SITUATION AWARENESS AT SEA—VESSEL TRAFFIC SERVICE SUPPORT

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Abstract Influence of Human Element in shipping industry is rapidly increasing. Human error costs the maritime industry $541m a year, according to the UK P&I Club. From their own analysis of 6091 major claims (over $100,000) spanning a period of 15 years, the Club has established that these claims have cost their members $2.6bn, 62% of which is attributable to human error, NI[1].

More serious and egregious attributions involving SA occur when "Bridge or Shore based Personnel" error due to loss of SA" is listed as a cause of accidents, M.R. Grech et al[2]. The results from maritime operations literature survey revealed that 71% of human errors were Situation Awareness related problems.

SA,from the view point of VTS operator, includes some Human Factors (psychological constructs), but we concentrate in this paper on navigational aspect and one of them is assessment (measuring) of navigational situation in certain area, which is highlighted and investigated in the proposed paper. The techniques to measure the situation closeness to approved standard from the view point of safety level are proposed.

Keywords Vessel Traffic Service(VTS); Situation Awareness(SA); Situation Assessment (SASS); Safety of Navigation

Situation Awareness is "the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent **situation assessments**" Smith and Hancock (1994).

0 Introduction

The most critical situation for a safety of navigation develops in approaches to ports. It explains enhanced attention to development of VTS (Vessel Traffic Services) that is expressed in realization of not only national, but also the international projects. The decision of SA problem, thus, is beyond one vessel and should to be considered in wider aspect. VTS personnel decision making procedures directly contribute to navigational safety.

There have been numerous attempts of developing both adequate definitions and formal models of SA in different industries. None of the more widely accepted approaches to defining and explaining SA are without flaws. At the same time, numerous techniques have been suggested for the assessment of SA, for example in aviation, and each of these techniques has relative strengths and weakness associated with them. The main first step of SA by VTS operator is Situation Assessment (SASS) which is to be visualized and measured.

1 Situation awareness and situation assessment

Endsely[3], defines three levels of situation awareness: perception, comprehension, and projection. Perception is the basic level of situation awareness (SA level 1). This level of awareness is achieved if VTS operators are able to perceive in the user interface information that is needed to do their job. The next level is comprehension (SA level 2). Not only must the information be perceived, it have to be combined with other information and interpreted correctly. The third level (SA level 3) is projection or the ability to predict what will happen next based on the current situation. As situations are dynamic, time is critical to situation awareness as well. User interfaces need to be designed to facilitate the continuous acquisition of SA.

Two elements are needed to support SA, W. Zhang et al[4]. The first is a representation of the situation. The representation needs to include information about relevant objects in VTS area (ships, dangers, weather,…), their features and logical, organizational and spatial relationships, actions for supporting and understanding the situation, and possible actions for responding to different perceptual input and external events. Here we use terminology introduced in W. Zhang[4], and call such a representation as *situation* (*navigation*) *template* or *template* for short.

The second element to support situation awareness of VTS operator is a set of tools for situation assessment. Situation assessment has at least three objectives. It is to correctly identify the relevant objects in a visual or audio fields from such information sources as radar, e-charts, AIS, communication aids…etc.; find association relationships among the perceived objects and create a structured representation of the objects and map the structured representation to possible situation templates and identify the most similar ones. We use partly this ideology and call a structured representation of a set of identified objects (vector) a *pattern*, W. Zhang et al[4].

In this paper a *situation* (*navigation*) *template* is the set of navigation regulations and safety standards covered the navigation area. Situation assessment is assessment of *pattern* against the appropriate template. The deviation of current situation from the template we call as a *safety level* and fix it from 1 (full compliance) to 0 (full incompliance).

Here we understand for purposes of clarity that the *Situation Assessment* is an active process of seeking information from the environment and assessing the level of safety linked with SA level 1 and SA level 2 to support the SA level 3.

The concept of SA is of great interest in research how the OOW or Master on board the vessel could be supported by VTS operator in their watchkeeping duties to maintain the highest safety of navigation level.

The main difficulty of SA and SASS is to "measure" the situation. In order to do it the criteria is to be appointed. In our paper this criteria is a *safety level* of current navigational situation at time t_i.. We investigated some conceptions which are not mentioned in known to authors literature.

