SURPASS – A Response to the Increasing Automation Failures at Sea and in Ports

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Abstract

Safety is a key issue at sea and in ports. The number of accidents due to automation failures has been on the rise. Increasing automation onboard ships has created a major challenge for operators, owners and ship crews.

In this paper, the competency requirements and the training of Deck and Engine Officers are discussed. It is important to understand what is essential for successful management of safety on board vessels. The recent research has shown that for successful management of safety, ship crews must be able to operate the automation systems safely, not only in normal operational conditions, but also in emergency situations. The paper reports on the work of the SURPASS project team working on developing a training course to address the deficiency in the education and training of ship officers in this increasing important area. It is crucial to define correctly the knowledge and the skills that the officers should acquire in order to overcome the increasing automation failures on board vessels, many of which have led to major accidents. The EU Leonardo SURPASS project, which is carried out by TUDEV with support from C4FF in the UK and four other European institutions, included a review of the current efforts in remedying the automation failures with the intention of developing a comprehensive short training course on ship automation based on real accidents at sea and ports.

Key word: *Ship automation, safety, training*

1. Introduction

Automation is major Engineering subject covering a whole range of areas in design and production of goods and services. In recent years ships are becoming increasingly automated and the development of maritime education and training standards such IMO STCW has not kept up with the developments and application of automation and the knowledge and skills needs of ship crews in this regard. The increasing number of automation failures at sea and in ports has become a major concern for ship operators and owners (SAS, 2010). SAS (2010) notes that some tanker companies are reporting one engine stop every week, one stop too many as these are argued to be accidents waiting to happen. Ziarati et al (2010) reported the increase in number of accidents at sea and ports. The question raised in IMO MSC82 (Ziarati, 2007b) was how can the international maritime community, including the IMO itself respond to the challenge presented as a result of modern ships becoming increasingly automated and what steps can be taken by all concern to reduce the number of accidents due to automation failures. The UK's MCA initiated a major research and concluded that MRM (Maritime Resource Management) could be an avenue for responding to automation failures (Ziarati et al, 2010). Ahvenjarvi (2010) argues that preserving the safety is a key issue in the maintenance of the automated systems and that the safety of automation can be undermined by poor maintenance. There are arguments that automation principles in practical terms need to be understood by ship officers and that a great deal can be learnt from accidents that happened due to automation failures in the past (Ziarati et al, 2007a). It is for the argument put forward by IMO, reported by Ziarati (2007b) that the project now known as SURPASS was initiated. This paper reports primarily on SURPASS project developments and its progress to-date.

2. Automation shipping

The subject of automation is relatively new and is based primarily on a range of knowledge and skills encompassing the subjects of mechanical engineering, electrical/electronic engineering and information technology (Ziarati, 1994, 1995a, 1995b; Ziarati et al, 2002). A good account of developments in ship automation is given by Ahvenjärvi (2011). Ahvenjarvi reports that distributed digital machinery automation systems for ships were introduced in the late 1970's and in the beginning of 1980's. On the bridge the computer appeared a few years later. Stating that although the core tasks of the automation systems have not changed so much and the users of the systems are still ordinary human beings, the technology to implement these systems has been replaced several times. He notes that new processor generations, new memory technologies, new ideas of transmitting the information from one place to another have been introduced within a few years' interval. Ahvenjarvi (2011) argues that although the architecture of the machinery automation systems in the late 80's were already distributed, the data transmission was still based on point-to-point connections reaching the capacity of a few kilobytes per second. Nowadays the systems utilise buses and networks at different levels within the overall automation system. Typical networks within a ship automation system is able to transmit information with ten thousand times bigger bit-rate than the old serial connections only twenty years ago. Integrated automated systems are increasingly being applied on board ships in response to the efforts by ship owners to reduce the manning level and to improve safety. Ahvenjarvi (ibid) gives examples of extreme integration on board ships such as satellite navigation systems, communication and Search-And-Rescue (SAR) systems, Automatic Identification System (AIS) and the e-navigation concepts all without exception using advanced automation, digital data processing and modern information transmission technologies (Ahvenjarvi, 2010).

