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1 Introduction

The main objective of Activity A6.3 Dynamic algorithm for analysing online situations was to develop a system which can provide real time prediction of risks for vessels and for a defined sea area. The system should be able to calculate and estimate dynamically the probability of collision, grounding and contact situations for individual ships and developing ship traffic situations. It was also anticipated that the system would estimate consequences of possible incidents based on ship and sea area characteristics. The final aim of the system was to aid the VTS Operator (VTSO) in his work by pinpointing situations with potentially risen risk level.

Risk indication systems were developed using two different approaches, both focussing primary on the accident probability part. The starting point of the system developed by VTT as a subcontractor of the Finnish Transport Agency was to model the traffic by dividing the sea area into cells and estimate probabilities for a ship to move from one cell to another. Using the transition probabilities, the most probable routes as well as potential collision or near-miss situations could be predicted. The system detects also abnormal behaviour, e.g. ships located in a unusual position. The system developed by SSPA was also based on a division of the studied sea area into cells, but this approach focused on collecting the typical values of different parameters characterising the ship and its movement (e.g. ship speed, length, draught, course over ground, wind, ship type and MMSI number) for each cell. Using this information, ships with a deviating set of characterising parameter values in a certain cell could be identified. The idea was that such ships may be in danger of going outside the fairway and run on ground. SSPA's model estimates also the meeting point of two ships in a defined fairway. Another feature visualises relevant information to be communicated to a certain vessel of a certain type or with certain characteristics (high speed crafts, loaded tanker, etc.). Both risk indication systems are described in detail in the EfficienSea report D_WP6_3_01 Final dynamic risk analysis tools/models (Hüffmeier et al., 2011).

This report evaluates the dynamic risk indication systems described above. The systems have been tested by potential end users, i.e. VTSOs, in order to assess their rationale, reliability and usefulness. The user feedback gives valuable insight to the pros and cons of the tools. The systems have also been evaluated by testing their performance in known accident or near miss cases. Furthermore, the uncertainties of the predictions have been assessed using statistical metrics. The risk indication system called IWRIS (Intelligent Water-borne Risk Indication System) developed by VTT is evaluated in Chapter 2 and the system developed by SSPA in Chapter 3. Chapter 4 concludes the report.

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2 Online offshore risk indication system based on probabilistic models – VTS tool

The Intelligent Water-borne Risk Indication System (IWRIS) developed by VTT was tested and evaluated by VTS Operators (VTSO) from Helsinki VTS both by reviewing recorded cases using stored AIS data and by reviewing real-time situations at the VTS centre during a test period 2011-06-01 - 2011-06-22.

2.1 User tests with recorded cases

2.1.1 Test setting

The user tests with recorded cases were conducted at VTT's office on 13th May, 2011. Three VTS Operators as well as one officer from FTA and three researchers from VTT were present at the session. The IWRIS risk indication system and its main features were presented to the VTSOs. A couple of different recorded cases were presented in order to demonstrate how the system works in different close encounter situations, i.e. crossing, meeting and overtaking situations of two or more ships. The examined area was the sea area between Helsinki and Tallinn where the north and south bound traffic crosses the east and west bound traffic following the traffic separation scheme of the Gulf of Finland. AIS data from 2007-06-01 to 2007-08-31 was used to train the system and the examined cases were from May 2007. The demonstration was followed with a semi-structured discussion regarding the tool.

2.1.2 User observations and remarks

According to the VTSOs, a 10-20 minutes time horizon for the traffic predictions in the model would be suitable. In situations requiring intervention by the VTSO, the ships are usually contacted when the Time to Closest Point of Approach (TCPA) reaches about 10 – 15 minutes, depending on the ship type. When the TCPA reaches 10 minutes, the ships usually start to interact by themselves and sort out the situation. If the TCPA falls below 6 minutes, the situation is no longer in the hands of the VTSO.

The VTSOs pointed out that there have been some changes in the traffic pattern on the area after 2007 due to changes in the traffic separation scheme and the opening of the Vuosaari harbour in eastern Helsinki. In addition, the small high speed vessels between Helsinki and Tallinn have been replaced by fewer large high speed vessels. In 2010 the traffic pattern was also affected by the laying of the Nordstream gas pipes. These important observations were taken into account when preparing for the following real time testing.

The VTSOs were asked whether they felt that the system could be beneficial also on-board vessels. In their view, there could be a risk for information overload and the system could also cause confusion, if the users are not familiar with its philosophy. Risks might occur if the users rely too much on the system, which cannot give totally accurate predictions in all situations. In addition, the large operating areas of the ships would form some technical challenges regarding acquisition of learning data for the model. Therefore they felt that the primary users for the system should be the VTS centres at least in the first implementation phase.

2.1.3 Improvement suggestions and desired features

Some inaccuracies in the traffic predictions were noted, which is partly a consequence of uncertainties in the clustering of the ships. Each ship is associated with a certain cluster depending on from which direction to which direction (e.g. east to west) it is travelling and to which speed class it belongs (see Hüffmeier et al., 2011). The clustering could be made more accurate, if the destination field in the AIS data was used.