1.1 Situation Assessment by template vector

By angle between vectors

The most simple template vector $\boldsymbol{S}_{\mathbf{i}}$ of navigational safety may be constructed as follows:

$$\boldsymbol{S}_{\mathbf{i}} = (s_1\ s_2\ s_3\ s_4\ s_5\ s_6\ \ldots) = (\ x_i,\ y_i,\ COG_i,\ SOG_i, RB_i,\ D_i\ldots) \quad (1)$$

where the vector components are: x_i,y_i –coordinates of a vessel; COG_i–course over ground; SOG_i –speed over ground; RB_i–relative bearing to a danger; D_i –distance to danger;

The standard template vector of vessel's state in the navigation area has all the components equal to 1:

$$S_{\mathbf{i}} = (1\ \ 1\ \ 1\ \ 1\ \ 1\ \ 1\ldots) \quad (2)$$

it means that in this case the vessel movement is completely meets the area regulations.

The pattern vector of vessel's running state can be expressed as follows:

$$\boldsymbol{R}_{\mathbf{i}} = (r_1\ r_2\ r_3\ r_4\ r_5\ r_6\ \ldots) = (\ x_i,\ y_i,\ COG_i,\ SOG_i, RB_i,\ D_i\ldots) \quad (3)$$

So, cosine of the angle β between vectors $R_{\mathbf{i}}$ and $S_{\mathbf{i}}$ is assumed as a "deviation to danger" from regular vector $S_{\mathbf{i}}$ and can be expressed in $2D$ space. Moreover it can be detected, decoded and indicated to VTS operator or navigator, Fig.1 (d), so:

$$SASS = \text{cosine}\ (\beta) \quad (4)$$

Some limitations of the proposed technique are as follows:

- if the vectors are collinear it is not working;
- if the angle between vectors is small (up to 10^0) then the cosine is non sensitive to reflect the proper deviations.

By relative deviation of pattern from standard template vector

The components of relative deviation vector $D_{\mathbf{i}} = (d1\ d_2\ d_3\ d_4\ d_5\ d_6\ldots)$ are formed as follows:

$$d_i = [\Delta_i - abs(s_i - r_i)]/\Delta_i, \quad (5)$$

then, for n-dimensional vector $\boldsymbol{D}_{\mathbf{i}}$**,** Fig.1 (C):

$$SASS = \Sigma d_i/n \quad (6)$$

where Δ_i- is the i-th maximum allowable deviation from standard of every parameter in navigation area and then we use arithmetic mean from all components to calculate SASS.

Fig.1 shows SASS as a cosine of angle β between four-dimensional vectors $\boldsymbol{R}_{\mathbf{i}} = (r_1\ r_2\ r_3\ r_4)$ and $\boldsymbol{S}_{\mathbf{i}}$

=($s_1\, s_2\, s_3\, s_4$) and SASS for the same vectors computed by formula (6). We can observe the very close similarity of curves. The example is based on simulated pilotage pattern to port of Boulogne using TRANSAS full mission navigation simulator.

The technique conceptually shown above works and can serve for the current assessment of situation, i.e. for measurement of *SA* level 2-comprehension if the vessel's parameters of movement and as their deviation from recommended standards are known.

Vector $\boldsymbol{D}_i$ can include the other components which define the current deviation of vessel state in navigation area from the established safety standards, for example:

- Weather conditions of navigation;
- If the voyage plan is in place or not;
- The geometrical size of ship and her draught;
- Crew competency, performance and its fatigue levels;
- Communication skill of the crew and VTS operator
- Condition of navigating equipment and charts;
- If the pilot is on board the vessel or not;

MOU on PSC target factors … etc.

