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ON NAVIGATIONAL SITUATION EVALUATION UNDER AMBIGUITY AND PARTIAL EVIDENCE

ABSTRACT

The paper depicts new approach involving navigational situation assessment. Nowadays operator at maritime traffic monitoring station have access to a great amount of various quality data. Information come from different sources and the data are generated by multiple of sensors. Multiple sources of data create new challenge regarding data association. The challenge is met by technology called data fusion. By means of fusion, different sources of information are combined to arrive at proper decision.
Ships safety factors were introduced to enable vessels' classification regarding potential consequences of an accident. It is assumed that safety factors are fuzzy, imprecise values. Small ranges of value were assigned to small craft without dangerous cargo. The largest intervals are reserved for huge crude carriers. Fuzzy factors (SF) depend on subjective evaluation of ships tonnage and on amount as well as harmfulness of their cargo. Extended scope of the SFs is introduced and reasoning on subjective classification discussed. Included numerical example illustrates presented material.

Keywords: Navigational Risk Prediction, Ships' Safety.

INTRODUCTION

The operational areas of sea going vessels can be divided into three major parts: port, restricted area and open sea. Published statistics show that collisions and groundings within confined regions create the biggest problems for the environment. Available data show that restricted areas create highest risk of collision and stranding. New approach is sought and solutions are to be suggested. Within restricted areas there are zones of routes intersections, where potential collision manoeuvres are hampered. Such zones are of particular concern for those who are engaged in practical as well as theoretic aspects of risk reduction.

There were many risk model developed all of them focused on probability of collision estimation. Most of them say that the probability of collision depends on the crossing area topology as well as on an encounter rate [1].
An encounter is a situation involving penetration of the domain area of any ship by another vessel. Thus any method of distributing the traffic that results in the avoidance of a local accumulation of ships should be considered vital in restricted areas since it would lead to a reduction in the number of encounters.

The paper deals with quantifying navigational situation within confined crossing routes areas. It is supposed to help in reduction of encounters for a particular vessel while passing through a restricted area. Alternatively, based on obtained evaluation, traffic within an area can be allocated over the whole region. Proposed evaluation of the navigational situation deals with uncertainty, ambiguity and incomplete evidence.

UNCERTAINTY AND IMPRECISION IN TRAFFIC ENGINEERING

Uncertainty and ambiguity is related to human judgment. Uncertainty differs its meaning referring to considered case. Stochastic and epistemic or subjective uncertainties are discussed in many papers. Stochastic also called aleatory uncertainty reflects unknown, usually unpredictable behavior of a system. The system behaves in stochastic way when its future states can be forecast based on probability theory. In maritime traffic engineering there are acceptable alternatives routes exist quite often. Attempt to point at the route taken by particular vessel is related the aleatory uncertainty. Traditional statistical approaches are helpful in this respect. Data gathered in stored records are to be analyzed in order to draw proper conclusions.

Shortage of knowledge, ignorance or lack of evidence creates another kind of uncertainty. Epistemic or subjective uncertainty results from ignorance or vague evidence. Question of identity of a spotted object refers to this sort of uncertainty. It is quite often when observer at monitoring station spots new radar mark and tries to find out what kind of vessel this could be. Usually there is some evidence available, for example radar echo signature and estimate of speed can be helpful. Modern AIS technology transfers data useful in identification but published statistics indicate errors in its functionality. Yet another sources point at wide misuse of the technology, many ships carry devices which are simply switched off.

Radars deliver plenty of data used for objects identification. These data are further used for navigational situation refinement. Quantifying navigational condition within confined crossing routes areas is crucial from overall safety standards. Questions that involve epistemic uncertainty that refer to an identity of a vessel could be:

What type of ship is associated with each of the marks seen on the radar screen?

- What is a tonnage (expressed in linguistic terms) of each vessel?
- What hazardous cargo (if any) does each of the vessels carry?
- How much of dangerous cargo does each of the vessels carry?

Aleatory uncertainty is imbedded in another issue, for example:

- What are time frames of passage through the intersection routes zone?
- Does the intended itinerary pass close to the middle part of the zone?

In classical probability theory the knowledge of the probability of an event can be used to calculate likelihood of the contrary statement. The theory also requires data regarding probability of all considered events. Because of this shortcoming probability theory disables modeling ignorance and partial evidence.