In the demonstrated system, the estimated route for each ship was indicated with white lines pointing at the locations where the ship could be after a certain time period. A fan-like group of lines indicate that there are several probable movements predicted for the ship, see Figure 1. The view of the VTSOs was that all the movement indicating lines clutter the screen and it was suggested that the movement lines would only be shown in cases where a collision risk is indicated by the system.

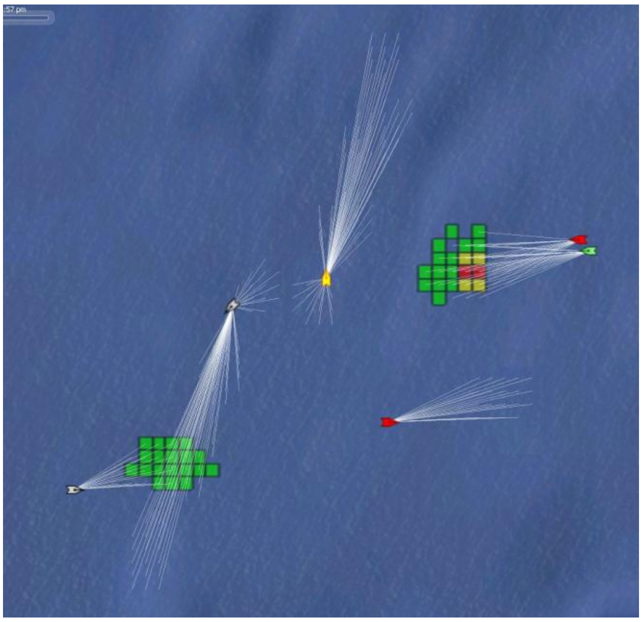

Figure 1 A screenshot with movement predictions shown as white lines

2.2 Real-time user test at Gulf of Finland Traffic Centre

2.2.1 Test setting

The real-time user test of the IWRIS risk indication system was conducted at Gulf of Finland Traffic Centre in Helsinki from 2011-06-01 to 2011-06-22. The system was installed on the computers of both of the GOFREP (Gulf of Finland Reporting System) work stations. Figure 2 shows the IWRIS system on the screen to the right and the normal VTS view to the left. The same VTSOs that participated in the user tests with recorded cases agreed to keep an eye on the system during their shifts at the centre. The operators were instructed to keep notes and make short reports of interesting situations, i.e. situations where the IWRIS system behaved very well or illogically or other noteworthy situations. In total, nine situations were reported from the test period. After the tests a feedback session was held at the VTS centre.

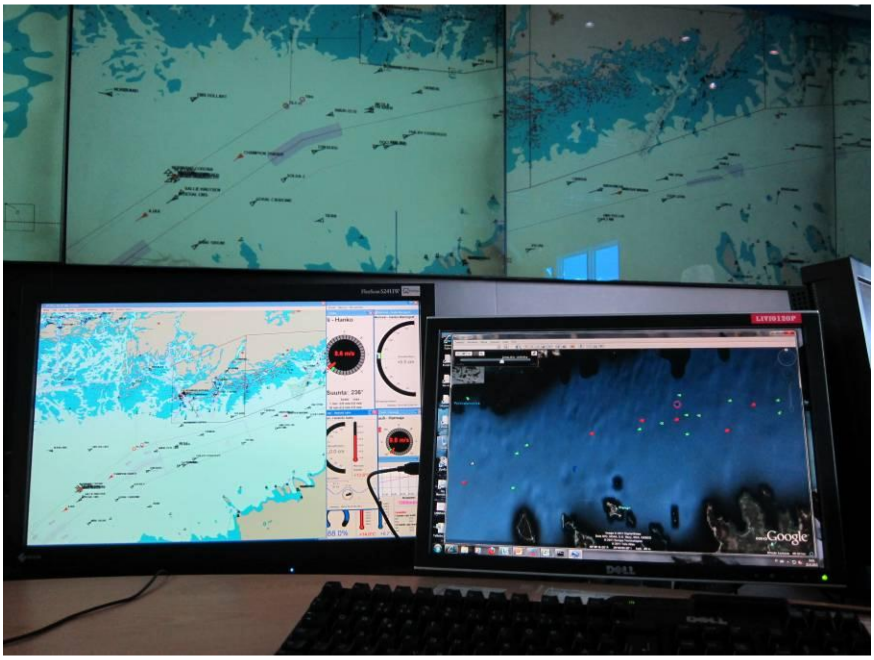

Figure 2 One of the GOFREP work stations at Gulf of Finland Traffic Centre. The IWRIS system is displayed on the screen to the right.

2.2.2 Findings

As a general finding, the VTSOs saw potential in the system, but thought that the model still needed some adjustment. By analysing the nine reported cases, it was found that the model features that inflict uncertainty were: 1) speed clustering, 2) direction clustering, and 3) the probabilistic nature of the model in general.