Automation technology is changing but the STCW has remained the same for some 25 years. How can crew use and manage automation effectively if the content/standards for education and training of ship officers have remained the same for many years? Ahvenjarvi (2011) argues that the importance of the human element is not eliminated or reduced but degree of automation has increased continuously, especially when considering the safety aspects. Research has shown that the new automation systems on board vessels must be maintained and operated in a safe way, even under emergency situations. These tasks require good knowledge about the operation and about the structure of the systems. Ahvenjarvi states that incorporating the subject of automation is a major challenge for the education and training of seafarers. Rapid development of the technology, he argues, must not lead into a situation where a large number of seafarers have a formal education and the licences to navigate a ship in international waters required by IMO and the national seafaring officials, but in fact are not able to maintain and operate the latest technology in a safe way. The question posed is, are Maritime Education and Training (MET) institutions really able to give their cadets a meaningful education and training that fulfils the demanding requirements set by the latest automation technology? What about those seafarers who have got their education some twenty or thirty years ago? Are they able to cope with often complex instrumentation and control systems which are now invariably computer-based as seen on new ships with different degree of sophisticated automated systems?

The safety of complex technical systems, such as nuclear power plants for instance, can be managed by looking at the whole lifecycle of the safety-critical systems. The lifecycle approach is very useful also in management of the safety of automation systems used in ships. The lifetime of an automation system can be divided into several phases, one following the other. Typical phases are the specification, the design of the hardware and the software, the manufacturing, the testing, the assembly of the system onboard, the commissioning, the maintenance and operation, and finally the dismounting and wrecking the system. The system is safe, or the integrity of the safety is maintained, only if all safety aspects have been properly treated and all requirements are fulfilled during each phase of the entire lifecycle of the system. The standard IEC 61508 is one of the basic regulations of management of the risk of safety-critical systems, based on the lifetime, or safety life cycle, approach (International Electro-technical Commission, 2002).

Many rules and regulations have been published in order to ensure that the safety aspects have been properly taken into different phases of the lifetime of the critical systems of ships. Publishers of such documents are International Maritime Organisation (IMO), International Hydro-graphic Organisation (IHO), International Standardisation Organisation (ISO), European Union, national maritime authorities, the classification societies and the International Electro-technical Commission (IEC), among others. For instance, IEC has published regulations about the testing of the equipment used onboard ships (International Electro-technical Commission, 1998).

It is interesting, that the vast majority of these regulations are to ensure that the design and testing of the automated systems are carried out properly. The most important rule related with the maintenance and the operation of automation systems on ships is in fact the STCW 1995 convention by IMO. The IMO's STCW 1995 convention with its amendments defines the minimum standard for the training and the competence of seafarers all over the world. A review of the STCW clearly shows that the standard does not concern itself with the design, manufacturing, testing, commissioning and the operational aspects of automated system used on board ships.

3. The surpass project

The SURPASS project (Leonardo SURPASS Project, 2009-11) was initiated as a result of the successful SOS project (Leonardo Safety On Sea (SOS) Project, 2005-07) led by TUDEV and initiated by C4FF (Ziarati, 2006; Ziarati et al 2007a). A good summary of the SURPASS project and the rationale for it is presented in a paper by Ziarati et al (2010). Both SOS and SURPASS were instigated to overcome the deficiencies of the STCW-95. The STCW with the 2010 amendment sets the minimum standard for the training and the competence for users of the automation onboard ships. However, the importance and validity of STCW – as with so many other official regulations regarding new technology – is weakened by the rapid development of the technology. To be fair, an official set of standards of this kind cannot be too detailed and at the same time it cannot be updated immediately after every new technological or technical innovation. And even if it was possible, there would still be a long delay between the introduction of the new technology and the time when trained seafarers enter the labour market with knowledge about this particular matter. This delay is caused for different reasons related to the management and the way MET providers operate and manage change.

Ahvenjarvi (2011) argues that there is a need for special training of seafarers to update their knowledge about the safe use and maintenance of the latest automation technology. Ziarati et al (2010) is of the view that the operation issues need to be identified so that the training is targeted at the right type and rank of ship officers. The research has shown that the older generations who received their education and training two or three decades ago are less familiar with the new technology than the younger generations who have become familiar with computer systems in their everyday life. But even for the younger generations, it is important to provide an education which introduces the subject of automation, operation and management of automated system used on board ships and, the use of safety-critical systems. Operating the Integrated Navigation System (INS) of a large passenger ship, argues Ahvenjarvi (2011), is not the same as playing a computer game!

