Volume 2 Issue 1

ISSN 2456-7035

ISF Institute of Research and Education (IIRE)

IIRE JOURNAL
of
MARITIME RESEARCH & DEVELOPMENT
(IJMRD)

MAY 2018

ISF Institute of Research and Education (IIRE)

Knowledge-Humility-Excellence

IIRE JOURNAL OF MARITIME RESEARCH & DEVELOPMENT (IJMRD)

Volume 2 Issue 1

May 2018

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ISSN: 2456-7035

Published by:
ISF INSTITUTE OF RESEARCH AND EDUCATION (IIRE)
410, Gemstar Commercial Complex, Ramchandra Lane Ext, Kachpada,
Off Link Road, Malad (W), Mumbai 400 064, INDIA.
Website: www.iire.in, www.isfgroup.in

Link of Publication: - http://iire.in/ojs/index.php/IJMRD

Place of Publication: - Mumbai

IIRE JOURNAL OF MARITIME RESEARCH AND DEVELOPMENT

Maritime sector has always been influencing the global economy. Shipping facilitates the bulk transportation of raw material, oil and gas products, food and manufactured goods across international borders. Shipping is truly global in nature and it can easily be said that without shipping, the intercontinental trade of commodities would come to a standstill.

Recognizing the importance of research in various aspects of maritime and logistic sector, IIRE through its Journal of Maritime Research and Development (IJMRD) encourages research work and provides a platform for publication of articles, manuscripts, technical notes, papers, *etc.* on a wide range of relevant topics listed below:

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- Other Current Topics of Interest in Shipping

Editorial Board

Editorial

The intervening six months since the last issue saw me travel far and wide on invitations to participate in matters covering various aspects of maritime industry. Korea Maritime University in Busan hosted the first Global On-board Training Conference in October last where issues related to this vital aspect of training, in particular the shortage of training berths was discussed. I had the opportunity to share the output of a project-research undertaken by self as part of a four-member team under the aggies of the Institute of Marine Engineers of India on trading-training-ship as an economically viable alternative.

The second trip was to Mombasa in Kenya in February this year where the core Education and Training Committee of the Institute of Chartered Shipbrokers, London, of which I am a member, met up to transact routine business of dynamically and continually improving on the thoroughly professional qualification in shipping commerce subjects that are held in very high esteem globally. Here again I seized the opportunity to dwell upon Professional Doctorates in the maritime domain. Professional Doctorates have strong relationship with the workplace and it places research at the service of professional practice. It aims to producing the critical thinking and critical thinkers that seek to surpass and transform current conceptions of practice in professions. A paper on the subject is included in this issue of the journal.

The third trip that took me the furthest was to Buenos Aires in April of this year on invitation by the International Federation of Ship Masters' Association at their Annual General Assembly that was hosted by the Argentina Ship Masters' Association. My presentation here was on the subject of Advances in Safety Science, on what is popularly known as Safety 2.0, glimpse of which one can have in the paper in this issue by Dr. Nippin Anand.

The balance three papers in this issue are by senior industry practitioners who are now pursuing research in topical themes of Ship Emissions, Reliability Engineering and Integrated Training respectively making this issue yet another invigorative reading.

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IIRE Journal of Maritime Research and Development (IJMRD)

Volume 2 Issue 1, May 2018

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PROFESSIONAL DOCTORATES FOR THE MARITIME DOMAIN

Suresh Bhardwaj

Professional Doctorates integrate professional and academic knowledge and have strong links with the workplace. It aims to improve practice and positively impact the employment culture. While the industry needs to appreciate and encourage this, the Universities also must respond and pave the way to offer doctoral level programs that facilitate professional learning and development, with proper pedagogical and organizational strategies.

It is a known fact that dissonance exists between the two cultures of learning - the academic and the professional. A complex and contested relationship between the constituents of academic and professional knowledge highlights problems with equating them and indeed poses a challenge for the Universities (Scott *et al.* 2004). However, a Maritime university that operates in the highly skills-oriented domain as that of the shipping industry needs to come up with innovative practices that challenge orthodox conceptions of doctoral study. It must build bridges with the world of work.

In many professions not only maritime, there has been rapid changes in environment that has led to interest in 'reflective practice', 'critical reflection' and experiential learning within continuing professional development (Brookfield 1995). There has been a perceived need for professionals to engage in higher professional development, to reflect critically on their practice, to develop transferrable skills and competencies, and to gain higher qualification. On the other hand, there is pressure for universities to diversify and offer more professionally relevant programs.

The Doctorate degree in UK is no longer only an academic qualification, but also a professional and in some cases a vocational qualification. In USA and Australia this has existed much earlier.

AN EXAMPLE FROM THE UK

The Engineering Doctorate (EngD) is a four-year doctoral research programme, involving a significant taught component. It is an alternative pathway for postgraduate research students; providing the technical, business and personal development competencies needed to become the senior research managers of the future.

The EngD combines advanced technical and commercial skills training with PhD level research, completed in collaboration with an industry sponsor. So they will have an industrial supervisor as well as a supervisory team at the University. Research projects are developed collaboratively by academic supervisors as well as the research student in consultation with their sponsoring company.

The EngD is a four-year course. The first year is University based; students participate in a taught course in advanced technical areas relating to their research, combined with appropriate commercial skills training. Years two to four are spent conducting applied research, with the opportunity to gain valuable industry and commercial experience through placements with the sponsoring company and an ongoing programme of commercial skills development.

Students conduct PhD equivalent research. Successful candidates are awarded the degree of Doctor of Engineering (EngD) and are addressed as *doctor*.

It belays the notion that somebody with a PhD is totally academic which sometimes industry may choose to treat it as a disadvantage rather than an asset.

The candidate for a professional doctorate is usually expected to undertake research aimed at making a contribution to the knowledge of professional practice. Rather than perceiving research as an end in itself, the professional doctorates have placed research at the service of the development of professional practice and professional practitioners. The professional doctorate is a rigorous research-based and research-driven qualification focused on the improvement of professional practice. It is an original investigation undertaken to gain new knowledge and with practical aims and objectives. It concerns with researching real business and managerial issues via the critical review and systematic application of appropriate theories and research to professional practice.

It is a form of professional education in which students are introduced to the professional practice of research and scholarship, with the supervisor responsible for assisting students to become independent practitioners. Key ingredients in this metamorphosis include reflection and planning by the student, appropriate work experience for and the development of personal capabilities in the student and changing roles and responsibilities for the research supervisor (Doncaster and Lester, 2002).

The UK Government's White Paper on Research Policy (1993) identified limitations of narrow career focus of traditional PhDs and introduced Professional doctorates.

