a particular field of interest. There are a few problems, which still remain unsolved, in vessels traffic engineering. First is a VTS supervisor problem when he is asked for advice on best possible passage for particular vessel. The problem is like “I am a VLCC scheduled to reach reporting point at some time. Please advise me the best route or an option for the passage. Should I delay in order to pass disturbed as little as possible”. The question is probably addressed to the VTS operator of the local control station. At the other side the advisory body of a VTS is supposed to be interested in such sporadic requests, but it also should be engaged in everlasting job of traffic allocation in order to avoid local congestions.

3 FUZZINESS

Often it is desirable to process imprecise or approximate values. Fuzzy numbers are useful when dealing with imprecision (Kaufman 1991). Fuzzy numbers are sets of the real figures that are treated as intervals. Their geometrical images are of triangular or trapezoid shapes and are called as membership functions. Triangular fuzzy value is referred as to triple of figures (a, b, c), trapezoid one as to quad (a, b, c, d). Fuzzy values express possibility of being within given range of values. They start from zero (lack of possibility) and reach maximum possibility level equal to one. Possibility is different than probability. Cumulated, integrated probability distribution must produce one as a final result. The requirement is not valid when dealing with membership functions.

Arithmetic of fuzzy values is related to the possibility level (α) and is based on α-cuts. The α-cuts of fuzzy numbers represent possibility levels and are closed intervals of real numbers. Mathematical operators on fuzzy values are applied to the boundary values of α-cuts. The idea of exploiting this fact delivers straightforward analytical method of dealing with non-linearity as a result of multiplication of a fuzzy values (Filipowicz 2006).

3.1 *Fuzzy Safety Factors*

Traffic should be classified taking into account gross tonnage of a vessel and a kind of cargo she has on board. Safety factors have been introduced to enable classification of vessels. In general approach environmentally dangerous freight and huge tonnage increase the factor. As it was proposed the factor vary on an integer scale such that the higher the number the more serious the consequences of an accident. Small value was assigned to small craft without dangerous cargo. The largest value was reserved for huge crude carriers. It was assumed that safety factor is easily assigned to every ship and classification is free from any ambiguity. Since small and huge are imprecise linguistic terms they should be treated as fuzzy values. Suggested assignment of imprecise, fuzzy safety factors to selected classes of crafts is presented in table 2.

Table 2. Fuzzy safety factors assignment.

Cargo		Tonnage of craft			
		Small	Medium	Large	Very Large
ND	SF	(0, 0, 1)	(0, 1, 2)	(2, 3, 4)	(4, 5, 6)
	Abr.	S	M	L	VL
	k	1	2	3	5
MD	SF	(3, 4, 5)	(5, 6, 7)	(6, 7, 8)	(8, 9, 10)
	Abr.	S&MD	M&MD	L&MD	VL&MD
	k	4	6	7	9
D	SF	(7, 8, 9)	(9, 10, 11)	(10, 11, 12)	(12, 13, 14)
	Abr.	S&D	M&D)	L&D	VL&D
	k	8)	10	11	13
VD	SF	(11,12,13)	(13,14,15)	(14, 15, 16)	(15, 16, 16)
	Abr.	S&VD	M&VD	L&VD	VL&VD
	k	12	14	15	16

General scheme of assignment is based on four classes of ship's tonnage: small, medium, large and very large. There are four categories of cargo: normal (ND - no dangerous), mildly dangerous (MD), dangerous (D) and very hazardous (VD). Table 2 contains proposal of assignment. Safety factors (SF) should be divided by 16 for the sake of normalization. Abbreviations used in examples included in the paper as well as k value to be applied with formula 1 are also presented in the table 1. Final assignment embraces distortion caused by supremacy of tonnage over cargo for the adjacent groups of carried load. Very large vessel without hazardous cargo has greater factor then small ship with mildly dangerous material on board.

For given *k*, indicating number included in table 2 normalized fuzzy safety factor can be calculated using formula (1).

$$SF_k = \begin{cases} [0, 0, w_1] & for\ k = 1 \\ [(k-1)*w_1, k*w_1, (k+1)*w_1] & for\ 1 < k < n_c \\ [1-w_1,\ 1, 1] & for\ k = n_c \end{cases} \qquad (1)$$

$$where \quad w_1 = \frac{1}{n_c - 1} \quad and \quad n_c \ is\ equal\ to\ number\ of\ classes$$

3.2 *Fuzziness in maritime traffic engineering*

Whenever restricted area passage is considered traffic encountered at routes crossings is to be taken into account as important factor. Awareness of other ships significantly increases wherever collision avoidance is hampered. To assess navigational situation within confined areas approximations regarding all scheduled traffic are to be taken into account.

Due to unforeseen deviations from intended track, bad estimation of main engine performance and collision manoeuvres seafarers always use estimated time of arrival. For the same reasons ship's presence within any area should be treated as trapezoid fuzzy value. The values consist of estimated earliest and latest time of arrival as well as earliest and latest possible time of departure from the region. Situation within confined area are vital from safety point of view. Figure 2 presents example with a few crafts that are scheduled to pass restricted area. There are four vessels that are very likely to encounter within the region where any collision avoidance manoeuvre is seriously hampered. Vessels types were classified as: S&D, L&D, S&MD, S&D (see table 2). Intended courses of the vessels are shown at figure 2. Sea and weather condition along with tonnage and speed of each craft are given and subsequently fuzzy timetable of crossing the area were estimated, example results are presented at figure 3.

