TRAINING ENGINEERS FOR REMOTELY OPERATED SHIPS OF THE FUTURE

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Abstract. A key driver within the developments of today's maritime technology is the quest for autonomous or rather remotely operated ships. With the current pace of advancements, it is inevitable that autonomous ships will become a key driver within the shipping industry during the next 30 years. The role of marine engineers will then shift from seafarers to shore based personnel requiring new skills and expertise that are yet to be clearly defined. Therefore, the aim of this paper is to identify and discuss this emerging area from a Maritime Education and Training (MET) perspective. The paper highlights potential use of simulator-technologies and their advantages in training engineers for future autonomous ships. In addition, the paper discusses the limitations of simulator-based training approaches and new developments required within MET institutes to cater for the broader training and education needs of future autonomous ship engine room machinery operators.

1 INTRODUCTION

With the technological advancements in automation and over 40 years of experience of running unmanned machinery spaces (UMSs), modern day shipboard machinery is highly reliable with a proven capability to run in excess of 16-hours per day without human intervention. Recent developments are pushing these boundaries by initially extending this duration to a few days and ultimately paving the way to remote operations and fully autonomous ships. The indications are that remotely operated local (coastal) vessels will be in operation in the next few years, closely followed by unmanned ocean going vessels. This will have significant impacts on the nature of work in the maritime sector and the personnel who will be doing the work in the future [1].

As reported in [2], autonomous and unmanned shipping will dramatically change or in the extreme, eliminate the role of seafarers. Nevertheless, the human element is inevitable and will remain, albeit performing different functions, such as remote or shore-based operators [3, 4]. The uniqueness of training needs for such shore-based operations are recognised and the requirements for new approaches are emphasized in several studies [5]. Nevertheless, a comprehensive understanding of new skills and expertise required for such roles are yet to be clearly defined. Moreover, the approaches, technologies and facilities required to train engineers to meet the demands of future autonomous ships are not clearly understood within the Maritime Education and Training (MET) community. The current Standards of Training Certification and Watch-keeping (STCW) convention [10] and the individual national maritime training regulatory systems do not account for training needs for the future autonomous ship operators. Therefore, there is noticeable lack of understanding of the training needs and approaches for future shore-based operators, which effectively impedes MET institutes from investing in the technology and systems required to train and service to autonomous ship personnel.

The aim of this paper is to explore this emerging area from the MET perspective and highlight the use of simulator-technologies as an essential and efficient approach to train future shore based technical personnel to meet the challenges associated with autonomous ships. The opportunities and advantages of simulator-based training are highlighted in this paper with recent experiences in delivering such programmes. In addition, limitations of simulator-based training approaches and new developments required within MET institutes to cater to the broader training and education needs of future autonomous ship engine room machinery operators are also discussed.

2 ESSENTIAL FEATURES FOR REMOTELY OPERATED MACHINERY

As with the introduction of any new technology, the initial breakthrough is fraught with difficulty, until it settles into accepted routines and trends. This stage is followed by a relentless pursuit for improvements, as economic factors drive the industry to improve and expand the technology and its use. Thus, the success of remotely operated and autonomous ships depend on the: reliability of the machinery; accuracy of the associated instrumentation and control systems; and critical thinking and decision-making ability of remote operators.

The reliability of the numerous on-board machinery systems will be an essential feature for un-manned operation of ships. For example, the diesel engines with significant moving parts can be replaced with propulsion motors having only the rotor as a moving part. It is accepted that the “electric solution” is a way forward for sea transportation in future, similar to electric trains, buses, trucks and cars for road transport. In addition to the operational flexibilities, the reduction of emissions is another motivation for moving towards electric propulsion. Thus, autonomous shipping and electric propulsion go hand-in-hand. An example is the *Yara Birkeland*, the world’s first fully electric autonomous container ship with zero emissions. The ship is scheduled to be delivered in 2019, initially running with a skeleton crew and becoming fully autonomous by 2020 [6]. Recently a Dutch company, Port Liner, commenced building Europe’s first fully electric emission free barges. The first five barges will carry 24 containers each, and will eventually become autonomous [7]. While the coastal shipping can depend on electric propulsion without fossil fuel powered generators, large ocean-going ships may need power generators to charge the batteries and/or supplying power directly to the propulsion electric motors. Although there would be preference to do so using renewable energy, in case of ships with high electrical loads, prime mover driven alternators cannot be ruled out.