CRITICAL DIFFERENCES

Starting Point for Research

For the Doctor of Philosophy, the candidate is normally expected to undertake a preliminary literature search and review to identify a gap. For professional doctorate research, the candidates are normally expected to start with a problem in professional practice that needs investigation and resolution. Whereas the PhD candidate starts from what is known (that is the literature review), professional doctorate candidates start from what is not known (that is, some perceived problem in professional practice).

Intended Learning Outcomes

The intended learning outcome of the PhD is to develop the capacity to make a significant original contribution to knowledge in a particular discipline through research.

By contrast, the intended learning outcomes of professional doctorates are considerably broader. They include the capacity to make a significant original contribution to knowledge of professional practice through research, plus one or more of the following:

- personal development (often specifying reflective practice);
- professional level knowledge of the broad field of study;
- understanding of professionalism in the field;

- appreciation of the contribution of research to the work of senior professional practitioners.

Experience as an Admission Requirement

The Professional Doctorate is intended for experienced practitioners within a profession, whereas the PhD is intended for apprentice researchers who may have no experience of the subject beyond the possession of a good first degree in the proposed field of study.

Candidates for a professional doctorate programme are usually required to provide evidence of significant experience of professional practice. This is usually specified in terms of minimum years of relevant employment, usually 3 years.

The professional doctorate is normally intended to be a form of in-service professional development, whereas the PhD is intended to be available as a pre-service training in research.

Furthermore, most professional doctorates are designed to be studied only by part-time attendance; the rest of the time the student is expected to spend in industry or a professional organisation.

ENDNOTES

It is the inevitable consequence of a drift towards vocationalism. From this perspective, the rise of professional doctorates is evidence that the competencies approach had at last reached the highest, doctoral, level.

Professional doctorates are attractive to those who view their own personal development and academic ambition as fully integrated with their professional development and have a commitment to furthering the cause of their profession.
Whilst it is important that higher education contributes to capabilities of students in terms of professional effectiveness, it is also important that higher education accepts the responsibility for producing the critical thinking and critical thinkers that will seek to surpass and transform current conceptions of practice in these professions.

The Indian Maritime domain is ripe to witness this transformational change.

It is the mutual recognition (by government, the professions, universities and, above all, the practitioners themselves) of the importance of this which will lead to the further rapid extension of the professional doctorate over the next decade in our country.

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LOST CONTROL? JUST STAY IN COMMAND.
WHAT IT MEANS TO BE A SHIP'S CAPTAIN

Dr. Nippin Anand
PhD MSc FNI

The previous year witnessed two experienced ship captains being humiliated and eventually criminalized. Accidents, with no evil intentions, were turned into acts of crime. So strong was this perception that even veteran captains and the so called 'experts' within the profession found it difficult to understand the 'erratic' behaviour and 'selfish' actions of the captain in one case, let alone the general public. This analysis is not intended to defend the behaviour of these professionals or make their actions morally acceptable. Professionals have to act mindfully, taking responsibility for their actions and directing their behaviour in meaningful ways.

Rather, we seek to understand what makes the position of a captain so prestigious, and yet so susceptible in the wake of an accident. Why is it that not only the maritime community but also society at large becomes unforgiving to the captain whose vessel has met with an accident?

And to what extent does our existing approach to the investigation and enquiries that follow these accidents shape those unforgiving opinions, both within the industry and in the public domain?

THE CAPTAIN'S ROLE:

Let us begin with what it means to be a ship's captain. There is no end to the stories of supreme command and control in this position. The confident and daring Captain Edward Smith, having done all he could do to save the crew and passengers, opted to stay at his post until the sinking of the Titanic. Captain Karan S. Mathur of the Erika apparently lost control but still maintained command and Captain Apostolos Mangouras of the Prestige, along with two crew members, chose not to be airlifted in extreme weather conditions when sinking became imminent.

Tradition has it that the captain is the company's representative on the vessel and the captain's subordinates are 'mates,' unlike 'first officers' in aviation. The complement on ships consists of the captain and the crew; the captain is not considered part of the crew. In the past, the company superintendent could advise but ultimately it was up to the Master to decide. The superintendent was aware that his knowledge of shipboard operations was limited and excess interference in matters of operations might have implications for risk and safety. The management of risk and safety is to a large extent a matter of technical know-how - a matter for the Master. But technical know-how alone does not guarantee command. If it did, professors, technicians and software engineers would be on a par with the captain.

A ship is a complex system of interdependencies in which system components (humans, processes and technology) work in harmony, both sequentially and in parallel, to achieve certain goals. The engines run, and the rudders respond as the helmsman applies the helm to turn the ship to the intended course. Of course, the helmsman should be adequately trained in taking orders from the captain, and the captain should be equipped with the knowledge of navigation and ship handling. The vessel should be kept shipshape by appropriate standards of maintenance and the company should supply adequate resources as needed. But this interdependence, as Charles Perrow describes it in his book Normal Accidents, can either be loosely or tightly coupled. A loose coupling means there is sufficient time, slack or redundancy within the system to rectify problems or correct an error of judgment without any serious implications to vessel or crew safety (for example allowing the vessel to sail to the next port with one engine down due to redundancy in the system or being able to delay ordering of spare parts because there is no urgent requirement). The balancing of safety and commercial goals is based on a careful cost/benefit trade-off.

Tightly coupled systems do not allow the luxury of back-up and redundancy. Even minor disruption to the interaction between components may put the entire system in danger (for example navigation in dense traffic areas or functioning of dynamic positioning systems during diving operations). The safe functioning of a tightly coupled system is contingent upon a centralized hierarchy of command and control. These systems do not allow the liberty of slowing down to think, reflect and decide what next. As a result, the ability to make accurate instantaneous decisions based on technical know-how while balancing safety with commercial goals is central to tightly coupled systems. This ability can be termed heuristics, rule of thumb or simply professional judgment and it sets professionals apart from ordinary people. But heuristics alone do not explain the attributes of a captain, as lorry drivers and crane operators also must act on reflexive decision making. Years of technical know-how and excellent decision-making capabilities are both essential to becoming the iconic hero of the marine profession.

PROFESSIONALS AND PROFESSIONAL IDENTITY:

Technical know-how acquired over time is a strong source of identity in many professions. In the maritime industry it is commonly referred to as 'seamanship'. It forms the basis of the work situation, market situation and the status of (maritime) professionals in the public arena. In work situations, it means that professional judgment takes precedence over rules and procedures, particularly in operations where interdependencies are tightly coupled. The ISM Code Section 5.2 and Collision Regulations Rule 2 (b) have readily acknowledged the limitations of the world of procedures and rules. There are too many unexpected events and uncontrollable variables in the real world for rules to cover every situation. Professionals must be trained to think and act in ways that go beyond following procedures and instructions.