As it was already mentioned time frame of ship crossing an area can be defined by trapezoid fuzzy value. The membership function starts at the earliest time of arrival and ascends to the appropriate latest moment. This part of the function represents entering phase, its inclination depends on the initial distance from the area, weather condition, tonnage as well as on propulsion ability of a particular craft. Collision avoidance manoeuvres (if any) introduce further delays. Right hand side of the function represents departure phase and consists of a leg joining earliest and latest possible time of leaving the region. Figure 3 shows example membership functions for situation presented in figure 2.

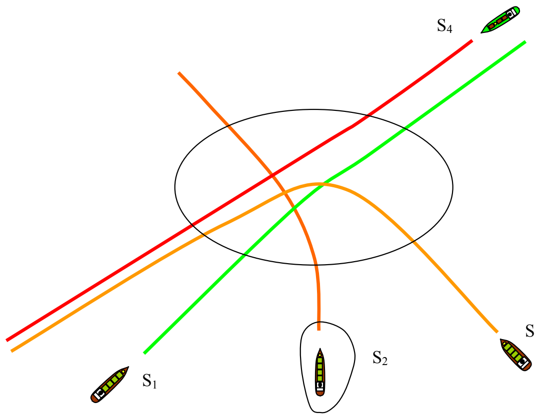

Fig. 2. Vessels that are likely to encounter within confined area create potentially dangerous situation

Let us consider situation presented at figure 2. We assume that one of the vessels marked as S_2 seeks for advice on best passage option (route to be taken and/or time frame suggested). In the presented situation, according to the COLREGS regulations (see International Maritime Organization website www.imo.org/Conventions/for details), she is supposed to be give-way with respect to S_3 and S_4. Her status referring to S_1 is stand-on. The status of the vessel of interest with respect to each another yields fuzzy weight factor. Table 3 embraces all close approach situations and suggested normalized fuzzy weight factors.

The most uncomfortable is crossing encounter with give-way (as stipulated by COLREGS) status. The potential of the situation gets even worse where there is confined room to carry out collision avoiding manoeuvre. For this reason respective weight coefficient is the highest one.

Table 3. Close approaches and their fuzzy weight factors.

Encounter type	Vessel status and its abbreviation	Fuzzy weight
Crossing	Give-way, CGW	(0.8, 1, 1)
Crossing	Stand-on, CSO	(0.4, 0.6, 0.8)
Overtaking	Give-way, OGW	(0.1, 0.3, 0.5)
Overtaking	Stand-on, OSO	(0, 0.1, 0.2)
Head-ons	Give-way (each vessel), HO	(0, 0, 0.1)

Abbreviations used at figure 3 stand for:

$A^{\alpha}_{l\,Si}$ - earliest time of arrival of the ship S_i to the given area taking into account α possibility level
$A^{\alpha}_{u\,Si}$ - latest time of departure of the ship S_i from the given area taking into account α possibility level
$f^{L}_{Si}(t)$, $f^{R}_{Si}(t)$ - left and right hand side boundary of the presence function for ship S_i (linearity assumed)
$f_{Si}(t)$ - overall presence function for ship S_i within given area
t_m - time for which maximum fuzzy congestion is found

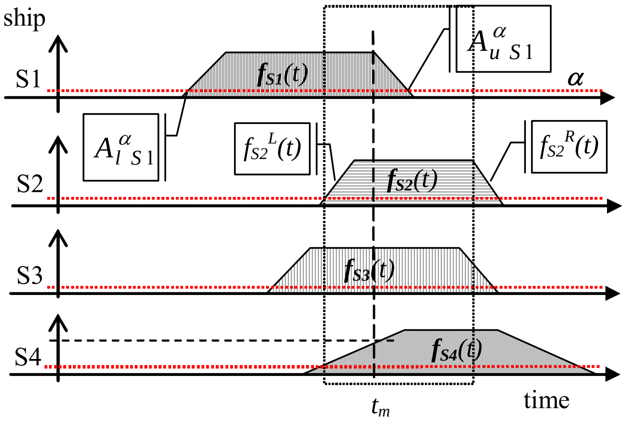

Fig. 3. Ship's presence within restricted area can be perceived as trapezoidal fuzzy values. To assess passage condition one has to scan entry phase and staying within time slot

To assess passage condition for given vessel one has to scan at least her entry phase and „staying within" time slot. The slot for the situation presented in figure 2 is marked in figure 3 with rectangular shape. Numerical calculation for the situation is included in table 4. Column „α-cut of the product" in this table contains boundary values for possibility levels α respectively equal to 0, 0.4, 0.8 and 1.

Table 4. Navigational condition assessment for example area.