TUDEV with support from Satakunta University of Applied Sciences, Maritime Division of the Centre for Factories of the Future (C4FF) together with several other European organisations initiated the SURPASS project, in order to find a solution for this apparent training need. The project started in October 2009 and will be concluded in latter part of 2011. The main aim of the project is to create a special training course for seafarers to enable them to have a better understanding of the structure and operating principles of automated systems and of these systems' weaknesses and limitations as well as the management of the safety of these systems. The course material to be produced will support web-based learning (Ziarati et al, 2010).

4. The goals and the methods

An essential question is: what should be trained if the goal is to give the officers the skills and the knowledge to cope with modern automation technology onboard? The answer to this question about the contents of the training can be found by thinking about the tasks of the officers onboard in relation with the automation systems. It is quite obvious that the officers have only two main roles. The first one is to use the systems and the other one is to take care of the maintenance of the systems. Hence the training should focus on proper maintenance of modern automation systems onboard and on a safe and efficient way of using the systems. Maximising the safety and minimising the probability of an accident, especially due to a human error, should be the general perspective in designing the contents of the SURPASS course.

Training of users of technical systems is often focused on operation of the system under normal conditions, while the management of abnormal situations gets very little attention. However, the user must be able to cope with different kinds of abnormal situations including emergency situations resulting from automation failures. These situations can be caused by hardware failures, software errors, different kinds of disturbances or by extraordinary environmental conditions. It is important that the user can efficiently monitor the system and that s/he is also able to notice abnormal variations on the performance of the system. If the user cannot do this, s/he becomes totally dependent on the system's built-in ability to perform self-diagnostics to detect malfunctions and failures and to raise alarms or warnings to the user in such situations. There are several accident cases, however, showing that the users should not rely on the self-diagnostics of complex automatic systems Ahvenjarvi (2009). Especially in complex systems, consisting of several computer-based units and sub-systems, it is practically impossible to create such self-diagnostics that would be able to raise an alarm of every possible failure mode. Consequently, there is always a risk of such failure modes that cannot be identified by the self-diagnostics. When the system does not provide the user a proper alarm about a serious malfunction or a failure, a dangerous "automation surprise" takes place: The system suddenly behaves in a way that the user did not expect and the consequence can be an accident. The event-tree of an accident resulting from poor monitoring and incomplete self-diagnostics of a safety-critical system is shown in Figure 1.