Given that such skills are scarce and irreplaceable it also means that the market rewards maritime professionals accordingly. Professionals in other industries benefit from similar work and market situations, for example airline pilots, surgeons and drilling crew on oil platforms.

THE PUBLIC ARENA:

The status of a ship captain is also acknowledged outside the professional community. Both history and fictional narratives play an important role in shaping such perceptions. But as with everything, respect for the profession comes with certain expectations – in this case, of ensuring maritime safety and resilience. In general, the expectation is fulfilled. Ships do not in general collide, run aground or pollute coastlines on a frequent basis despite the ever-increasing density of maritime traffic. The prestigious status of captain also carries an immense societal expectation, whether the Master is aware of it or not.

SHAMING AND BLAMING PROFESSIONALS:

In the wake of an accident, the same professional identity which is otherwise a source of resilience and prestige also gives rise to accusations of 'negligence' and 'human error'. Partly, this is the result of how we understand and investigate accidents. The outcome does not match the intentions and the outcome is morally wrong and psychologically disturbing. Society seeks the 'causes' of accidents, and investigators hardly ever look beyond the tightly coupled situations that are closest to the outcome. The tighter the coupling of interactions that lead to an accident, the more detailed is the investigation of professionals and their judgments.

The issue that faces most captains involved in an accident is to justify their actions against ambiguous expectations of rules and regulations such as the 'ordinary practice of seamen'; 'special circumstances'; 'safe speed'; 'ample time'; and 'good seamanship'. What is good seamanship and safe speed, once you have already met with a collision, and how do you justify that your actions and decisions were in accordance with good seamanship if your vessel has already run aground? With the benefit of hindsight, professional judgment and common sense becomes known as 'human error'. Litigation and law suits thrive even more on such murky phrases, as blaming professionals for their actions (or inactions) becomes much easier against the background of rules, regulations and 'objective evidence' that serve well to establish 'the facts of the case'.

However, practical challenges, goal conflicts, incomplete knowledge at the time of making decisions, commercial pressures and manning constraints are seldom considered in detail when establishing these 'facts'. Working effectively in a demanding resource-constrained environment requires considerable professional ingenuity. This involves constant improvisations, trade-offs, negotiation, adaptability and resilience. But in the case of an accident, these professional abilities are distorted into fallibilities in court. Systemic issues within the organization are presented as the foibles of an incompetent captain, ensuring that the organizational reputation is not undermined by the actions of an individual worker.

TOO MANY EXPERTS, TOO LITTLE EXPERTISE:

The exaggerated responses of the maritime community to an accident are not helpful either. It is as if the professional identity of every individual in the community has been challenged. Any association with those involved in the accident would imply approval of their decisions and competences.

On average, maritime professionals spend their entire lifetime within the industry, starting at sea and progressing to shore-based opportunities. Until recently, most shore-based positions were reserved for those with adequate seagoing experience. This provides a high level of experiential knowledge that is an immense source of resilience in the system, but more expertise also means more opinions and judgments about those involved in accidents. Temporally outdated perceptions and contextually irrelevant experiences of 'safe distance' and 'good seamanship' are brought up on social media to criticize those involved in the accident, when in truth no two professionals can agree on what is safe and what is good. And if so-called experts and professionals cannot agree what should have been done or what actions were reasonable, how can we possibly expect the general public, with its iconic image of the all-knowing captain, to come up with a fair explanation? The gap is eventually closed by bringing the public over to the professionals' and experts' side. All this has serious and far- reaching implications for those involved.

Another line of inquiry with accident investigations and 'expert' judgments is that it focuses excessively on the failures of those closest to the accident – for example, that the collision resulted because the watch keeping officer 'lost situational awareness' or the Master should have slowed down to 'safe speed' when he encountered restricted visibility. Issues that appear to be less immediately related to the accident, such as organisational factors, are not subject to the same level of scrutiny.

It all depends how the timeline of an accident investigation is decided and on what basis. If we seek to find answers within the confines of bridge and engine room, we may choose to focus only on the past 24 hours' recordings on the Voyage Data Recorder (VDR), on the period from the start of the voyage, or at the most from when a crew member first joined the vessel. However, the major contributing factor may be a substandard design chosen for cost reasons when the vessel was originally built thirty years ago, or cheap travel arrangements that led to an overtired crew member long before hours of rest could be officially recorded. The purpose of the ISM Code in addressing the latent and organisational factors that contribute to accidents seems to be lost when it is required the most. But the existing system serves extremely well for a company that wants to save its reputation in the wake of an accident – get rid of a few 'rotten apples' and safety is restored.

Many captains I have come across, active and retired, have been highly critical of recent cases where the captain chose to abandon the vessel much before the rest of the crew and passengers were able to do so. Interestingly, the same professionals also admitted that both technological advances and detailed micro-management have shifted the balance of power from ships to the shore end. This is not necessarily the intention; it is the unintended consequence of the restructuring of work. The status and position of a captain is seriously undermined when an assertive young manager in the office demands an immediate response to an email query. In one instance, a chief officer was asked not to make too much fuss about shifting a few hundred metric tons of weight from a lower deck to a higher platform on a drilling unit. Micromanagement from less experienced middle managers or those with outdated operational knowledge can lead to serious breakdown in communication when technical complexities are not understood by those in decision making roles ashore, and yet intervention is considered necessary.

The offshore industry was quick to realize the production pressures and the need to transfer decision-making ashore and found a solution to this issue by replacing the term 'Captain' with 'offshore installation manager'. Here is a paradox. While public opinion - and to a large part, industry opinion as well - is still based on the outdated perception of the days of Titanic, production pressures have significantly altered the role of a captain. What we see as unwillingness and inability to command may well be a result of the erosion of decision-making and degradation of the profession due to enhanced control from ashore.

HUMAN FACTORS OR SOCIAL STRUCTURES?

When a Master gets a few hundred metres too close to the shore, the self- proclaimed human behaviour experts (and there are many!) are swift to assign the problem to 'human factors'. The first question is whose fault was it? How close was the vessel to the coast and why on earth was the captain attempting such an insane manoeuvre? We are convinced that the problem lies with the pesky human and his perception of risk and safety. But even if we take this position, why do we design and operate capital-intensive systems in such a manner that catastrophic failures can result from the fallibility of one human - whether deliberate or not?

Even this is only a partial explanation. If an investigation is carried out according to the spirit, rather than the letter, of the ISM Code, these same human factors should be examined as part of the general structure of authority within an organisation. A systematic study of success and how success stories are shared across the company, incentives, sanctions, reporting lines and accountability should give us a fair understanding of an individual's risk perception, and how it is shaped by company expectations. The question to ask is what motivates people to go that extra mile (or that few hundred metres too close to shore) – sustainable business objectives or merely fulfilling the expectation to perform faster-better-cheaper-safer? If bureaucracy and control leave only limited room for professional judgment, then it becomes imperative to examine the constraints imposed on decision making in the wake of an accident, simply because this is when the need to exercise judgment is felt the most. Unfortunately, investigation reports rarely go into this level of detail, even though most are full of the terms 'safety culture' and 'leadership'.