Speed clustering leads to uncertainty, as the system does not take into account the exact speed of the ships when making predictions, but predicts movement purely based on the learned transition probabilities. Each transition matrix contains transitions of a certain speed cluster, where the ships' speed can vary from 5 to 15 knots depending on the speed cluster. When these matrices are used for prediction, it may lead to a risk prediction at a wrong time or to an unjustified collision risk indication especially in crossings.

Diagonal ship routes, i.e. course over ground about 45°, 135°, 225° or 315°, are problematic for the direction clusters, as the routes are divided based on the cardinal points (north, east, south, west). If a ship's route is e.g. from south-east to north-west, it is possible that some of the transitions would be recorded in south2north cluster, some in east2north, etc. Due to this there is a chance of using a wrong transition matrix for the prediction, which may lead to an unjustified location anomaly alert.

Because the system warns of collision risks based on the movement probabilities, the overall risk in the situation is not actually assessed. For instance a slow overtaking is not likely dangerous, because it can be assumed that the ships are aware of the situation. The model does not take this into consideration.

These findings will be taken into account in the future work. Instead of the direction clusters the destination information of the ships could be used to get more accurate transition matrices. There are also several possible ways to incorporate the current known speed and course over ground into the model. To make the predictions more intelligent rules could be added to the model to indicate what kind of situations are especially dangerous. These rules could be used for instance for weighting the risk predictions accordingly.

A summary of all the reported cases is given in Table 1.

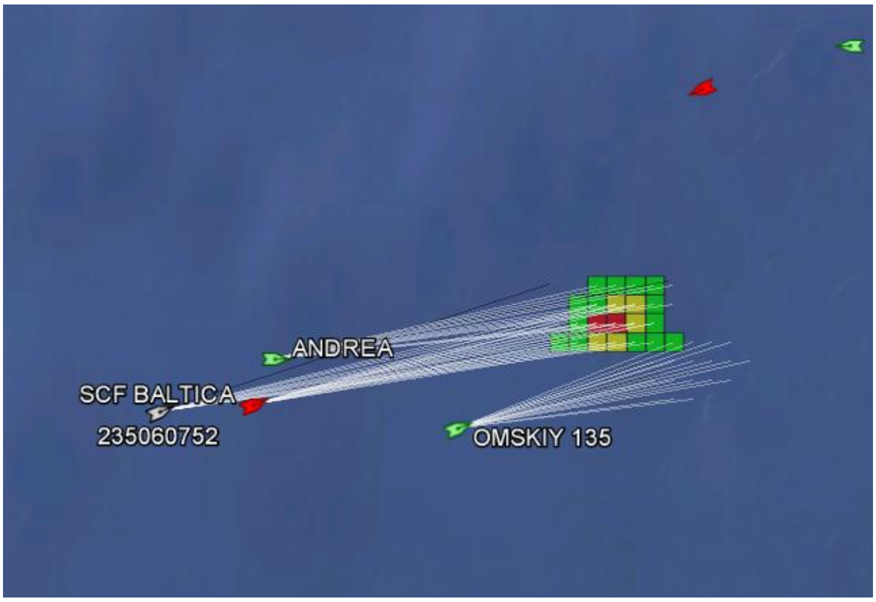

Figure 3 A well-grounded collision risk indication, Case 2 in Table 1.

Table 1 Summary of cases noted by the VTSOs during the real-time tests.

Case	Situation	Description	IWRIS response	Reason
1	Crossing	CPA 0.6nm according to VTS equipment	Green collision risk indication (could be higher), large uncertainty in the route prediction for one of the ships	Large uncertainty because of a diagonal route (inaccuracy of the direction clustering)
2	Overtaking	One ship overtaking between two	Well-grounded collision risk indication	See Figure 3

		other ships		
3	Overtaking	CPA 0 – 0.2nm according to VTS equipment	Identifies risk only partly: shows either green or no risk	Maybe caused by uncertainty that derives from clustering of traffic using speed classes
4	Crossing	CPA 0.2 – 0.3nm according to VTS equipment	Anomalous location indicated for one of the ships, no risk indication although would be justified	Risk prediction is not possible due to reported anomalous location. This means that there is no training data available from this position. (The system may have used a wrong transition matrix because of a diagonal route)
5	Head-on	Two ships meeting at safe distance, CPA 1.3nm.	Unjustified collision risk indication.	Model uncertainty
6	Overtaking	Slow overtaking at safe distance, CPA 0.8 – 1.0nm, TCPA 30-40min	Unjustified yellow or green collision risk indication	Uncertainty that derives from clustering of traffic using speed classes
7	Overtaking	TCPA 20-25min	Indicates green or yellow collision risk in 15 minutes. Not consistent with VTS equipment	Uncertainty that derives from clustering of traffic using speed classes
8	Overtaking	Quite safe overtaking at 0.4 – 0.5nm distance	Red collision risk indicated, unjustified	Feature of the purely probabilistic model: if the ships would continue on their current track, they would end up in the same cell
9	Overtaking	Two ships travel in same direction with similar speed at safe distance from each other	Unjustified yellow risk indication	Model uncertainty

