Influences of System Integration to the Safety of Navigation and to the Training of Seafarers

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Abstract In this paper, the influence of the increasing system integration to the safety of navigation is discussed. Increased integration has been a key trend in the development of navigation systems during the last decades. The modern navigation system of an ordinary commercial ship integrates the radar, the speed log, the gyro compass, the Electronic Chart Display and Information System (ECDIS), the autopilot and the satellite navigation system into one single entity. It might be difficult for the user to figure out all connections between different parts of the system. Understanding the hidden interrelations between individual devices in a complicated integrated system is a true challenge, especially in fault situations. A fault of the speed log, for instance, could lead to false operation of the gyro compass, the autopilot, the ARPA radar and the ECDIS of the ship. Consequences of such single failure can be dangerous if these situations have not been anticipated in the design of the system and in the training of deck officers. Automatic Identification System (AIS) has raised the integration to a new level: The officer of the watch has on the ECDIS display in front of him symbols and texts which are based on information produced by equipment on-board another ship. The AIS system integrates the navigation systems of all ships on the same traffic area logically into one single network. Such high level of integration has both positive and negative influences on the safety of navigation. The designers and the users of these systems should be aware of the potential new safety risks related to integration. This should be taken into account also in training of deck officers.

Keyword*: Navigation systems, integration, safety, training*

1. Introduction

Wider integration has been one of the key trends in the development of navigation systems during the last decades. Integration is not a target as such, but it has been virtually a necessity in development of the performance and the safety of navigation systems.

Until the 1970's the devices used for navigation operated individually, without interconnections. The officer of the watch had to perform the everlasting ”triple-jump” between the radar display, the navigation desk and the steering stand. The integration of navigation devices into bigger entities began in the 1980's. The integration changed the navigator's work as the information and control of the equipment was concentrated into one place on the bridge. The integration of the radar image and the digitized chart was an important step in the development towards the modern Integrated Navigation System (INS). An important milestone in development of the steering systems was reached when the significance of the dynamic error of the gyro compass was understood and effective methods for eliminating the error were introduced. Due to the operation principle of the gyro compass, after every turn of the ship, an oscillating error component appears in the gyro heading signal. This oscillating error component, the dynamic error, gradually weakens and disappears. However, if the ship makes several consecutive turns the dynamic error can accumulate into several degrees. The active correction of the dynamic error of the advanced gyro compasses keeps the error below one degree.

A major goal of the development of steering automation was to introduce a system for fully automatic track keeping. Accomplishment of this function was not possible without means to define the precise position of the ship in real time. Introduction of the Global Positioning System (GPS) satellite navigation system and the differential GPS correction system finally made it possible to build a fully automatic track keeping system for merchant ships, accurate enough also for the narrow archipelago fairways [1], illustrated by Figure 1.

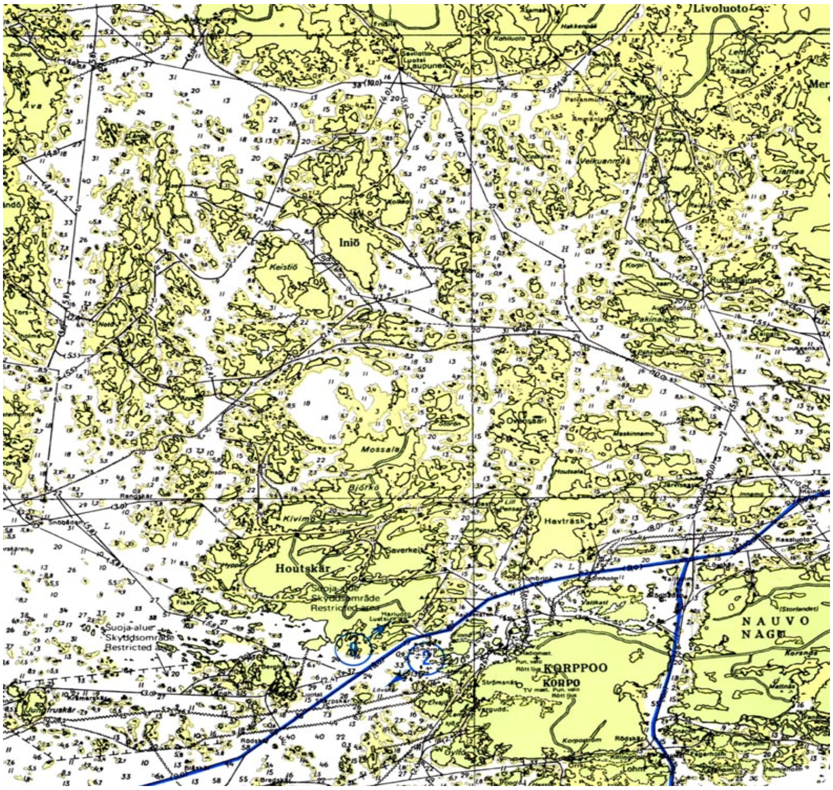

Fig. 1 Typical archipelago fairways near the Finnish coast.