ARE WE LEARNING THE RIGHT LESSONS?

Major accidents offer tremendous potential for learning from failures. But this opportunity for learning is easily lost if human fallibility is viewed as the 'cause' behind accidents. This is an egregious, overly simplistic and naïve understanding of human factors. Part of the problem is that, unlike other high-risk industries, the marine industry does not value the human and behavioural sciences in the same manner as engineering sciences.

As members of a prestigious professional community we must act responsibly in expressing our opinions and values in the wake of accident – even more since the perception of ordinary people is highly dependent on our opinions. It is unfortunate that professional misjudgements (or mistakes if you prefer) are increasingly being judged as negligence and crime. This is compounded by the fact that neither the judge nor the jury understands the complex and challenging nature of the maritime profession. Today, the responsibility borne by a ship captain rarely comes with the corresponding authority, and exercising authority can be challenging in an international labour market characterised by questionable labour laws and weak institutional support.

Both professional judgment and technical know-how are immense sources of resilience in high risk work. History has proved countless times that professionals are willing to give up their lives to restore safety when everything else fails. We need to avoid making the Master the single point of failure within the system, but at the same time there is a serious need to empower the master-on-the-scene and treat their judgment with utmost respect, given its role in ensuring safety and resilience within the maritime industry.

About the Author

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Brief Description

Nippin is presently employed with DNV GL as Principal Surveyor / Safety Management System Specialist. Previously he has worked as a Research Fellow at the University of Nottingham. Nippin is very interested in (socio-technical) systems safety, resilience and risk management and is extremely passionate about linking theories (of safety) with practice. He is an Associate Nippon Foundation Fellow of the Seafarers International Research Centre at Cardiff University. Nippin has spent 11 years at sea, holds a master's degree in International Transport and Economics and the highest seagoing qualification of a Master Mariner.

DEVELOPMENT OF METHODOLOGY AND MODEL TO ASSESS AND MANAGE SHIP EMISSIONS

Ongoing Research and Literature Review on Emission Factors (EF) using Resources available from Maritime Industry and Academic Institutions

Jai Acharya

Abstract

Emissions from international shipping can be estimated from activity data and also from international fuel statistics data. However, it is observed that the activity-based different ship sizes and types give a better prediction of global fuel consumption and emissions factors from international shipping than fuel statistics due to apparent under-reporting of marine bunker sales.

Considering the different activity-based estimates reported, the lower estimates of fuel consumed by the oceangoing world fleet in 2000 is around 200 Mt, while estimates as great as 290 Mt of marine oil would include all internationally registered ships including fishing vessels, the military fleet and auxiliary engines. This does not account for growth in emissions that may be reflected in estimates for more recent years. The latter is about 110 Mt higher than the reported total (*i.e.* sum IEA categories Internal Navigation and International marine bunkers) IEA marine sales (IEA, 2003). Despite the ongoing scientific debate regarding whether bunker fuel sale statistics are representative when estimating fuel-based emissions, and whether input data on engine operational profiles for different ship types and size categories are representative, these estimates demonstrate some convergence in terms of uncertainty bounds. More importantly, there is agreement among researchers that better input data on ship activity and improved means of allocating activity geospatially will reduce current differences among inventories.

The current methodologies in the Emission Factors Inventory provide an estimated and good framework for standard practice for estimating and reporting the emissions from ships activities.

The main difficulty and uncertainty lies in the several factors such as variations of fuel specifications between domestic and international use. Consequently, good practice methodologies are particularly needed in order to collect relevant and accurate data on domestic fuel used for marine transportation.

Keywords: Methodology and Model to Assess Ship Emissions, Review on Emission Factors (EF), Emission Factors Inventory System (EF Inventory), Ship Emissions Modelling.

1. INTRODUCTION:

The proposed research studies focus on maritime environmental protection under the regulatory compliance of IMO MARPOL Annex VI addressing ships emission, emission factors (SOx, NOx and $PM_{2.5}$). The research is aimed to provide economically viable solutions to the maritime industry regarding management of emission from ships operating in different conditions and formulation of strategies for environment management for future ship design and operations.

Environmental impact and air pollution from ships have received increasing attention the last decades. Due to poor combustion characteristics of typical marine engines and a wide-spread use of residual unrefined fuel, the global fleet emits significant amounts of SO_2, NO_2 and particulate matter (PM) to air. Impact assessments and information on emitted amounts are important inputs to decision-making in regulation development and also for ship designers who aim at environmentally improved designs.

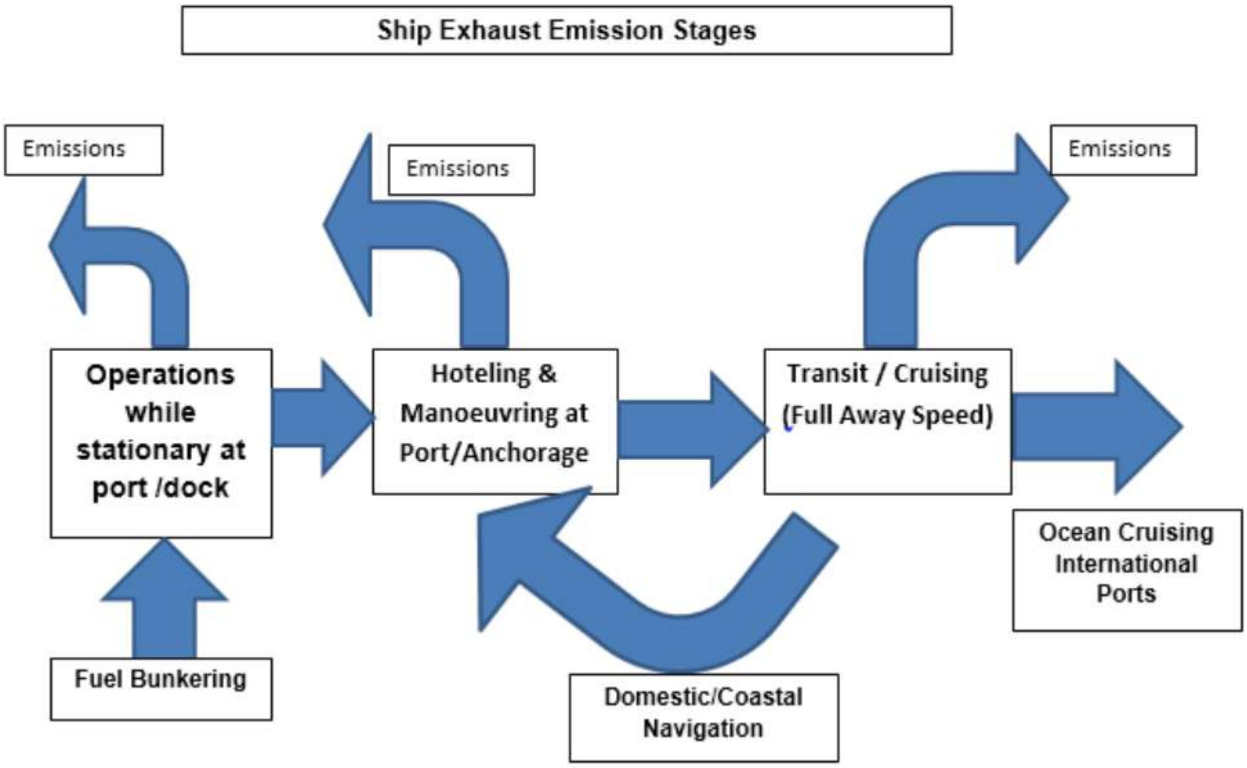
In order to assess the impacts caused by ship emissions to air, information on ships' activities in the regions or the corresponding fuel usage is essential. An emission factor (EF) can be defined as the "mass of pollutants emitted based on the work done or based on the mass of combusted fuel by ship engines or the mass of combusted fuel. The units of emissions factors generally expressed in g/kWh or g/kg fuel are related to each other by the specific fuel consumption (SFC) of the engine.