2.3 Uncertainty analysis

To validate the approach the predicted movement probability distributions and encounter area probabilities were compared with real recorded and on-line situations. This is essentially the same method that can be also used for detecting anomalous movement. When the testing component takes a new snapshot, it is compared to a prediction of the same moment, if such a prediction is available. The idea is to validate how accurately the system predicts normal ship movement, and how accurate the risk predictions are. A list of close encounter situations from May 2007 was used in selecting the test times for recorded data. The list was compiled using the methods developed in the near miss analysis conducted at VTT for AIS data of 2008-2010 (Berglund & Pesonen, 2010).

The model was validated with three different use cases. 1) A day when no close encounters were detected was selected, because it can be assumed that a close encounter situation may result in correction manoeuvres that are not in the scope of normal ship movement. 2) Near-misses were selected where the closest point of approach was less than 0.13 nm (approximately half of the cell width) and compared with the risk predictions. 3) Two tests were performed on real-time AIS data in a dense traffic situation.

The movement prediction validation method is as follows. A *weighted average prediction error* (D_{wap}) was calculate for all movement predictions, i.e. for each ship the distances between the predicted locations and the ship's real position were calculate and each distance was weighted with the prediction's probability. These weighted distances are summed up to form D_{wap} for the movement prediction distribution. The predicted locations as well as the ship's real position are set to the centre of the grid cell in question, because a cell is the smallest unit considered in the model. More formally, for a ship *s* in location *l*

$$D_{wap}(s) = \sum P(l_p) D(l_p, l),$$

where $P(l_p)$ is the probability of a predicted location l_p and $D(l_p,l)$ is the distance between the predicted location and current real location. The D_{wap} value describes the width of the movement prediction "fan", i.e. how wide the predictions are spread. It gives us a numerical characterization of the model's uncertainty.

According to the tests there is not much difference in the prediction accuracy between cases 1) and 3) when the test period duration is several hours. However, the prediction accuracy correlates with the speed cluster of the vessel. High speed vessels have a bigger D_{wap} compared to other types. Hence, the more the test period contained high speed vessels (clusters *fast* and *very fast*), the bigger the weighted average prediction error. D_{wap} tends to vary around 0.5 nm (roughly two-three grid cells) for other vessels and around 0.8 nm (three-four grid cells) for high speed vessels. Average results per speed class are given in Table 2.

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Table 2 Average weighted average prediction errors per ship speed class

Ship class	Very slow	Slow	Normal	Fast	Very fast
Average D_{wap} in the test cases (nm)	0.45-0.55	0.50-0.54	0.49-0.59	0.58-0.78	0.86-1.1

There were seven near-miss situations in test case 2), four crossings and three cases of overtaking. The system gave alert for all except one crossing. This was due to the fact that the crossing took place at the border of the monitored area when one of the ships in question just arrived there. Therefore the system did not have a movement prediction for the ship before the time of the encounter. In the test a 15 minute time horizon for the alerts was considered, because according to the VTSOs that is the most suitable moment to contact ships that require intervention. In crossings the system alerted in the scale of ±5 minutes from the TCPA, i.e., the system gave 15 minute risk predictions, where the estimated time of the situation was from 5 minutes before the actual TCPA to 5 minutes after TCPA. In overtaking situations the alerts were even more spread, as the overtaking may last tens of minutes. The alert type was *high risk* (red cell colouring) in three of the six detected close encounters, and *medium risk* (yellow) in the rest of them. One of the test case predictions – a crossing between KATRIN and BALTIC JET with distance of CPA 233m – is depicted in Figure 4. The system gave the prediction in the figure exactly 15 minutes before the time of the CPA. In this prediction the risk level is set to medium. It can be assumed that the situation developed into something more hazardous because of the many ships involved.

Figure 4 A risk prediction for a near-miss situation

3 Online risk indication system for restricted waters based on geometric models – VTS tool

3.1 Test settings

The user test environment has been programmed in MATLAB. The graphical user interface includes a sea chart of the relevant areas, VTS West coast (Göteborg) and VTS Sound. There is the possibility to show layers with information on accident statistics and traffic patterns. Some screenshots are shown in the pictures below. There is a control for a time slider to increase play speed. The warning levels are visualised by colour schemes from white (normal behaviour) over yellow and orange to red (dangerous behaviour) for the grounding tool. For the collision tool the estimated passing positions for the ships are marked with a ring. If the position falls within a "no-pass" area, the positions are marked with a red ring. If several passage positions fall within a radius of 500 meters, a big red circle is used as a warning. Three simple generic cases explain the thoughts and background to the mathematical model for the grounding tool. One near-miss case is used to explain and visualise the collision warning tool.