A fully automatic track keeping systems was developed by the Electronics department of Hollming Ltd in Rauma, Finland already 30 years ago. The flagship Keldysh of the Academy of Science of the Soviet Union, delivered by Hollming Ltd on the 24th of January 1981, was equipped with an INS capable of steering the ship automatically along a programmed track [2]. The system integrated the autopilot, the position and speed measurement devices, the gyro compass and a digital chart plotter into one single entity. The system utilised Kalman filtering technique in calculation of the real-time position and speed of the ship. Due to the limitations of the accuracy of the available positioning methods, the accuracy of the system was not, however, sufficient for archipelago routes.

The practical requirement for the dynamic positioning accuracy in the Finnish archipelago routes is ten meters. This requirement was finally fulfilled when the public differential GPS (DGPS) service by the Finnish Navigation Administration was put into operation on the 23rd of March 1991. This was the world's first public differential GPS service [1]. It brought the average error of the position fixes below 5 meters. Now the INS of a merchant ship is able to take the ship virtually automatically from port to port along a programmed track with the accuracy of a few meters.

Introduction of the Electronic Chart Display and Information System (ECDIS) brought the integration even further by combining the electronic chart with the navigation system. The Voyage Data Recorder (VDR) was another step on the way towards the modern bridge system, which integrates the radar, the speed log, the gyro compass, the ECDIS, the autopilot, the satellite navigation system and a few other systems into one single entity, as presented Figure 2.

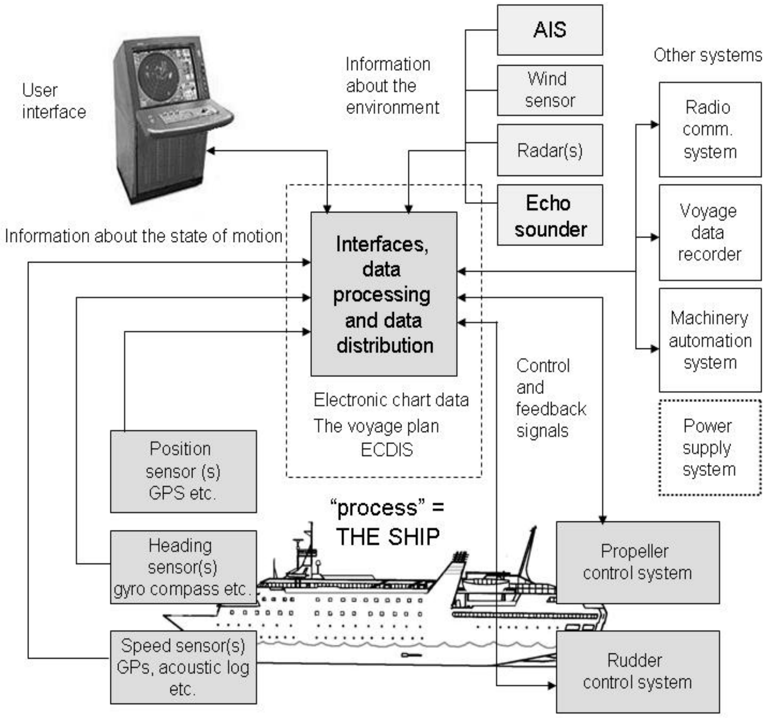

Fig. 2 A generic block diagram of an INS system.

The integration of modern bridge systems is not anymore limited to the equipment on-board the ship. The navigation satellites on the sky and even the navigation equipment on-board other vessels may communicate in real time with the ship's equipment, thus belonging to the same logical entity. The Automatic Identification System (AIS) is an example: The officer of the watch has on the ECDIS display in front of him symbols and texts which are based on information produced by equipment on-board other ships. The AIS system integrates the navigation systems of all ships on the same traffic area logically into one single system. Consequently, the decisions by the officer on the bridge of a modern ship are strongly influenced, not only by the operation of satellites 20 000 km above the earth's surface, but also by information processed and produced by navigation equipment on-board other ships. This high level of integration has influences on the safety of navigation, both positive and negative ones. Consequently, it also has implications to the training needs of deck officers. These implications have to be understood and taken into consideration.