Ship engines are diverse, and the emission factors are insufficiently quantified for certain operational modes and specific pollutants which makes assessments difficult. Measurements aboard ships are thus conducted in order to determine emission characteristics during manoeuvring periods and for engines operating on fuels of different qualities.

Exhaust emissions from ships includes emissions from the main propulsion engines as well as auxiliary engines used to generate electrical power and auxiliary services within vessels. General process of ship operation can be divided in three operational modes and corresponding stage of engines emission factors (Figure-1: Flow diagram):

Vessels alongside berth during the cargo operations (loading / unloading) or whilst they wait for next voyage are termed as "hoteling". They can cast off and manoeuvre from their mooring point before sailing away from the port. Upon departure from port / anchorage, the vessel cruises to high seas for its destination which may be coastal area or same country (domestic voyage) or a different country (international voyage). This simplistic pattern may get complicated by other stopping patterns, so does the engine operations and exhaust emission patterns.

Figure.1.: Flow diagram for the contribution from navigation to mobile sources combustion emissions



2. OVERVIEW OF IMPACTS OF AIR POLLUTION CAUSED BY SHIPS:

Pollutants such as Particulates Matter ($PM_{2.5}$ and PM_{10}), NO_X, Ozone, SO_2 and CO_2, all of which are products of combustion of fuel oil, can be classified as either primary or secondary pollutants. 'Primary pollutants' is a term used for the pollutants that are formed during the actual combustion process, while 'secondary pollutants' are formed in the atmosphere as a consequence of chemical reactions involving the primary species. The potential impact categories influenced by air pollution from oil combustion are health problems, acidification, eutrophication, photo-oxidant formation and climate change, to name the most important. An overview of these pollutants and their corresponding impact categories are illustrated below in Table-1.

3. SHIP ENGINES, FUELS AND POLLUTANT FORMATION:

Marine diesel engines are the predominant form of power unit within the marine industry for both propulsion and auxiliary power generation. In 2010 an analysis of about 100,000 ships indicated marine diesels powered around 99 % of the world's fleet, with steam turbines powering less than 1%.

In an earlier analysis, about 67% of these ships are powered by four-stroke compression-ignition engines (operating on the compression- ignition, or diesel cycle, and therefore referred to as diesel engines). Some 26% are powered by two-stroke diesel engines. Six percent of the ships have ''unknown'' diesel engines (*i.e.*, either two- or four-stroke) and only one percent are turbine-driven. Most turbine-driven vessels (80%) are steam turbines with oil-fired boilers; the number of aero-derivative gas turbine engines in the commercial fleet is very low. (Corbett and Koehler, 2003)

The only other type of engine highlighted was gas turbines, used virtually only on passenger vessels, and only used in around 0.1% of vessels (Trozzi, 2010). Diesel engines can be categorised into slow (around 18% of engines), medium (around 55%), or fast (around 27%) speed engines, depending on their rated speed. (Carlo Trozzi, EMEP/EEA)

Emissions are dependent on the type of engine, and therefore these will be reviewed further in details in subsequent submissions.

The majority of fuel types used by the international fleet today are variants of bunker heavy fuel oil (also called as Heavy Fuel Oil). Heavy fuel oil contains residues from refineries' processing of crude oil and are highly viscous and need heating before being used on board a ship. The trend in using heavy fuel oil (HFO) as a marine fuel started in the 1950s (Goodger 1982). In this paper, the term heavy fuel oil will be used for all fuel qualities containing refinery residues, also including so-called intermediate fuel oil (IFO), which is an HFO blended with refined oil qualities. There are HFO being used from Viscosity of 180 Cst to 380 and even up to 650 Cst at 40ºC / 50ºC and specific gravity from 0.92 to 1.01.

The marine heavy fuel oil is characterized by high sulphur content, high viscosities and densities and also high content of aromatics and minerals.

However, the limits are significantly higher than those for transport modes on land, which can be in concentrations of 10 to 50 ppm.

Table.1.: Primary pollutants from the combustion of Bunker Heavy Fuel Oil (HFO) and their major potential impacts.

	Pollutant					
Impact Categories	Particles	SO_2	NO_X	CO_2	HC	CO
Health Effects	X	X	X			X
Acidification		X	X			
Photo-Oxidant Formation			X		X	
Eutrophication			X			
Climate Change				X	X (CH_4)	

4. NITROGEN OXIDE EMISSION FROM SHIPS:

NO_X is a collective name for NO and NO_2, where NO is by far the most abundant in exhaust gases. About 5 - 7% of NO is converted to NO_2 in the exhaust system or engine (Henningsen 1998). The share of NO_2 in NO_X that leaves the combustion chamber is partly determined by local temperature conditions (Heywood 1988). According to MAN BandW Diesel, approximately 1% of NO will form N_2O (MAN-BandW, 1996) in slow speed engines than engines of higher speeds (Cooper and Gustavsson 2004).

Additional NO is formed from nitrogen in the fuel or via reactions between molecular nitrogen and the hydrocarbon species in the fuel. Whilst Heywood (1988) states an average nitrogen content of heavy distillates is 1.40% by weight, the nitrogen contents of nine marine HFOs from published emission measurement studies (Lyyränen *et al*. 1999; Cooper 2003; Fridell *et al*. 2008; Winnes and Fridell 2009; Winnes and Fridell 2010) were below 0.5%.