There are several examples included in the tool to show the features of the model and to ease understanding of the background. They are shortly described below:

3.1.1 Oresund 1

This is a generic example showing a vessel in the Sound. The ship is sailing through the Drogden channel with a low draught. It is leaving the common route and the vessel is changing color based on the grounding calculation tool from white to red (normal to abnormal behavior) and getting back to the common fairways changing the color back to white. This generic example gives a quick introduction to the tool.

3.1.2 Oresund 2

This is again a generic example showing the effect of being outside the fairway and marking the ship with the red color if outside the common fairway while being white in the fairway.

3.1.3 Göteborg 1

This example shows a larger ship changing heading and COG in the fairway, visualizing the effect on abnormal/ normal behavior. The vessel changes color while the ship turns away from common COG and headings. This is again a generic case.

3.1.4 Göteborg 2

The very same example as "Göteborg1 but this time with a tugboat, where the different headings and COG are more common for such small vessels, so the change in color deviates from the one shown prior.

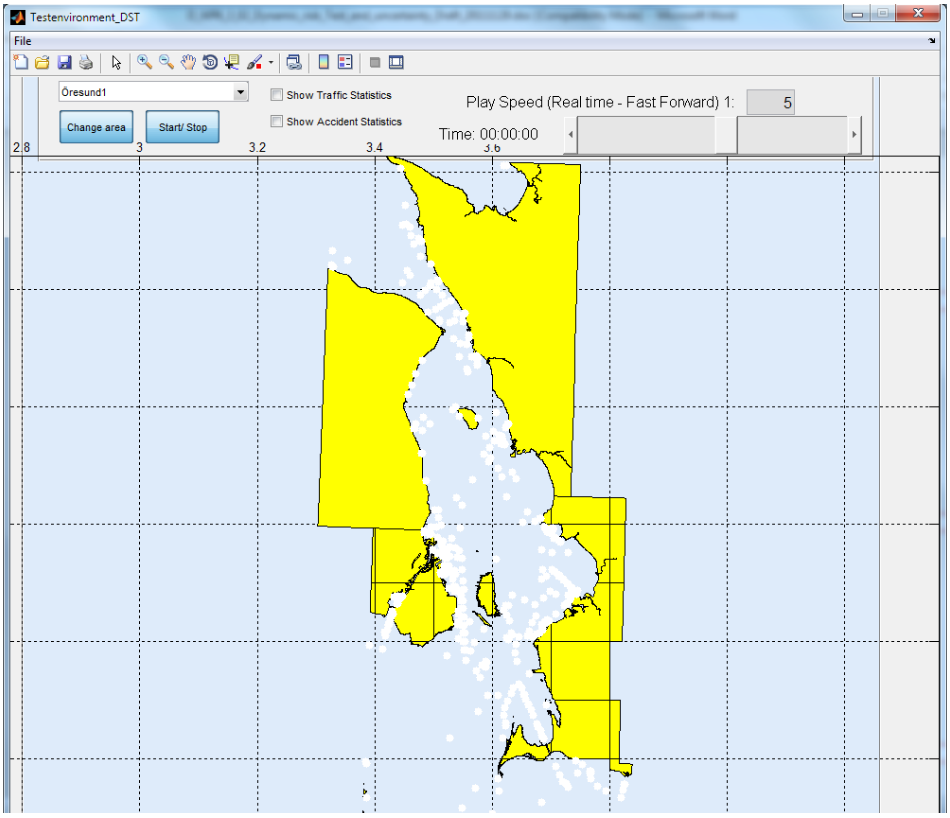

Figure 5: User interface, the Sound area

3.1.5 Göteborg 3

This case is an accident from the Gothenburg archipelago with three vessels involved. It is a near-miss as all vessels met in a difficult turn in the fairway to Gothenburg. The near-miss ended with a grounding of the ferry that was involved. The sequence is fairly long to show the features of the collision warning tool.