When generators driven by diesel engines are employed, it introduces the additional aspect of the reliability of the prime mover and the time between overhauls (TBO) of various components. Although the TBO has increased significantly in diesel engines, liquefied natural gas driven gas turbine generators (GTG) have significantly higher TBO’s (up to 50,000 hours) [8] and will find their due place on-board ships during the autonomous transformation.

The extended operating hours of UMSs is another indicator of the reliability of machinery in modern ships. In the late seventies when the UMS ships were introduced, many were skeptical as to its future. Forty years later, majority of the ships operate in the UMS mode up to 16 hours per day. A major driver is that the shipping companies find it more productive and cost effective. Electric propulsion with less moving parts, higher and greater flexibility is another technological advancement that contributed towards extended UMS hours.

Once the machinery design and material technology requirement is achieved, the next essential feature for un-manned operation will be the accuracy and reliability of the instrumentation and the control systems associated with the various functions on board large ships. In this respect, smart connected machines, or Robotics and Autonomous Systems (RAS) are providing tools and systems to support and working alongside personnel and even work alone, making independent decisions. [9]

Finally, the human intervention or the presence of the remote operator cannot be underestimated within the operation continuum of the marine engineering function of the autonomous ship. Irrespective of the degree of automation installed on the vessel, it is yet important to enable human intervention if all else fails. On the road to transition towards fully autonomous ships, it is inevitable that technology needs to have avenues to enable humans to interface with relevant systems to mitigate unforeseen circumstances. Once the autonomous ship Yara Birkeland is in operation, the reality of such vessels and the required competencies of the marine engineers to remotely operate such vessels will be clearer [1].

The transition requires marine engineers who are able to remotely operate machinery from shore based stations via remote communication channels such as satellite communication. The future marine engineers will not be ‘sailing’, but may gain the required experience, i.e. virtual ‘sea time’ by operating the machinery during the ship’s voyage albeit remotely. The concept of remote operation of ships machinery from shore may pave the way for a new breed of marine engineers/remote operators. In a world with autonomous shipping, the future role of the marine engineer will essentially be confined to a shore based operating station, making decisions based on the telemetry from the machinery managed remotely. This technology is currently used in the aviation industry and defense, where aviation and marine platforms are controlled remotely and/or allowed to operate autonomously to carry out various short and long term missions. Aspects of these operations have already made inroads into civilian applications, providing proven technology to assist the transition to autonomous ships.

Beyond the engineering challenges associated with remotely operated ships, the effective application of autonomous technology would depend upon the environment in which it is deployed. It is not just the physical maritime environment that needs to be considered, but also the business, regulatory and legal environments that all present significant challenges affecting the development and application of the technology itself [6].

3 TRAINING THE FUTURE MARINE ENGINEER

Ever since the employment of machinery for ship propulsion, engineers were required to operate, maintain and repair the main propulsion machinery and the associated auxiliary systems scattered across the vessels. The training philosophy for engineers in the past dictated apprenticeships and engineer cadet schemes with a mix of shore and ship based training. The certification of competency required appropriate duration of sea service with certain propulsion machinery and both written and oral assessments. Once qualified, the engineers at various levels of competency required further sea service and associated education/training in order to appear for further written and/or oral assessments to progress up the hierarchy.

Before investigating the issues and implications of training the future marine engineers, it is necessary to backtrack the role played by marine engineers and how they were groomed and nurtured to play that role.

As explained, the past training regime for marine engineers the common acceptance was that the marine engineer is more a ‘hands on’ person. Many chief engineers preferred engineers with hands on skills such as welding and fitting since the shipboard machinery at the time needed more maintenance and repairs than today. Besides the machinery was relatively simple compared with those of today and had very little or no automation associated with marine machinery plants. Trouble shooting did not require theoretical knowledge stemming from thermodynamics, electronics, electro-technology etc. The International Maritime Organization (IMO) convention on STCW 1978, 40 years ago effectively supported the hands on criterion by prescribing various workshop competence towards certification. Subsequently, the STCW 1995 convention, further enhanced the workshop requirement under the function “Repairs and Maintenance” in the STCW Code and its expansion through Section AIII/1 and AIII/2 [10], although the theoretical aspects are also covered in “Marine Engineering” and Electrical, Electronic and Control” functions. However, the code does not adequately focus MET institutions towards the required theoretical concepts essential to prepare engineers with the required knowledge and skills to deal with future trends and advanced technology. This situation unfortunately continues to date with many (MET) institutions and administrations not actively gearing up to face the transition to autonomous shipping that is fast approaching reality..