2. Positive and Negative Consequences of Integration

2.1 Safety through integration

The obvious purpose of integration of the navigation equipment and systems is to enhance the efficiency and the safety of navigation. These are the positive consequences of integration. The officer of the watch does not any more need to look for the necessary navigation information from different places on the bridge. The information from different devices is concentrated to a single work station and it is displayed in real time. Moreover, integration makes it possible to process, compare and to combine the information in new ways. By intelligent integration one plus one is more than two. The ECDIS is a good example of this. The real time position and speed of the ship are received from the GPS receiver and displayed on the electronic chart. Similarly, the heading of the ship is read from the gyro compass and indicated graphically on the electronic chart. The planned route is also shown on the chart. These pieces of information are not only collected on the display but combined and processed to form new type of information and a new function: The system compares the position of the ship with the planned route in real-time and activates an off-track alarm if the position of the ship deviates too much from the planned track.

Many useful functions of the modern INS would not be available without integration: precise automatic steering of the vessel along a planned track, on-line display of the position and heading of the ship on the electronic chart, display of the AIS targets on the ECDIS chart, the predictor display (see Figure 3), automatic identification of other vessels. Overall, integration has made it possible to anticipate and avoid hazardous situations and to avoid accidents much better than before. And the development towards even deeper and wider integration has not reached the end. The idea of e-navigation is very much connected with wider integration. A key task is to make the exchange of information between different parties easier and more efficient. Logical and physical information links between parties integrate them into larger and more complicated systems than ever before. The basic principle is that better exchange of information means better safety.

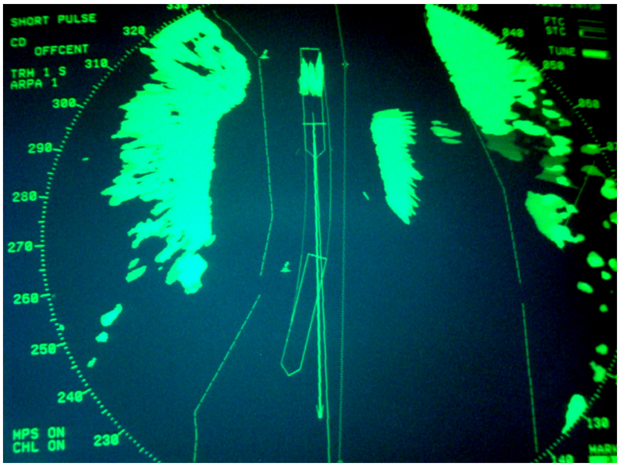

Fig. 3 The predictor on the radar screen

2.2 Tighter couplings and increasing complexity

There is always the other side of the coin. Increased automation and integration have created new safety risks that did not exist earlier. While the integrated navigation system offers many features that enhance the safety of navigation, it also contains much more dependencies and couplings than the old-fashioned bridge with separate navigation instruments. According to Charles Perrow the risks of an accident within a system has a relation with two factors: the couplings and the interactions within the system. The couplings vary from loose to tight and the interactions from complex to linear [3]. In a large integrated bridge system, the interactions between the subsystems have become more and more complex and the couplings have become very tight, which means that a malfunction of one subsystem will inevitably cause a malfunction of another subsystem. The critical functions of the integrated navigation system are dependent on a great number of individual devices and subsystems. In the early navigation systems, the couplings were loose and the interactions rather linear than complex. In the light of the criteria by Perrow, the risk of an accident caused by the navigation system of a ship has increased.

The automatic steering system of a ship is an example of a system with tight couplings and complex interactions. The autopilot controls the rudders of the ship according to the information received from the gyro compass and the route plan from the ECDIS. An error in the gyro heading would immediately cause an error in the operation of the autopilot. But, surprisingly, the measured speed of the ship has also a critical role in this activity. The speed information is utilised in the gyro compass to correct the speed error, and it is also necessary for the on-line self-tuning of the autopilot. Consequently, a malfunction of the speed log would cause a direct error in the operation of the autopilot, and it would cause another, indirect error by causing a deviation to the gyro heading. A malfunction of the speed measurement has a direct impact also to the operation of the ARPA radar, the AIS and the ECDIS.