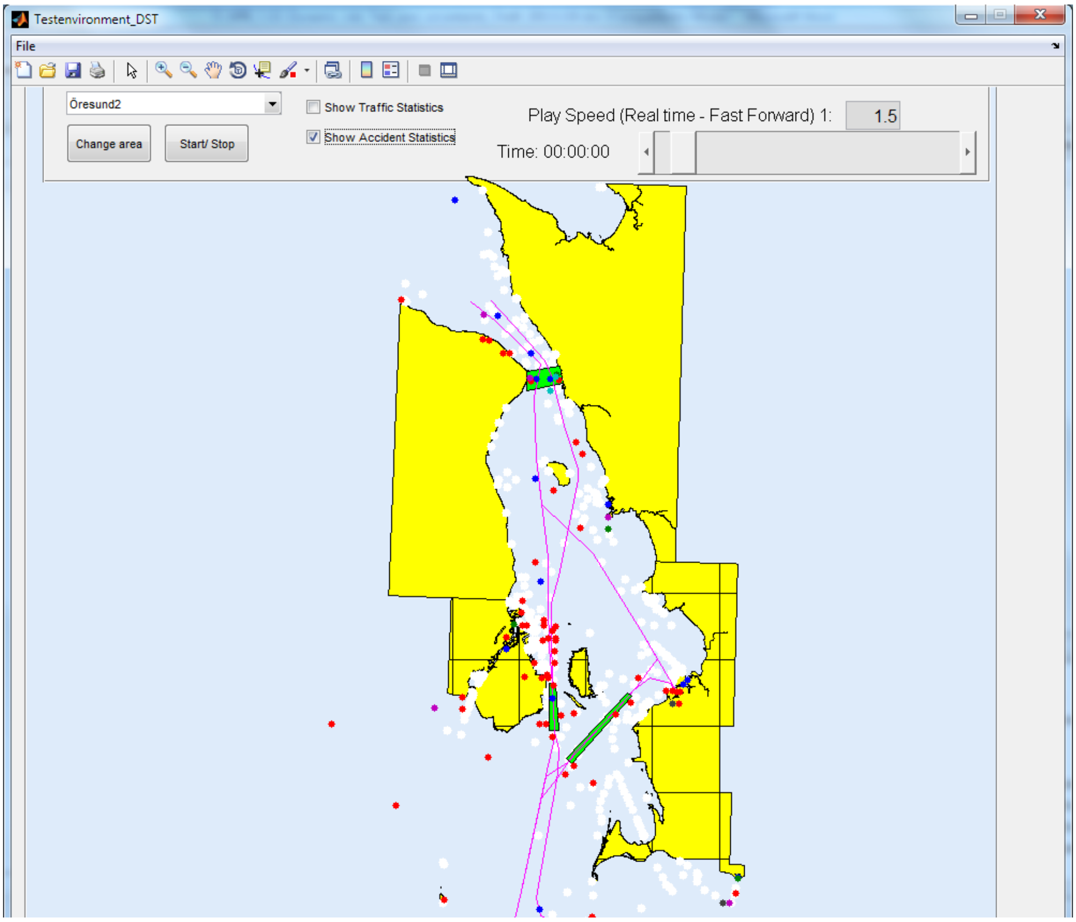

Figure 6: User interface with fairways, "nopass" areas and accident statistics, the Sound area

3.1.1 Oresund 3

This AIS track shows one of the near-misses reported by the Sound VTS, (based on real AIS data).

3.1.2 Oresund own

In this part, own AIS data can be read in. As an example one day of AIS from the Sound is included.