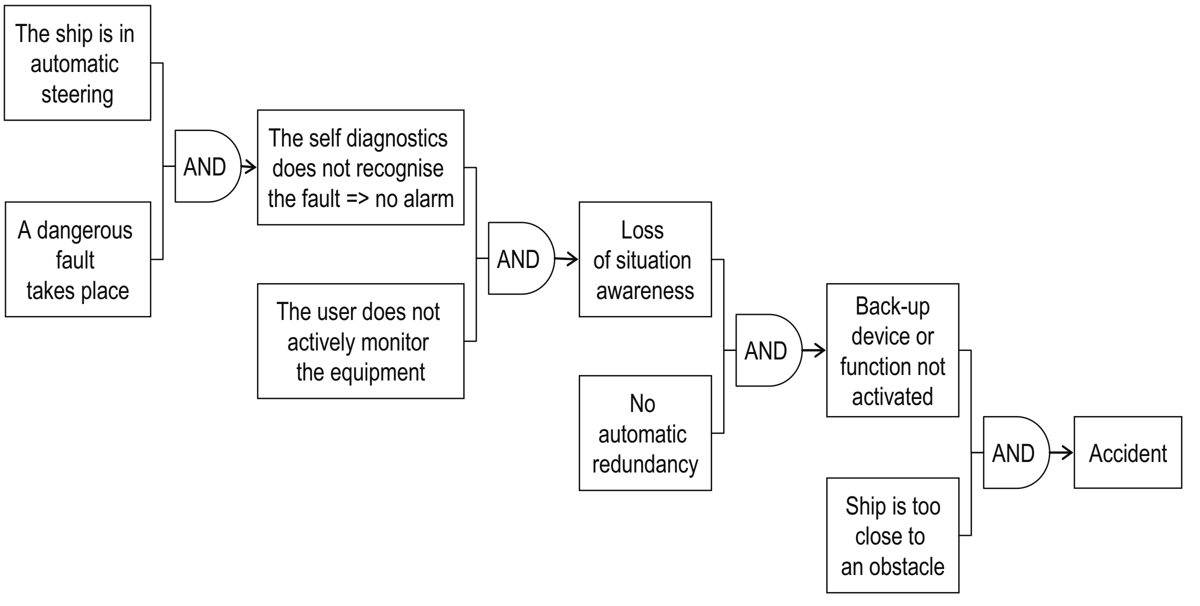

Figure 1. The event-tree presentation of a typical accident after a failure in a safety-critical automation system *(Source: Ahvenjarvi, 2011)*

Training of management of abnormal situations, however, is not a simple task. Efficient management of failure situations and proper monitoring of the performance of the system require good understanding of the structure and the operation of the system. This should be an essential part of the training, but on the other hand, training can not be loaded with too many technical details and theoretical information about the algorithms and functions. Moreover, such information is usually very system-specific, which means that every system and every ship should be studied individually. That is impossible in real life. So the conclusion is that the general training of users can contain principles of the structure and operation of modern automation systems. Also understanding of interrelations and dependencies between various sub-systems in a large integrated system and the data transmission between the sub-systems should be handled. Technical problems within automation systems are very often connected somehow with transmission of signals. But no detailed ship-specific subjects can be included. These skills and knowledge must be studied onboard. The general course should contain material to motivate the cadets and officers to complement their knowledge onboard.

Accident cases from real life would perhaps be useful for this purpose. The ship owner has the responsibility of arranging appropriate training for all users on the ship-specific subjects. An extremely useful tool for training of management of abnormal situations is a type-specific simulator. The air traffic industry has used type-specific simulators for decades to train cockpit personnel to handle different kinds of abnormal situations. Unfortunately in the shipping industry this is not usually possible, because ships are more or less individuals and each ship require its own type-specific training simulator.

In training of proper maintenance of modern automation systems, it is important to pay much attention to human errors, both in the understanding of why human errors occur and in learning how to prevent them. A useful book on these subjects is "Managing Maintenance error" by Reason and Hobbs (2003). The book gives information about the nature of human error and draws some guidelines towards error-free maintenance.

When the contents of the user training is being planned, it is wise to utilise modelling of the human behaviour. One alternative is the famous three-level model of human behaviour by Jens Rasmussen (cited in Ahvenjarvi, 2011). This model divides the behaviour of a human operator into three levels: the Knowledge-based level, the Rule-based level and the Skill-based level. There are also other classifications available. A model for maintenance of situation awareness would also be very useful. Figure 2 illustrates the structure of this model. The process of situation awareness is recursive, consisting of reception of information from the real world, combining it with the expectations, updating and maintaining the mental model of the reality and finally the task of controlling both the information reception and the real system in concern. Which ever model is used, it helps to ensure that all important areas and aspects of the human behaviour are taken into account.

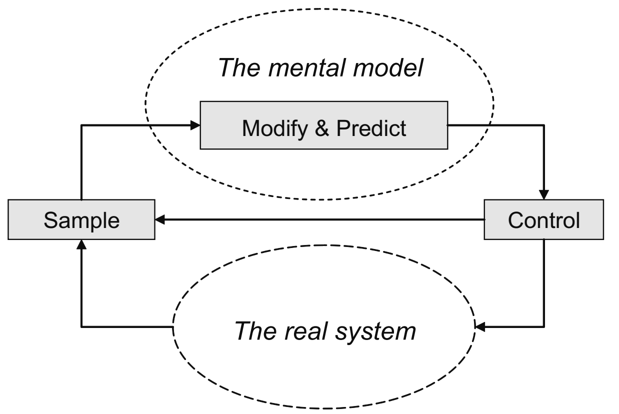

Figure 2. The recursive model of Situation Awareness
(Source: Ahvenjarvi, 2009)

5. The proposed contents of the training course

The proposed contents of the training course on the safe use and maintenance of automation systems is presented Appendix 1. It can be seen that there are many different topics and competences to be included in the syllabus of the course. It is, indeed, quite challenging to design a course on a rather demanding technical subject for people who do not necessarily have much earlier training on electronics, computers or automation. However, if there is not enough knowledge about the structure and operation of the system, the user may not be able to manage critical fault situations safely hence the argument by Ziarati et al (2007a) that knowledge of principles of automation is not negotiable. Also the Deck and the Engineer Officers of the ship must know something about risk analysis techniques and about avoiding human error during operation and maintenance, in order to successfully respond to a failure situation or handle the maintenance of the automation systems onboard.