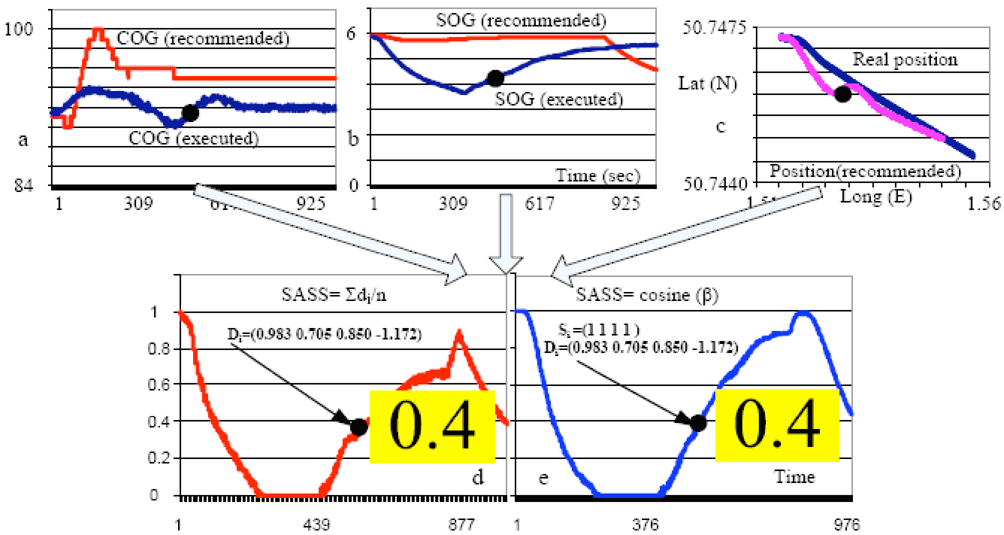

Fig. 1 SASS: a, b, c. input parameters; d. average sum of relative deviations of components; e. consine of angle between vectors

1.2 Situation Assessment by Fuzzy Inference System (FIS)

The main idea to use fuzzy logic is to avoid the shortcomings associated with possible non proper functional dependency of parameters describing the navigation area in mathematical models and to use language which is the instrument to construct the regulations, V. Loginovsky et al[5].

Let us suppose that in some navigation area restricted by coordinates (x, y) for vessel proceeding southward alongside the reference line it is necessary to comply to some navigation regulations, that means to keep recommended COG=135^0 and SOG=8 knots. Deviations from this COG and SOG equal to more than 5 degrees and 2 knots are prohibited. Additional requirement is the following: any danger should appeared within relative bearings of 20 degrees at distance at not less than 25 cables. If the distance to danger is shorter it means that the navigation situation is not meeting the area regulations. So this is the standard template vector of vessel state.

The following conceptual FIS is applied for SASS:

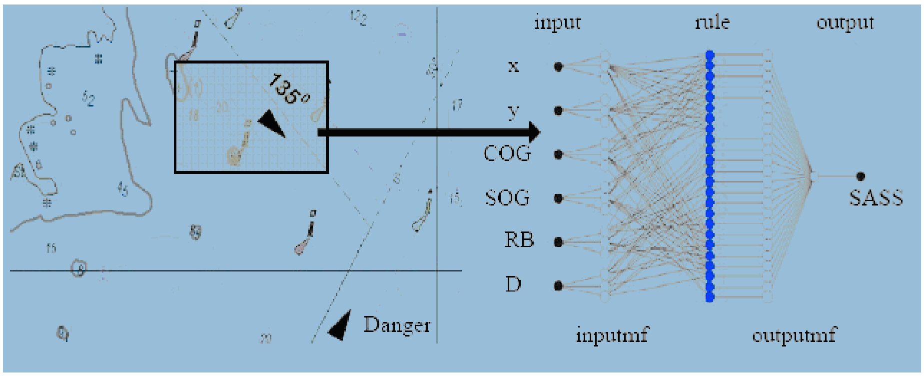

Fig. 2 SASS area and it's FIS model

The triangular membership functions and fuzzy rules are presented in Fig. 3. Sugeno algorithm is used for FIS construction.