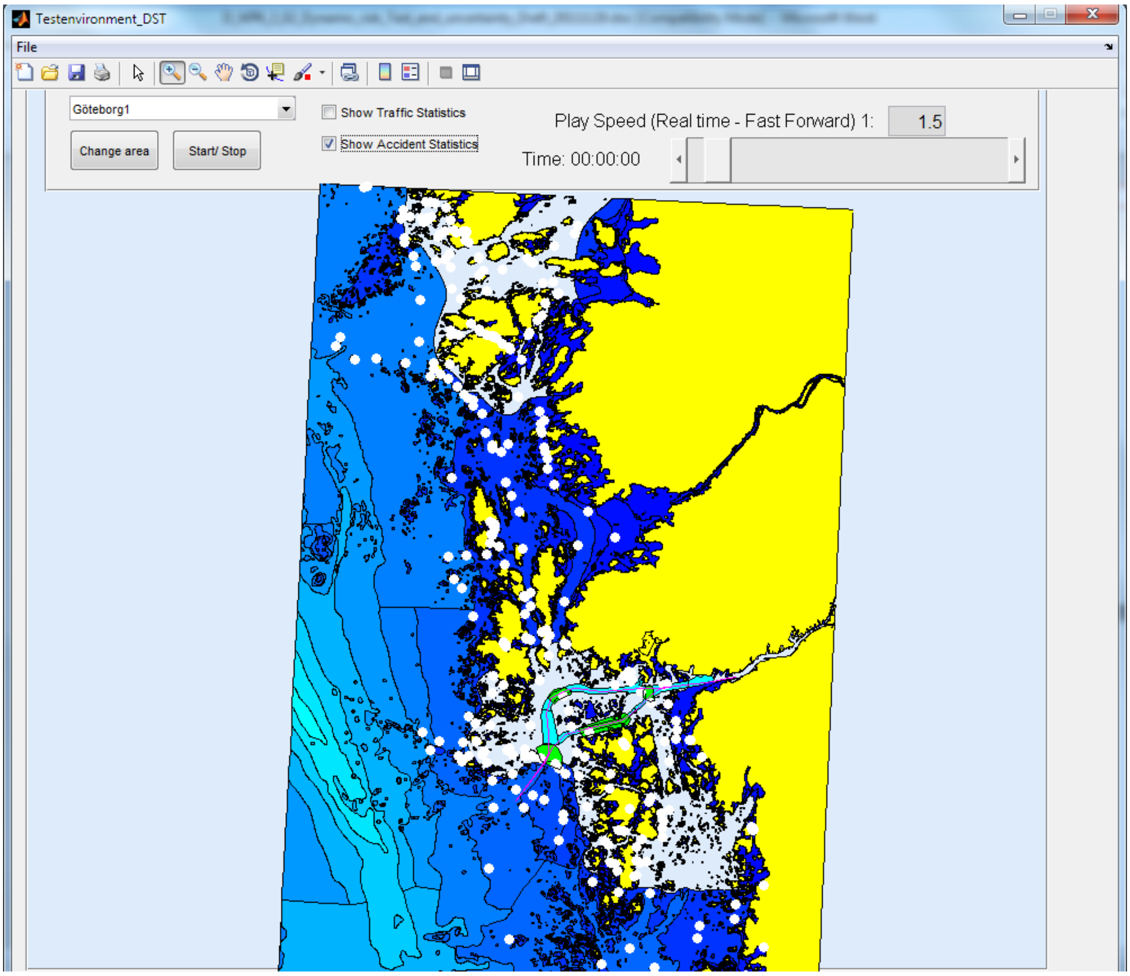

Figure 7: User interface for the Göteborg area

3.2 User tests performed

SSPA has performed user tests with personnel with experience as VTS operator (VTS Göteborg) in form of interview, presentation, testing and discussion. This form has been chosen to give input to the background of the model and to explain the differences to existing tools. The main feedback is described below.

3.2.1 Benefits and potential

The VTS user has a lot of information available. The potential is therefore seen in presenting the data in a condensate, minimising it to the relevant level. Today's VTS operators need to filter quite a bit of the data and skip many sources of information.
The information overload might lead to missed opportunities for the VTS operator to detect abnormal situations. VTS tools are often not following the perception, cognitive process and reaction. If the tool is able to fit into the VTS operators work process, the tool is beneficial and has the potential to support the operator sufficiently.

The **grounding tool** is seen as good additional information. The presentation of the information is not disturbing and cannot be misunderstood. At the VTS, the operator is able to follow and observe certain vessels accurate and narrow, but he/she will not be able to follow all the vessels in that way. Therefore this support is seen positively.

The **collision tool** supports the VTS operator with relevant information. The VTS operator is able to see were vessels in the area will meet and can see how the vessels plan their passages and possibly follow input from the VTS operator. The choice of the inappropriate meeting places is relevant and future passages should result in warnings.

The **database/ visualisation tool** has some potential, but there is the danger of information overload and the tool should be limited to relevant information.

3.2.2 Drawbacks and challenges

The tool is not thought to replace existing VTS software but only to serve as a test-bed. Therefore the functionality is limited to the relevant mathematical models and a simple presentation of the data. This in some ways makes it more difficult to compare the additional information to the information the VTS operator has at the work station. Some of the features are technical and difficult to understand, so it is hard to just if some parts of the tool will give relevant information. As mentioned before, the information should be compact and filter irrelevant data.

The **collision tool** should be limited to just showing the critical meeting spots, as otherwise there will be more information on the screen than necessary. The more complex mathematical model for typical passing distances in the area will give too many false alarms and should not be implemented in the tool. Uncommon behaviour here does not need to be wrong or dangerous behaviour and the available AIS data history is probably too limited for sufficient foundation.

The VTS operators in Europe are not involved in active organising actions after an accident. Therefore the tool should not include information on consequences of an accident, as this will not support the VTS operator in his/her daily work.

From **the visualisation feature** there is some information that could be useful. If there exists a database of information relevant for a vessel type, vessels with a certain characteristic or particular vessels, some information would be good to have accessible fast, such as restrictions for a certain vessel (speed restrictions, safety zones, tug and visibility restrictions, etc.).

3.2.3 Improvement suggestions and desired features

For the **collision tool**, the user should be able to choose, which information should be shown. This can include, that the user should be able to visualise the meeting point for selected vessels. If the VTS user suspects unsuitable passages he/she can visualise the point for the CPA on the screen for exactly the involved vessels. The warning should only occur if the passage falls within the "no-meeting" places. All other information should be hidden and do not need to be available for the VTS operator.

To take into account the data from the weather and current should help the tool to give even better information from the **grounding tool**. The data foundation might get more uncertain for some spots but could result in even better warning levels at other spots. The warning levels could possibly be more variable, in order to give the VTS operator the possibility to change which vessels should be warned for and which not.