Mathematical Theory of Evidence is more flexible in this aspect. Contrary to probability theory it enables modeling knowledge and ignorance. Evidence can be combined, even partial knowledge associated with less meaningful facts end up in valuable conclusions. In combining evidence probability judgments can be obtained for each hypothesis. Hypothesis refers to atomic and/or molecular events. Sometime atomic cases are beyond available scope of knowledge. At the same time reasoning can be made with respect to a structured or molecular event. New extensions to cope with imprecision are also available since it is often that to obtain precise figures is infeasible.

Automatic Identification System and imprecision

Automatic Identification System (AIS) enables automatic data exchange among vessels as well as shore stations. The data can be also exchanged among ships and aircrafts. It was designated to enrich functionality of radar equipment. The last is known for its limitation in its ability of object identification. Accuracy and time delay in an object refinement are main disadvantages of modern radars. Packets of data transmitted within the AIS transfer: ship's identifier, her dimensions, heading, speed, destination and intended itinerary. Information regarding dangerous goods carried onboard is also exchanged.

For this reason it seems source of valuable data enabling ships refinement. Unfortunately data transmitted are not always correct [2]. Percentage of cases when ship borne AIS equipment is simply switched off is also significant.

Method of collecting and combining evidence with AIS as one of unreliable sources is sought. System exclusively based on AIS as the only source of data seems not acceptable. Statement like “too many large vessels encountered nearby buoy X create high risk of accident” widely used among VTS operators remains formally unsolved. Meaning of such terms as “large ship” or “dangerous cargo” is subjective and imprecise. Classification of vessels and their cargos using linguistic terms involves ambiguity. Classification process itself can be evaluated as poor or good if such limited scope of propositions is used.

Safety Factors

Traffic is 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. 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. There was range from 1 to 10 suggested by the author [3]. 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 safety factors to selected classes of crafts is presented in table 1.

General scheme of assignment was based on five classes of ship’s tonnage: very small, small, medium, large and very large. There were three categories of cargo: mildly dangerous (MD), dangerous (D) and very hazardous (VD). Quantity of cargo was classified using the similar terms as for ship’s tonnage. Table 1 contains k value to be used with formula 1 in order to calculate a fuzzy factor.

$$SF_k = \begin{cases} [0, 0, w_T / 2 * w, 0.5 * w] & if\ k = 1 \\ [(k-1) * w, k * w - w_T * w, k * w + w_T * w, (k+1) * w] & if\ 1 < k < n_c \\ [1 - 0.5 * w, 1 - w_T / 2 * w, 1, 1] & if\ k = n_c \end{cases} \quad (1)$$

where: $w=1/(n_c-1)$

$n_c=n_T*n_H*n_{QH}$ – is a product of tonnage terms (n_T) and hazardous cargo quantity (n_{QH}) and quality classes (n_H).

$w_T \in [0, 1]$ – is a trapezoid factor. Note that $w_T = 0$ means that SF_k is a triangular fuzzy value and $w_T = 1$ means rectangular one.

Table 1. Factor k for extended set of fuzzy safety factors assignment

	Quality of cargo											
	mildly dangerous				dangerous				very dangerous			
	Cargo quantity				Cargo quantity				Cargo quantity			
Tonnage	small	medium	large	very large	small	medium	large	very large	small	medium	large	very large
very small	1	2	3	4	5	6	7	8	9	10	11	12
small	13	14	15	16	17	18	19	20	21	22	23	24
medium	25	26	27	28	29	30	31	32	33	34	35	36
large	37	38	39	40	41	42	43	44	45	46	47	48
very large	49	50	51	52	53	54	55	56	57	58	59	60

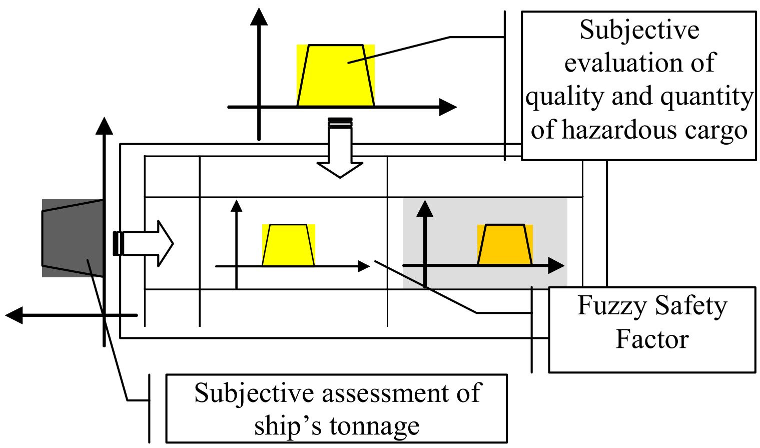

Fig.1. Fuzzy Safety Factor assignment involves subjective evaluation of ships tonnage and hazardous cargo

Safety factor calculation, see figure 1, involves fuzzy reasoning on ships tonnage, harmfulness of her cargo and quantity of the cargo. Details regarding imprecise reasoning could be found in [4].