Nitrogen in fuel has been shown to be an important source for NO, especially at high air to fuel ratios (lean to stoichiometric conditions) during combustion (Bowman 1975). The lean combustion of diesel engines and a relatively high concentration of nitrogen in heavy fuel oils make fuel nitrogen a potential contributor to significant NO_X concentrations in ship exhausts.

5. EMISSION FACTORS:

The emissions produced by ships are a consequence of combustion of the fuel in an internal combustion (marine) engine. The principal pollutants are CO, VOC, NOx and PM_{10}, in this list $PM_{2.5}$ is derived from soot which is mainly have to do with engine technology, and CO_2, SOx, heavy metals and further PM (mainly sulphate-derived) which originate from the fuel speciation.

Specific emissions (mass of pollutant per work performed by the engine or mass of combusted fuel) of pollutant species differ between the operational modes due to the combustion characteristics at different loads and at transient operations.

The units of specific emissions, g/kWh or g/kg fuel are related to each other by the Specific Fuel Consumption (SFC). The SFC also depends on the fuel type due to the differences in specific heating values of fuels. The SFC for modern marine engines range between 165 g/kWh for the most efficient two-stroke engines to around 230 g/kWh for small four-stroke engines (Buhaug *et al.* 2009).

Emission Factors play an important role in inventories of air pollutants. In the Table shown below, the emissions factors for CO_2, NOx, SOx, PM, HC and CO in g/kg fuel used, obtained from emission inventory sources, are presented together with their cited sources.

Table.2.: A Typical Study of Researchers on Emission Quantity and Estimates of Fuel Consumption for the International Fleet from Recent Global Inventories

	Corbett and Koehler, 2003*	**Paxian *et al.*, 2010**	**Dalsøren *et al.*, 2008**	**Buhaug *et al.*, 2009**
Source of emission factor	Entec, 2002	Test bed results, Eyring *et al* (2005)	Cooper, 2004, Entec, 2002	CORINAIR, IPCC (HFO/MGO)
Total Fuel consumption (MT/year)	289 (Year 2002)	221 Year (2006)	217 (Year 2004)	276 (Year 2007)
Included in the fuel estimate	International shipping, Military vessels	All ships	All ships	Non-military international shipping
CO_2 (g/kg fuel)	3179	2905	3179	3130/3190
PM (g/kg fuel)	6.1	6.0	7.6	6.7/1.1
NO_X (g/kg fuel)	82.5	76.4	41 – 92	85 and 56**
S content of fuel (%)	2.5%	2.4-2.6%	54 or 10 (g/kg fuel)	2.7%/0.5%
HC (g/kg fuel)	2.9	7.0	2.45	2.7
CO (g/kg fuel)	-	4.67	7.4	7.4

** Original emission factors are in the unit g/kWh; these values have been converted to emissions in g/kg fuel by division of a specific fuel consumption of 206 g fuel/kWh which is used in by Corbett and Koehler (2003)*

*** kg NO_X/ tonne fuel for slow-speed and medium-speed diesel engines, respectively, independent of fuel type.*

The values presented in Table 2 merely demonstrate the difficulties of drawing conclusions on emission factors for even the most abundant pollutants from ship engines. It is to be noted that the inventories cover the global fleet, which makes aggregated factors like the ones presented subject to many estimates, *i.e.* estimates on average fuel type and average engine type.

Emissions from test bed engines can be suspected of deviating from emissions from engines in operation due to wear on the engine and how it is operated. However, correlations of specific emissions based on engine size or engine age, have proven to be difficult due to limited datasets and large variations in data (Whall *et al*. 2002).

The specific emissions from 155 measurements from ships and test bed measurements in Wärtsilä's facilities shown in Figure 2 (Whall *et al*. 2002; Agrawal *et al*. 2008; Winnes and Fridell 2009; Winnes and Fridell 2010). The measurements from Whall *et al*. are reported in an aggregated way. These measurements are presented as average emission factors at 500 rpm for medium speed diesel (MSD) engines and at 100 rpm for slow speed diesel (SSD) engines. They are also weighted by the number of measurements.

6. MOPSEA EMISSION MODEL – THE METHODOLOGY:

To generate an emission inventory two approaches can be adopted, these being: the so-called "bottom-up" and "top down" approach. The top-down approach, starts with data describing the total potential polluting activity throughout the whole geographical area of interest, for example the total marine fuel sales for a country. The fuel sold can then further be subdivided into different types of oil: residual bunker fuel oil (heavy fuel oil) and distillate fuel (gas oil and marine diesel oil), or other fuel types.

A geographical break-down of the calculated emissions can then be performed when necessary (M. Vangheluwe, J. Mees and C. Janssen).

The bottom-up method starts, with geographically disaggregated data, for example the number of ship movements on a shipping route. Emission data are calculated for each individual ship or per ship type. To obtain the total emissions for a geographical area the different contributions are summed up. This method requires detailed data and may be quite time consuming to perform.

A bottom-up emission quantification study requires as much information as possible regarding ship movements, shipping routes and ship characteristics to obtain a predetermined accuracy level. This data is provided by several sources like national authorities, private companies, questionnaires and the internet. After analysis, adaptation and correction if necessary, all information is processed into calculation models. Due to analysis and comparison with other data sets, it is possible to determine accuracy, advantages and disadvantages of each data source. The main data sources are shipping companies, ports authority database, Lloyd's register (LMIU), internet shipping schedules and seafarer questionnaires.

A different engine load indicates a divergent emission value. This implies that the engine load (of the main and auxiliary engines) is the most important factor in the calculation process of ships' emissions in combination with the different marine areas and observation methods. The different aspects of the methodology are presented in Figure 1.
Two main classes are identified:
(1) Sea emissions and
(2) Port emissions.

The sea emissions indicate all emissions from shipping in the at Sea. This class is subdivided into two types of activities that take place in the sea area (however with different engine load patterns), namely cruising and anchoring.

"Sea emissions" are divided into emissions from (a) cruising vessels, and (b) vessels at anchor. Cruising vessels represent all merchant ships including dredgers and tugboats that are 'underway'

7. CALCULATION OF TECHNOLOGY RELATED EMISSIONS:

NOX, CO, HC, and PM are technology related emissions.