Ship	Fuzzy SF	$f_{Si}(t_m)$	Status/ Weight	α-cuts of the product
S_1(S&D)	(7, 8, 9)	1	CSO/ (0.4, 0.6, 0.8)	[0.145, 0.436] [0.192, 0.367] [0.244, 0.303] 0.273
S_2(L&D)	(10, 11, 12)	1	own ship/ (1, 1, 1)	[0.727, 0.909] [0.764, 0.873] [0.800, 0.836] 0.818
S_3(S&MD)	(3, 4, 5)	1	CGW/ (0.8, 1, 1)	[0.073, 0.273] [0.112, 0.236] [0.157, 0.200] 0.182
S_4(S&D)	(7, 8, 9)	0.8	CSO/ (0.8, 1, 1)	[0.223, 0.436] [0.281, 0.407] [0.335, 0.378] 0.363
TOTAL				[1.178, 2.055] [1.349, 1.883] [1.536, 1.717] 1.636

Final result shows total non normalized and non regular fuzzy value. To compare such values one has to normalize and defuzzify them. Defuzzification converts imprecise intervals into crisp value. Many fuzzy number ranking methods can be used. However, no one can rank fuzzy numbers satisfactorily in all cases and situations.

3.3 *Membership functions estimation*

To foresee encounter numbers a timetable of arrival at given points are to be constructed for each scheduled vessel. Timetable of passage, for each vessel, and for given area is a vector of fuzzy slots, which are quads of values that define membership or "presence in the region" function. Earliest arrival time (A_{lE}) and the latest departure time from the area (A_{uL}) of the particular vessel are reference values that create a time frame. The frame is to be scanned to evaluate crossing condition.

Shapes of the presence functions, associated with difference between earliest and latest moments of arrival or departure primarily depend on necessary deviation from the prescribed trajectory. To foresee what will take place within given area one has to construct (or learn) all presence functions. Approximate numbers of collision avoidance manoeuvres are to be counted since they influence inclinations of ascending and descending slopes of the functions. These can be estimated based on simulations. Modeling and simulation computer environment is necessary for implementation of the discussed idea.

Basic assumptions of the environment concept embrace:

- there is a module with interface enabling definition of the routes scheme (arrival and turning areas). Route consists of legs linking turning areas
- there is an interface enabling input of initial positions and intended route for all crafts
- there is an interface enabling ship domain(s) definition and selection, there must be database of domains available
- decision regarding collision avoidance manoeuvre is based on domain penetration by another vessel. Adequate manoeuvre, as stipulated by COLREGS, is carried out if required. There must be an option of passing through without looking at others (no collision avoidance manoeuvres carried out)
- Close quarter approaches are classified and recorded, all data necessary for further analysis of ships involved in close approach are also stored
- movement along prescribed trajectory is double screened random Markovian process.

For the sake of membership function estimation all initial positions of all scheduled traffic for given moment, using all available sources and techniques must be calculated. Schedule traffic destinations and intended or assumed routes are to be fixed. Average values of their engines performances must be gathered.

Two steps of analyses „for presence within" functions estimation are suggested. At first earliest arrival times are calculated and close quarter situations registered. Shortest possible paths assuming no violation of the separation schemes are taken into account. During simulation with collision avoidance option switched off encounters are detected when safe distance limit is violated. All close approaches are recorded for further analysis. Data of ships involved in close approach are also stored. Two ships are registered being involved in close approach when it first occurs, their subsequent mutual positions are not considered unless category of encounter is changed. Categories list of encounters embrace: meeting, overtaking and crossing, which is further subdivided regarding angle of crossing.

At the next step latest arrival times are estimated. Selected domain and all encounters are taken into account and numbers of collision avoidance manoeuvres are estimated for each of the vessels. It is assumed that necessary collision avoidance is carried out whenever adopted domain is penetrated by another vessel. Such manoeuvre influences presence function within all regions remained for passing along given route. All these lead to estimation of latest moments of presence functions.

4 FINAL REMARKS

Data fusion approach to deal with multiple data sources in vessels traffic engineering was briefly presented. Navigational situation within restricted regions were characterized using fuzziness. Ships fuzzy safety factors related to gross tonnage and sort of carried cargo were proposed. Presence within confined area was also considered as fuzzy set. Membership function learning method was also discussed. Arrival and departure from selected routes crossing areas are trapezoidal imprecise values. Membership functions are to be learned for particular region, weather condition and each class of vessels. The imprecise, approximate data were used to assess navigational situation within routes crossing area. Product of fuzzy factor and imprecise weight creates non linear result. To enable calculations the α-cuts proved to be helpful.

Having at his disposal reliable and fused large quantity of data and appropriate software tools VTS operator seems to be able to forecast traffic congestion within each confined region. Traffic encountered inside such area is important and contributes to overall safety standards. Adequate methods for building hierarchy among alternatives with widerange of parameter types have been implemented and discussed by Szlapczynska (Szlapczynska 2005).

Multi criteria problem faced by VTS control station operator was also considered by the author (Filipowicz 2006). Practical case of decision making in vessels traffic engineering was presented. Example included there dealt with system of routes with rather heavy traffic with one of the vessels that sought advice on best passage. Best option was calculated using extended multi-criteria decision aid software.

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