Membership functions

Membership functions in fuzzy events are considered subjectively. Such functions are usually arbitrary selected regular ones, for example trapezoids for mentions linguistic terms. There are also membership functions created based on expert opinion. Basic for these functions are belonging frequency for unit interval x_i. Let us consider statistical experiment in which experts are asked what they think about 40 000 dwt tonnage of a vessel in terms “very small”, “small”, “medium”, “large”, “very large”. It is also assumed that experts are aware of local conditions. The conditions should be taken into account whenever experts deliver their opinions. Experiment scenario is presented in table 2.

Table 2. Meaning of “how large is 40 000 dwt ship” delivered by five experts

	linguistic term															
	very small				small			medium			large			very large		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	25	16
#1									x	x	x	x	x			
#2							x	x	x	x	x					
#3								x	x	x	x	x				
#4										x	x	x	x			
#5											x	x				
Freq.	0	0	0	0	0	0	0.2	0.4	0.6	0.8	1	0.8	0.4	0	0	0

Membership function of an assessment “how large is 40 000 dwt vessel” for the above experiment is as follows: $\mu_{40\,000}(x_i) = \{0.2/\ 7,\ 0.4/\ 8,\ 0.6/\ 9,\ 0.8/\ 10,\ 1/\ 11,\ 0.8/\ 12,\ 0.4/\ 13\}$.

Consecutive columns of the table 3 are related to a unit interval of specified linguistic terms. Shaded columns indicate overlapping. Consequently assuming regular trapezoid fuzzy values related to the term “large” yields: $\mu_{large}(x_i) = \{0.5/10,\ 1/11,\ 1/12,\ 0.5/13\}$. One of the primary achievements of fuzzy sets theory is ability to evaluate inclusion. Credibility can be calculated regarding statement “to what extend $\mu_{large}(x_i)$ is included in $\mu_{40\,000}(x_i)$”, or in any other similar proposition or in set of propositions [4]. Credibility is usually given as a range [belief, plausibility] (see table 3).

NUMERICAL EXAMPLE

Usefulness of presented methodology is presented through the example. To assess situation within confined areas approximations regarding all scheduled traffic are to be estimated. Ship's presence within an area is trapezoid fuzzy value. The values consist of estimated earliest and latest time of arrival and earliest and latest possible time of departure from the region. As an example let us consider situation when four crafts are scheduled to pass restricted area. There are four vessels that are very likely to encounter within the region. The vessels were identified as: small with small quantity of dangerous cargo S&S&D, medium with large quantity of dangerous cargo M&L&D and small with small amount of dangerous cargo S&S&MD, the last one is large container with large amount of dangerous cargo onboard L&L&D. Data regarding involved ships are gathered in table 4. Consecutive columns in the table contain:

– abbreviated ship characteristic,
– k – factor extracted from table 2,
– Safety Factor calculated with formula 1 for given k,
– [Belief, Plausibility] - limits of credibility attributed to the identification process,
– $f_{si}(m)$ – "staying within an area" membership function value.

Table 3. Data regarding ships mentioned in the example

Ship	k	Safety Factor	[Belief, Plausibility]	$f_{si}(m)$
S&S&D	17	(0.271, 0.281, 0.295, 0.305)	[0.40, 0.60]	1,0
M&L&D	31	(0.508, 0.519, 0.532, 0.542)	[0.55, 0.85]	1,0
S&S&D	13	(0.203, 0.214, 0.227, 0.237)	[0.40, 0.60]	0,8
L&L&D	43	(0.712, 0.722, 0.736, 0.746	[0.37, 1.00]	0,9

The result figures for selected possibility levels are given in table 4. The figures are left (L^{α}) and right (R^{α}) boundary values for specified α- cuts.

Table 4. Final result as irregular fuzzy value

α	L^{α}	R^{α}
0,0	0.485	1.000
0,2	0.487	0.996
0,4	0.489	0.992
0,6	0.492	0.988
0,8	0.494	0.984
1,0	0.496	0.979

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