Energy use (kWh)
The energy used is calculated by multiplying the used power and the duration:

Energy use (kWh) = power (kW) x duration (h)

The used power is dependent on the maximum installed power and the percentage of the maximum continuous rate (MCR) that is used:
Power (kW) = % of MCR x maximum installed power (kW)
Technology related emissions (ton) are calculated according to the following mathematical expression:

Emission (tons) = Emission factor (g/kWh) x energy use (kWh) x 10^6……………….… (4)

8. SEA EMISSION CALCULATIONS (CRUISING):

For sea emissions, a specific methodology is developed, based on the best available data with regards to the study area. The methodology is summarized in the following formula:

$$\sum SE_{1,\,st,\,rs} = \sum (T_{st,\,rs} * P_{st,\,me} * EF_{st,\,rs} * LF_{st,\,me} / CF_{me}) + \sum (T_{st,\,rs} * P_{st,\,ae} * EF_{st,\,rs} * LF_{st,\,ae} / CF_{ae}) \quad (5).$$

Where,

*Multiplying sign

$SE_{1,\,st,\,rs}$	Sea emissions from ships determined per ship type and voyage route segment
$T_{st,\,rs}$	Sailing time as acquired by an average speed value route segment, multiplied with the sailed distance per route segment per ship type
$P_{st,\,me/ae}$	Average installed main or auxiliary engine power per ship type
$EF_{st,\,rs}$	Emission factors per ship type and activity in gm/kWh
$LF_{st,\,me/ae}$	Load factor of main engine or auxiliary engine, per ship type while sailing (% of MCR)
$CF_{me/ae}$	A correction factor to compensate for loss of efficiency at reduced load.

9. EMISSION CALCULATIONS DURING MANEUVERING:

During manoeuvres, vessels employ variable loads resulting in higher emission levels. This implies the establishment of port boundaries as an important factor in emission calculation process. The employed methodology for manoevring operations is summarized in the following mathematical expression:

$$\sum MA_{1,\,st,\,p} = \sum (T_{st,\,p,\,ma} * P_{st,\,me} * EF_{st,\,ma} * LF_{st,\,ma,\,me} / CF_{st,\,me}) + \sum (T_{st,\,p,\,ma} * P_{st,\,ae} * EF_{st,\,be} * LF_{st,\,ma,\,me} / CF_{st,\,ae}) \quad (6).$$

Where,

$MA_{1,\,st,\,p}$	Port emission from manoeuvring vessels determined per ship type and port
$T_{st,\,p,\,ma}$	Manoeuvring time as acquired by the specific port database per ship type and port

$P_{st, me}$	Average installed main or auxiliary engine power per ship type
$EF_{st, ma}$	Emission factor per ship type for 'manoeuvring activities' as determined by database provider (LMIU/ENTEC or similar) in g/kWh
$LF_{st, ma, me/ae}$	Load factor per ship type for main or auxiliary engine per ship type at berth (% load of MCR)
$CF_{me/ae}$	A correction factor to compensate for loss of efficiency at reduced speed

*Multiplying sign

10. EMISSIONS CALCULATIONS FROM BERTHED VESSELS (HOTELING PHASE):

During the vessel at berth, most of the time main engines are shut down and auxiliary engines are used to supply electrical power to boilers, galley equipment, refrigeration/air conditioning plants, cargo gear equipment on board like cranes, pumps, ventilation system *etc*.

The methodology used for these calculations is shown in the following mathematical expression:

$$\sum BE_{1, st, p} = \sum (T_{st, p, be} * P_{st, me} * EF_{st, be} * LF_{st, be, me} / CF_{st, me}) + \sum (T_{st, p, be} * P_{st, ae} * EF_{st, be} * LF_{st, be, me} / CF_{st, ae}) \quad \ldots\ldots (7).$$