3.2.4 Comparison to current VTS equipment

All the relevant tools are not implemented in today's VTS system providers and give help that eases the work of the operators. The tool would need to improve the user interface and some

3.3 Uncertainty analysis of the VTS tool

There are a couple of constituent parts in the warning tool that imply a source of uncertainties. These uncertainties can lead to that the system gives wrong information, i.e. that it warns for an uncritical situation (too many warnings), or that it does not warn (not sensitive enough). Other features that do not follow the structure of thinking of the VTS operator or the bridge personal would disturb the personnel and abstract them from their original tasks. The main sources of uncertainty can be summarised as:

- AIS data quality
- Mathematical models and assumptions for the program code
- Warning levels
- Unnecessary information disturbing the VTS operator
- Warnings appearing too late
- Unclear role of the VTS operator

The different sources are described in further detail below:

AIS data quality

The main question is if the AIS data quality is sufficient so that the VTS operator can get support through the system and to what extent should he/ she then relay on it? As the grounding and collision warning tool is partly based on historical AIS data, the data quality from AIS is crucial. The system takes care of the most important lacks in the historical data set. The system gives uncertain results in case the AIS data of the individual ship is wrong. That can be wrong position message, dynamic messages such as speed, COG and SOG, wrong static messages such as length and draught of the ship and GPS position indicator (A, B, C, D). Here it is referred to the work package on AIS data quality to get an idea of the share of incorrect AIS data.

Mathematical models and assumptions in the program code

The steering parameters for appropriate grid sizes should be collected to avoid longer computer executing time as well as the sensitivity to splitting into different ship length classes and speeds. Assumptions made could lead to wrong warnings or too few warnings in critical situations.

Warning levels

The faulty warning levels can lead to that it warns for an uncritical situation (too many warnings), or that it does not warn (not sensitive enough). Further data tests could be done to improve the system quality and improved mathematical models.

Unnecessary information disturbing and abstracting the VTS operator

There are many studies made on user adaption of systems for decision making purposes. A typical problem is that the operators work are disturbed by information overflow. If the system does not follow the logical thinking process of the operators, the information will not be recognized and used. In a worst case scenario the available information will lead to abstraction of the operator to irrelevant information. Therefore the system lay-out is kept as simple as possible and only a wrong warning level should lead to the abstraction of the operator.

Warning appearing too late

There are three stages that are part of the accident avoidance process.:

- detecting the dangerous situation,
- warn the vessel(s) involved
- after detection and warning, manages to perform successful avoidance manoeuvres.

It seems impossible to define how much time is needed to alert bridge personnel prior to accidents for different causes of accidents (e.g. fatigue, distraction). Therefore each warning that appears prior to the detection of the VTS operator will support the work and increase safety. The VTS operator needs to be aware of the traffic situation and should not only rely on the automatic system. In case he/ she relies on the system too much and the warning comes too late, a late warning could be a problem.

Unclear role of the VTS operator

What is the responsibility/ duty of the VTS operator? Should the duty include only information service when the personnel at the VTS centre has detected a dangerous situation or may it also include others, such as a navigational assistance service or a traffic organization service? How can the border between these services be defined? The un-clarified role could repress efficient work of the VTS operator and the situation should be improved.

4 Conclusions

This report evaluated two different approaches to detect and indicate real time risks in ship traffic. The systems have been tested by potential end users, compared to known cases and evaluated by statistical means. Although the systems require further development, both of them have merits and show potential in aiding the work of the operators.

The IWRIS risk indication system based on probabilistic models described in Chapter 2 was tested in real time by VTSOs at Gulf of Finland Traffic Centre in Helsinki. The operators saw potential in the system and their feedback guided the research group on how to still improve it. The system performed well when tested with recorded near-miss situations. The prediction accuracy was also quantified by calculating the weighted average prediction error of the ship locations. It can be concluded that the collision warnings and anomaly detections behaved consistently without any systematic errors and the fundamental principles were sensible. However, the prediction accuracy could still be improved e.g. by better exploiting the current speed and destination data of the ships. The evaluation of the risk level could also be amended by taking into account the specific characteristics of different encounter situations, e.g. overtaking and crossing situations.

The SSPA warning tool can be used as an additional feature in the VTS software to give the VTS operators automated support to his/her main task. The VTS grounding avoidance tool is able to predict deviation on an early stage and give the VTS operator more time to warn the ships on a grounding course. It will give the VTS operator additional hints on critical near miss groundings.

The VTS collision avoidance tool is a data source for the VTS operator on how vessels will meet and pass each other in the VTS area prior to the passage. The VTS operator is then able to inform the ships involved, get indication on how appropriate it is for the vessels to meet at the estimated position, based on accident statistics, geographical features, common passing distances at the position and predefined "no-pass" areas.

The ship individual information database give the VTS operator filtered data allowing him/ her to be aware of the relevant information and to communicate this information to an individual ship. In this way the VTS operator is aware of the most important data relevant for ships passing the VTS area.

Further improvements can be made with the tool and more detailed implementations could be made to improve the output quality. These could be adding the present information of the currents and weather information in the grounding tool, a more detailed description of the "no-pass" areas for the collision tool and advanced database for different ship types and sizes for the visualisation tool.

The traffic analysis of the AIS data shows interesting results on traffic pattern and ship behaviour in different geographical areas.

The user input gives acknowledgement of the tools and there is a potential seen in supporting the VTS operators sufficiently with relevant and filtered data. Some more features have been suggested, while some parts of the tools are not seen as relevant for the daily work of the VTS operator.

Especially the collision and grounding tool can give valuable support and further tests should be made with these tools as they seem to be a complement to existing VTS systems.

5 References

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