In a future world of autonomous ships, once the role of the marine engineer is confined to a shore based operating station away from the ship’s engine room, we find the STCW function “Repairs and Maintenance” becomes redundant to those remote technical operators. It is however recognized that this function will yet have to be carried out at various intervals by a team of dedicated personnel. This repair and maintenance staff will be located in strategic ports and repair yards.

Further, the current function “Controlling the operation of the ship and care of the persons on-board” will be partially redundant and will need significant modifications as there will not be any persons on-board. Therefore, following competency requirements under the function “Controlling the operation of the ship and care of the persons on-board” will cease to exist once the ship becomes fully autonomous:

1 Operate lifesaving appliances
2 Apply medical first-aid on-board
3 Application of team working and leadership skills
4 Contribute to the safety of personnel

The two STCW functions “Repairs and Maintenance” and “Controlling the operation of the ship and care of the persons on-board” will diminish with the respective associated competence requirements. The remaining two functions “Marine Engineering” and “Electrical, Electronic and Control Engineering” will need modification and changes to provide the required knowledge and skills to carry out the duties as the remote operators of the autonomous ships of the future.

4 TRAINING PHILOSOPHY FOR FUTURE MARINE ENGINEERS

The fact that the modern day marine engineer is more an operator is evident from the way that technology has advanced and reduced the number of engineers in the engine room while increasing the time between overhauls of machinery. At the same time, the engineers need more of a theoretical foundation to understand the practical applications, which was not as crucial in older ships.

Hitherto the marine engineering training philosophy was to divide the theoretical and practical concepts and treat them as two separate entities. Unfortunate this continues to date, with many (MET) institutes categorising the theoretical subjects as ‘Part A’ and the practical or operational subjects as ‘Part B’. In many cases, the certificate of competency examinations also tend to separate them, with the ‘Part A’ subjects often treated as less important or relevant, although the overall curriculum requires both theoretical and practical subject knowledge. In reality, the engineers need a range of competencies in order to successfully carry out their duties. To achieve these competencies, engineers require exposure to both theory and practice. However, as there is less emphasis on Part A (the theoretical subjects), students tend to pay more attention to the learning of operational concepts, as they are perceived as more relevant and pivotal to their duties on ships and their final examinations.

The knock-on effect of the whole practice is that engineers do not see the essential connection between the theoretical foundation and the practical application. Although some find it within their ability to analyse and theorise some of it, a considerable void exists within engineers trained in such systems from grasping real situation that may hamper their critical thinking and problem solving skills. This connection is essential for the future marine engineers who are destined to operate the autonomous ships.

The Marine Accident Investigation Branch (MAIB, UK), in its reports, highlighted the separation of the theory from the application, as the cause of recent machinery failures. The

MAIB report on the catastrophic failure of harmonic filters on *RMS Queen Mary 2* in 2010 [11] states, "…it is important that the ship's engineers gain a thorough understanding of the issue of the harmonic distortion and harmonic mitigation equipment, so that they are better able to appreciate the importance of the equipment on board and take timely action if such equipment fails or deteriorates". A similar statement was issued by MAIB in the accident report on the 8500 TEU container ship *Savannah Express* with regard to its engine failure and collision at Southampton in 2005 [12]. It states, "…although the engineers on board were experienced and held appropriate STCW certificates, they were unable to correctly diagnose the reason for the engine fault at the Nab Tower and later at the Upper Swinging Ground. The increasing levels of electrification of engine control and propulsion systems require increased training requirements in the operation, maintenance and fault finding of these technically complex and multi-discipline systems. The STCW training standards for ships' engineers have not been updated to account for modern system engineering requirements". The accident also highlighted the essential need for the development of adequate type specific training.

It is evident from reports like that presented above, that when it comes to issues involving electrical, electronic, control and automation, shipboard, marine engineers are insufficiently skilled and trained. However, as on-board technology relies on electrical, electronic, control and automation, the training needs to be significantly upgraded and modernised through amendments to the STCW code and changes to the curriculum and practices. One major option is the use of simulators to develop suitable training programmes and using it as an interactive training and assessment tool. The following looks at the use of engine simulators as part of the training programme.