It is interesting how interactions tend to get more complex as new technical aids for navigation are introduced. The Automatic Identification System (AIS) is an utmost result of this development. Firstly, the operation of AIS system is totally dependent on perfect timing, or synchronisation of the AIS transponders with each other. The synchronisation need is solved by utilising the time signal received from the GPS satellites. Each AIS transponder transmits the real-time position of the vessel. This information is also measured using the GPS satellite navigation system. Consequently, the AIS system is tightly integrated to the GPS system, i.e. without the operation of the GPS system the AIS system would not work either. Moreover, the AIS system connects together also the navigation systems of all ships sailing in the same area. On each ship, the officer of the watch can monitor the real-time position, heading and the speed of all other ships, provided by the AIS system. Thus, the officer of the watch will base his/her predictions and steering decisions partly on information produced by navigation sensors on the other ships! The introduction of the e-navigation idea indicates that this kind of integration development will continue in the future.

3. Implications of Integration to the Training of Deck Officers

The operator is a critical component of such socio-technical system as the integrated navigation system of a ship. Much attention has been paid to management of the human factor of the safety of navigation. The officer of the watch must be properly trained to be able to operate the integrated navigation system correctly and to monitor its performance. The role of the user becomes crucial if the operation of the system differs from the normal. The user has to make a quick and correct diagnosis of the situation and to initiate rapidly the necessary corrective actions to prevent an accident or other unwanted consequences of the abnormality. Operation of the user in abnormal situations is one of the weak points of the entity [2].

Monitoring becomes more and more demanding as the complexity of the systems increase. It is practically impossible to know the exact status of a large system consisting of several intelligent or computer-based devices communicating and interacting with each other. The user must rely on self diagnostics of the system in order to efficiently detect its abnormal behavior. The system has to tell the user that there is something wrong in its performance. The problem with large integrated systems is that the self diagnostics does not necessarily cover all abnormalities within the system. It is possible that although the operation of two individual devices is correct, the operation of the entity formed by these two devices is not [4]. In such situation, the ability of the user to monitor the system and to make correct judgments is crucial.

The officer of the watch must have good knowledge about the structure, operation and limitations of the performance of the integrated navigation system he/she is using. For instance, the user must be aware that the AIS information displayed on the ECDIS monitor in front of him/her is produced by equipment on-board another vessel.

The following list contains some of the aspects that should be taken into account in training of users of large integrated systems:

1) The user should know the structure of the integrated system: what are the devices connected with each other and what is the role of each device in the entity, i.e. what information it produces, what information it receives and what kind of processing of information it carries out.

2) The user should know the operating principle of each device in the system, at least on a general level, and the limitations of the performance of each device.

3) The user should know the principles of the communication between the devices.

4) The user should understand how the functions of the entity depend on the performance of different devices of the system.

5) For each individual critical device, the user should know how a disturbance or a malfunction of that device affects the operation of the entity, especially what are the safety risks associated with such malfunction

6) The user should also know how to detect and how to manage different abnormal situations.

7) The user should know how to replace the functions of the integrated system with lower-level automation in different practical situations. This should be trained in a simulator.

The important question is: how the demanding requirements of this list could be met? It is a well known fact that the integrated bridge systems are not yet standardized. There are hundreds of different hardware configurations and tens of different system architectures being used on-board ships. On the other hand, to know how a specific system behaves in an abnormal situation, the structure of that particular system needs to be known. Therefore, a thorough knowledge on the subjects listed above can not be reached if these aspects are discussed only on a generic level, i.e. on a level which applies to all – or at least most of - the existing systems. Apparently the requirements set by highly integrated systems are too hard to be met by the present training systems of the MET institutes. Therefore, the ship owner shares the responsibility of training the deck officers to manage the integrated systems they are using.

4. Conclusions

Increased integration has been a key trend in the development of navigation systems during the last decades. The modern navigation system of an ordinary commercial ship integrates the radar, the speed log, the gyro compass, the ECDIS, the autopilot and the satellite navigation system into one single entity. The user should be aware of the critical connections and dependencies between different parts of the system. Understanding the hidden interrelations between individual devices in a complicated integrated system could be critical for proper management of fault situations. These needs must be taken into account in training of seafarers. However, the low degree of standardization of the systems makes it difficult, if not impossible, to design such training courses that could give the required knowledge on the systems used on-board modern ships today. This is a hard challenge for MET institutions. The variety of different system configurations leads to the conclusion, that the ship owners must share the responsibility of training the officers to know and to manage the integrated systems in normal and abnormal operating situations.

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