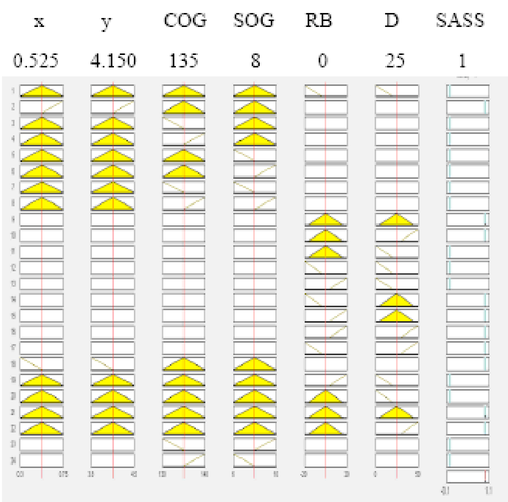

Fig. 3 Fuzzy rules demonstrate the SASS at standard state

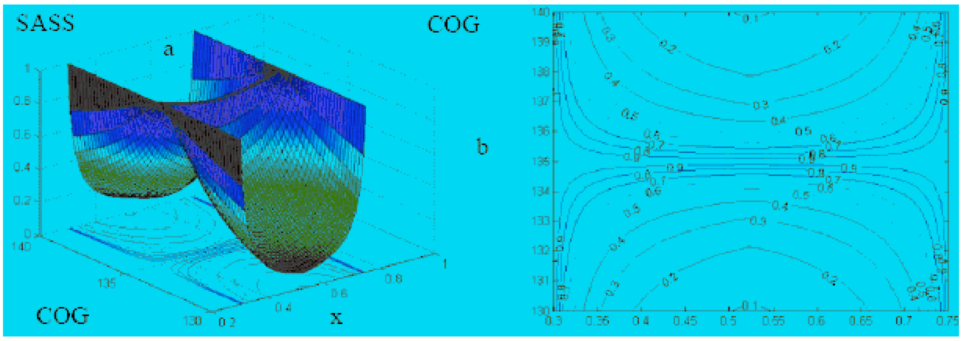

Fig. 4 a. SASS=(x-4.15 COG 8 0 25) as a function of COG and x; b. SASS contours

Here, as an example, we show some findings and results from FIS, representing SASS as function x and COG, Fig. 4:

- Safety regulations can be presented in graphical format by fuzzy rules, so we can see their action in appropriate navigation area using different coordinates systems;
- FIS may be used to construct regulations and to monitor their level of flexibility and rigidity, so FIS can be a very important addition to Formal Safety Assessment procedures;
- VTS operator (or OOW), switching on such pictures on e-chart, can observe the dangerous parts of an area and make appropriate effective decisions;
- Here the standards are generated for central (reference line) part of a navigation area;
- A degree of affinity to area regulations is a safety level in this area (SASS);
- Density of contours of safety level (a gradient of SASS) shows the rate of the situation change in area.
- The situation changes in the most quick mode are near the recommended *COG* in the central part of an area. Here the regulations are the most rigid ones.

Receding from the reference line, the regulations become less strict, i.e. safety level is high enough when entering the area with a *COG* deviation ± 5° and at recommended *SOG* with a deviation ±2 knots. And, central part of an area is to be proceeded with parameters $\boldsymbol{R}_i$=(*COG*=135°; *SOG*= 8 knots; *RB*=0°; *D*=25 miles);

The additional information can be mined from graphs on Fig. 5.

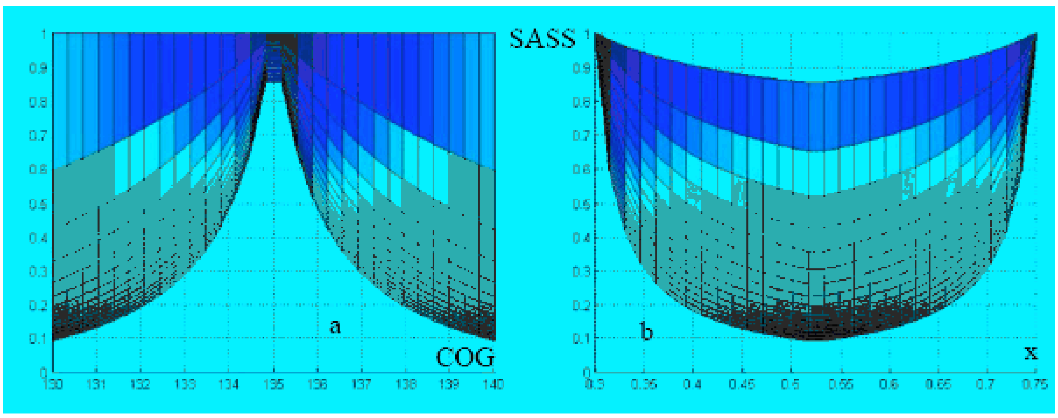

Fig. 5 a. SASS as a function of COG; b. SASS as a function of x

2 Conclusion

Situation Assessment made by VTS operator can be formalized and it supports the operator and Bridge Team on board the vessel in Situation Awareness and decision making. Relative deviation of pattern from standard template vector is the most simple technique but Fuzzy Inference System is more rich and flexible, that may give it more opportunities in construction of Situation Assessment algorithms. These techniques can be merged in optimum way to obtain the more plausible results.

Safety regulations can be presented in graphical format by fuzzy rules, so we can see their action in appropriate navigation area using different coordinates systems.

FIS may be also used to construct regulations and to monitor their level of flexibility and rigidity, so it can serve as a very useful addition to Formal Safety Assessment procedures.

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