The course content shown in the table is not the final one, and it will be adjusted according to the feedback from seafarers and other interest groups during the remaining period of the SURPASS project. In the course of developing the content for SURPASS a BTEC Unit was developed and approved by Edexcel, who are a partner in the project. The BTEC Unit relates to general aspects of instrumentation and control as well as hydraulic and pneumatic systems and their operations.

6. Conclusions

The review of recent research on automation on board ships (Ziarati et al, 2007a, 2010) including the work of several serious maritime organisations such the UK's MCA clearly shows that there is a need for SURPASS. Ziarati et al (2010) reports in some detail the recommendation by the UK MCA that MRM is an appropriate mechanism for incorporating the automation competences for seafarers. The recommendation of MCA was fully experimented by the SURPASS team when through the Swedish P&I Club and with support from TUDEV and the Satakunta University, an MRM course was run for a group of seafarers in Istanbul. C4FF also carried on an extensive evaluation of the MRM and the course that was piloted in Turkey. It was quite clear that for automation to be incorporated into an MRM, the nature and content of MRM has to change substantially and many scenarios and case studies based on automation have to be added to the content and delivery of the MRM courses.

Furthermore, since the development of the training of seafarers cannot keep up with the pace of the development of the technology, it is apparent that the users will not be able to use and to maintain the modern automated systems of ships safely and efficiently considering arrangements. STCW-2010 does not set precise requirements for the knowledge of automation-related issues and for the training on automated systems specifically. Obviously these official requirements must be complemented, as the development of technology continues.

The SURPASS team has learnt from the recent research, particularly the good work carried out by the UK's MCA as well as the IMO's effort to incorporate automation problems in its human element workshops (Ziarati, 2007b). As a result a novel data-structure has been developed for the SURPASS course content (due its size it will be presented at the conference) incorporating the principles of automation, operational and maintenance issues as well as a set of videos and slides to support and complement the intended content. The course includes a set of scenarios based on real accidents so that the previous automation failures are studied and lessons are learnt. Another innovative aspect of the course is that it is an on-line course and contains a series of e-assessment exercises which are used as part of the learning and assessment strategy for the course and can be run on a PC, so that MET institutions with no or limited access to bridge and engine-room simulators or to realia can learn a great deal from the SURPASS on-line platform. As a short course and being on-line SURPASS will be accessible easily by many seafarers and maritime organisations and authorities and this is expected to create opportunity for feedback and continuous up-dating.

The time is also opportune that the IMO has revised the STCW albeit not focussing on automation systems but at least there are no immediate changes expected which would help to develop the SURPASS to complement the existing IMO courses. The introduction of the new type of officers, viz., Electro-technical could take advantage of the SURPASS course developments. Appendix 1 shows the SURPASS Unit Content in its present form.

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APPENDIX 1 – SURPASS Unit Content

1. Investigate the fundamentals of instrumentation systems used in automated process controls.

Need for process control: quality; safety; consistency of product; optimum plant performance; human limitations; efficiency; cost; environmental protection.

System terminology: accuracy; error; repeatability; precision; linearity; reliability; reproducibility sensitivity; resolution; range; span; zero drift; hysteresis: distance and velocity lags; transfer lags; multiple transfer lags; capacity; resistance; dead time; reaction rate; inherent regulation; dead time; open loop; closed loop; load; supply; static gain; dynamic gain; stability; loop gain,

Process controller terminology: deviation; range; span; absolute deviation; control effect; set point process variable; manipulated variable; measured variable; bumbles transfer; process variable tracking direct and reverse acting; offset; proportional band; gain; on-off control; two step control; cycling proportional; proportional with integral; proportional with integral and derivative; proportional with derivative.