5 SIMULATOR-BASED APPROACH FOR TRAINING ENGINEERS FOR FUTURE AUTONOMOUS SHIPS

The effective use of simulators in engineering education has been in practice world-wide for decades. Initially the context of simulation training was restricted to applications where it was possible to prove certain engineering concepts with laboratory demonstrations. With the introduction and development of Information and Communication Technology (ICT), the capabilities of simulators in engineering education crossed the threshold of conventional simulators and entered into a new era of full mission simulations.

Simulator training has over the last few years proved an effective training methodology in training engineers, especially where an error of judgment can endanger life, environment and property. A dynamic real-time computerized simulator can compress years of experience into a few weeks, and provide knowledge of the dynamic and interactive processes typically encountered within shipboard engine rooms. Proper simulator training will reduce accidents and improve efficiency, and give the engineers the necessary experience and confidence to face crucial incidences in their job-situation. It is important that the trainees experience life-like conditions on the simulator and that the tasks they are asked to carry out are recognized as important and relevant in their job-situation. The trainees are challenged at all levels of experience in order to achieve further expertise and confidence [13].

A collaborative study between Kobe University, Japan, and Australian Maritime College, (AMC) Australia, reiterated the need to connect the theory and practical to optimize the outcomes from MET programmes [14]. For such programmes the best simulation tools are the 'full mission' simulators, which enable the students follow training programmes that includes:

- gaining the theoretical concepts within a class room and/or lab setting;
- observing and participating in the same concept and its application in a simulator demonstration and/or setting; and
- being assessed of the relevant competence using the simulator through appropriate and authentic assessments.

Example: Synchronising and connecting an incoming AC generator to a running generator.

1. In a classroom setting a lecturer can explain the relevant aspects of three phase alternating current. This will lead to an explanation on what parameters need to be matched between the incoming generators and the system, at what point this needs to be carried out, how it's done and consequences of not meeting the requirements.
2. For a first or second year student this is not easy to comprehend purely through a class room explanation. With a full mission simulator exercises can be designed to allow the instructor to demonstrate this operation and the students to practice the relevant operations. This will include the starting of the generator, preparation for synchronizing, carrying out the operation, and post synchronizing tasks. The instructor can also demonstrate the consequences of incorrect operation by carrying out various tasks incorrectly. The practical interactive nature of this exercises will consolidate the learning that commenced in the classroom, with an understanding of the consequences.
3. Finally an assessment task will provide the student with the opportunity to demonstrate the competence attained, including variations. The assessor and the student clearly sees the outcome and progress, with clear avenues of feedback. This will provide the student with the confidence to carry out these tasks in real life under varying conditions.

Proper design of simulator exercises also enables the clear demonstration of the relevant theoretical concepts; for example: thermodynamics, heat transmission, electro-technology etc. can be clearly demonstrated using the 'simulator trend groups'. This enable the students to apprehend the behavior of several dependent variables when a single independent parameter is varied. The capability of the simulator to subject the onboard machinery and plant to extreme conditions is a major advantage that usually cannot be replicated with real equipment. The very large number of possible malfunctions available to instructors can be very effectively used in simulator exercises to bridge the gap between the theory and the practical in many ways. However, care should be taken to ensure that the exercises and assessments are realistic, and that they are designed not to overwhelm the students, rather to gradually introduce and progress them through the appropriate concepts and scenarios to develop the required competence.

6 CONCLUSIONS

This paper focuses on the training requirements associated with the inevitable entry of autonomous ships. The nature of new ships and their operational modes will require new training strategies and tools in order to prepare personnel to meet the new challenges such as remote operation of these ships. The autonomous ship's machinery will have a very high degree of reliability and an acceptable degree of redundancy to enable them to operate without any down time. However, this will also require the remote operator to make appropriate decisions and carry them out in a timely manner.

The operators will need to be marine engineers with a strong engineering background. Given the nature of modern and future shipboard machinery and systems, they will need to have high levels of relevant theoretical and practical knowledge as the autonomous ships will be most likely to move towards electric propulsion with batteries, charging on renewable energy or power generators consuming fossil fuels. If the implementation of autonomous ships is to achieve economic benefits to shipping companies by reducing and ultimately eliminating the crew, remote operators of machinery must be capable of handling the operational and emergency situations by making appropriate and timely engineering decisions. This critical factor depends on the knowledge and skills received through appropriate training and assessment programmes. The use of engine simulators provide MET Institutions with highly appropriate technology and tools to provide such training to prepare the future workforce to operate autonomous ships.

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