Regulating unit terminology: body; trim; plug guide and seat; valve; stem; bonnet; packing; gland yoke; actuator; motor; stroke; direct and reverse action; air fail action; repeatability; CV; turndown flow characteristics; linear, equal percentage, quick-opening, modified parabolic, split range.

Sensors/transducers, Transmitters/signal converters: current to pressure; pressure to current; microprocessor based ('smart') digital; analogue.

Transmission medium: pneumatic; hydraulic; electrical; fiber-optic.

Signal conditioners: operational amplifiers; voltage to voltage; voltage to current; current to voltage charge amplifier.

Tuning techniques: Zeigler-Nichols; continuous cycling; reaction curve; ¼ decay methods; tuning for no overshoot on start-up; tuning for some overshoot on start-up.

System representation: P and I diagrams; loop diagrams; wiring diagrams; constructing and using diagrams to appropriate standards.

Regulating units: dampers; power cylinders; louvers; valve positioners; valves (globe, ball, diaphragm gate, double seated, 3-way, solenoid, split bodied, butterfly)

2. Be able to use information and energy control system

Information systems: block diagram representation of a typical information system (eg. Audio communication, instrumentation, process monitoring); qualitative description of how electrical signals convey system information; function, operation and interfacing of information system components (eg transducers, transducer output and accuracy, amplifier types, typical gain, resolution of analogue to digital and digital to analogue converters, types of oscillators and operating frequencies); effect of noise on a system; determination of system output for a given input.

Energy flow control systems: block diagram representation of an energy flow control system (eg AC electric drives, DC electric drives, heating, lighting, air conditioning); qualitative description of how electrical signals control energy flow; function, operation and interfacing of energy flow control system components (eg transistor, thyristor, temperature-sensing devices, humidity sensing devices, speed control elements for DC and AC machines, dimmer devices and relays); determination of system output for a given input; selection and interfacing of appropriate energy flow control system components to perform a specified operation,

Interface system components: identification of appropriate information sources; select and interface information system components or select and interface energy flow control system components, to enable that system to perform desired operation

3. Be able to use operation of instruments and automated systems

Instrumentation and Automated systems provided at the Bridge: Conning Display (Magnetic and gyro compasses; Steering System Control/Autopilots; Echo sounders; Logs; Rate-of-turn indicators); Vessel Hardware, hands-on controls and their indicators: (Radar ARPA and/or Radar TX Imitator; Navi-Sailor ECDIS module with or without ECS Radar Overlay); Navaids: (Radio-navigational equipment: GPS/DGPS, Loran-C; Direction finders; Automatic Identification Systems; Ship alarm system; Exchange Data Interface with integrated bridge equipment; Dynamic Positioning System; Navi-Sound System; GMDSS; Generator of NMEA messages).

Instrumentation and Automated systems provided on the Deck: Windlass; Capstan; Deck crane; Offshore crane; Marine cranes ; Cargo Winches; Towing winches; Mooring winches; Electro-hydraulic grab; Davits; Bunkering boom.

Instrumentation and Automated systems provided in the Engine room: Main Propulsion Power (Diesel Engines; Steam Turbines; Gas Turbines); Main Propulsion Power Transmission (Propellers; Shafts; Stern tube); Ship control (Rudder; Steering Gear; Thruster; Stabilizer; Ballast Water); Electric Power (Generators; Electric Transmission and Distribution); Auxiliary systems (Compressed Air; Fuel Oil; Lub-Oil, Cooling; Air-conditioning; Refrigeration; Desalination; Boiler; Fire Alarm; Fire Fighting; Bilge Water)

4. Be able to manage the automated systems

Managing the Automated Individual (independent) systems: (Algorithms; System components; Operation; Data Analysis; Maintenance (Test, Alignment; Calibration),

Managing the Automated cooperative (Dependent) systems: Correlation and/or Influence; Relations; Effects,

Malfunction: Trouble shooting; Fault Sourcing; Fault Analysis; User's Attitude and Behaviour

In summary, the SURPASS course is expected to built on the recently developed BTEC approved course containing many general aspects of the instrumentation and control as well as hydraulic and pneumatic circuitries. The SURPASS course is being transformed into a BTEC Unit and is expected to be offered as a short course leading to a professional award by Edexcel. Partner METs will have the option of offering the BTEC Unit or run the course as part of their existing MET programmes.