Where,

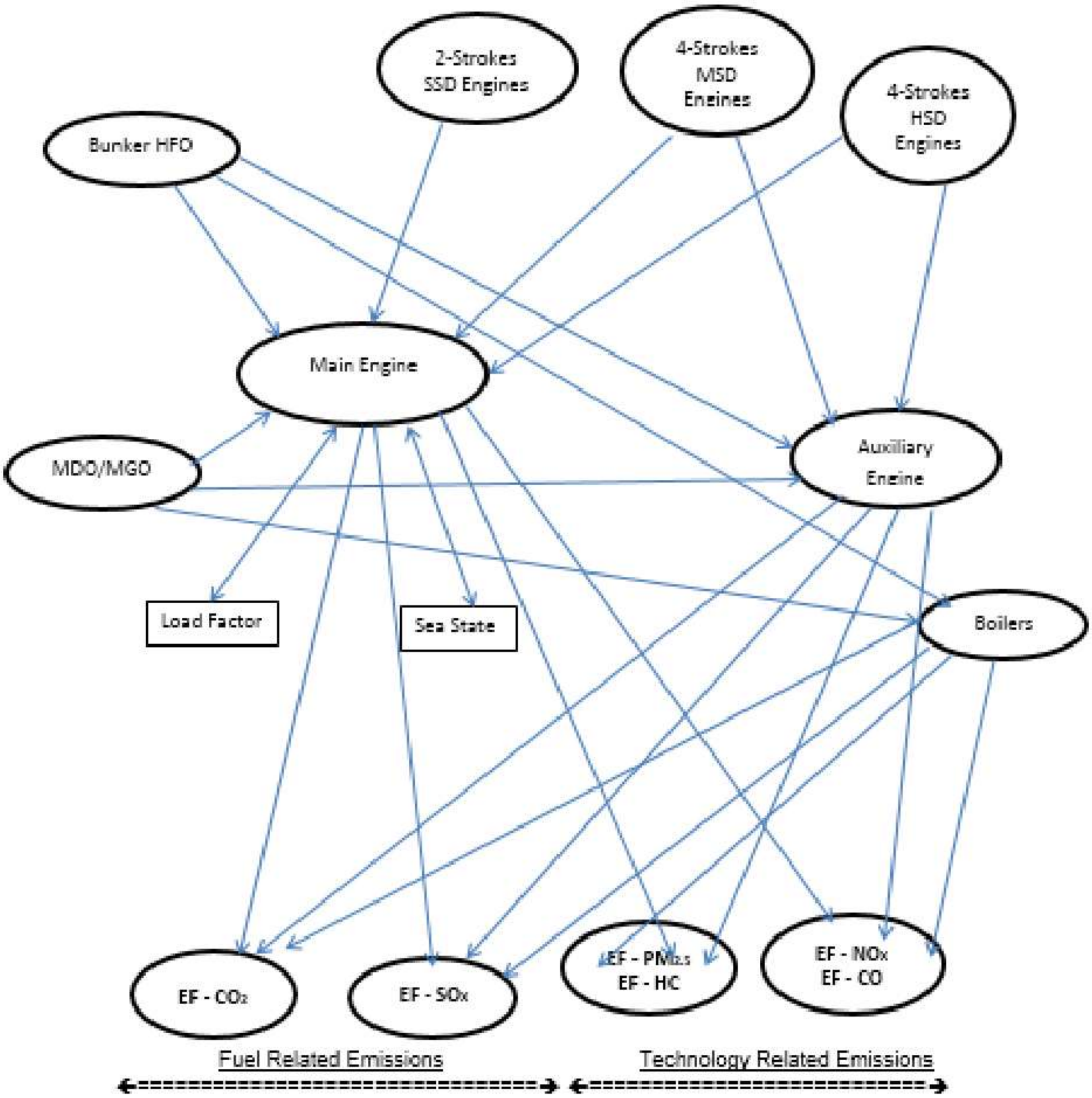
*Multiplying sign

$BE_{1, st, p}$	Port emission from berthed vessels determined per ship type and port
$T_{st, p, be}$	Lay time at berth as acquired by the specific port database per ship type
$P_{st, me/ae}$	Average installed main or auxiliary engine power per ship type
$EF_{st, be}$	Emission factors per ship type for 'activities at berth' provided by EF database provider agencies (ENTEC/LMIU *etc*.)
$LF_{st, be, me/ae}$	Load factor per ship type for main or auxiliary engine per ship type at berth (% load of MCR)
$CF_{me/ae}$	A Correction factor to compensate for loss of efficiency at reduced load

In above study, it is observed that EMS, MEET and MOPSEA Emission Model are very close in methodology and overlap on several points.

11. PROCESS MODEL FOR SHIP EMISSION:

Figure - 7



12. EMISSION MODEL AND METHODOLOGY ADOPTED FOR THIS RESEARCH TASK:

The emission model and methodology adopted for our research in assessment of ship emissions would be of "bottoms up" activity based MOPSEA basic model with novel methodology and new approach to bring further accuracy in emission assessment addressing the specific requirement of IMO directives illustrated in MARPOL Annex VI and various MEPC on reductions of CO_2, SO_X, NO_X and $PM_{2.5}$ through technical and operational measures.

In March 2010, the MEPC began consideration of making the technical and operational measures mandatory for all ships irrespective of flag and ownership; this was expected to be completed by July 2011 and concluded accordingly. The activity based emission models have made it possible to forecast the emissions from sea-going vessels for near future.

The approach adopted in our emission model is consistent with the methodology for quantifying ship emissions on following information:

- Vessel Type
- Installed engine power
- Type of fuel consumed
- Vessel route, speed and distance travelled (or the time spent during the sea passage)
- Time Spent in port, during maneuvering and anchorage (hoteling phase)
- Main and Auxiliary engines load factor during various phases of vessel activities
- Emission by boiler operations

The research study though our selected emission model and methodology would develop a novel ship emission calculation and inventory with comparative lesser uncertainties due to integration of current methodologies after considerable phasing out of potential uncertainty. Along with the fuel consumption, the following pollutants have been taken in to account in the emission calculations:

- Oxides of Sulphur (SO_X) - Sulphur Dioxide (SO_2)
- Carbon Dioxide (CO_2)
- Oxides of Nitrogen (NO_X)
- Particulate Matter (PM2.5)
- Non-Methane Volatile Organic Compounds (NMVOC) – HC
- Carbon Monoxide (CO)

The development of a suitable new emission model is based on shipping movement. It is intended to create a model that is specific vessel type which can be validated on various types of ship operations at different locations, fuel type and other parameters. The integration of the technological aspects of the sea-going vessels is an important selection criterion for a reproducible emission assessment methodology. Both are important for the scientific relevance for ship emission policy making, economics and for the feasibility.

The ship type selected for emission model is a handy-size bulk carrier installed with a 2 stroke slow speed diesel engine (SSD) powered by bunker fuel oil (HFO 380 cSt) and four-stroke auxiliary engines (MSD) powered by marine diesel (MDO) /(MGO) marine gas oil. The Auxiliary Boilers of the ship type consume marine diesel oil (MDO). The activity data consists of times spent at sea with cruising speed, maneuvering activity time duration, arrival / departure of ports and duration of stay at port and anchorage.

The model itself is based on voyages and hoteling periods of ocean going vessels. The voyage is defined here as the journey of a ship between an entry and exit point. Therefore, a round trip comprises at least two voyages. Further, all the integrated emission factors in the proposed emission model would compute:

- Fuel related emissions - Oxides of Sulphur (SO_X) - Sulphur Dioxide (SO_2) and Carbon Dioxide (CO_2) for SSD and MSD engines and auxiliary boilers.

- Technology related emissions – NO_X, PM2.5, HC and CO for 2-stroke SSD engines.

13. KEY FINDINGS FROM THE THIRD IMO GHG STUDY 2014:

Shipping emissions during the period 2007–2012 and their significance relative to other anthropogenic emissions further analyzed in subsequent years during MEPC sessions.

For the year 2012, total shipping emissions were approximately 949 million tons CO_2 and 972 million tons CO_2e (CO_2 equivalent) for GHGs combining CO_2, CH_4 and N_2O. International shipping emissions for 2012 are estimated to be 796 million tons CO2 and 816 million tons CO_2e for GHGs combining CO_2, CH_4 and N_2O. International shipping accounts for approximately 2.2% and 2.1% of global CO_2 and GHG emissions on CO_2 equivalent (CO_2e)

basis; respectively. MEPC 67 (25 July 2014) provides in the annex the complete final report of the "Third IMO GHG Study 2014", which provides an update of the estimated GHG emissions for international shipping in the period 2007 to 2012.

A comparative analysis of GHG illustrated in MEPC 67 in Table (a) and (b)

Table - 5 (a): Shipping CO_2 emissions compared with global CO_2 (values in million tonnes CO_2

Year	Global CO21	Third IMO GHG Study 2014 CO_2			
		Total Shipping	% of Global	International Shipping	% of Global
2007	31,409	1,100	3.50%	885	2.80%
2008	32,204	1,135	3.50%	921	2.90%
2009	32,047	978	3.10%	855	2.70%
2010	33,612	915	2.70%	771	2.30%
2011	34,723	1,022	2.90%	850	2.40%
2012	35,640	949	2.70%	796	2.20%
Average	33,273	1,016	3.10%	846	2.60%

Table - 5 (b): Shipping GHGs in CO2e (compared with global GHGs (values in million tonnes CO:2e).

Year	Global CO22	Third IIMO GHG Study 2014 C02e			
		Total shipping	%of Global	International shipping	% of Global
2007	34,881	1,121	3.20%	903	2.60%
2008	35,677	1,157	3.20%	940	2.60%
2009	35,519	998	2.80%	873	2.50%
2010	37,085	935	2.50%	790	2.10%
2011	38,196	1,045	2.70%	871	2.30%
2012	39,113	972	2.50%	816	2.10%
Average	36,745	1,038	2.80%	866	2.40%

This study estimates multi-year (2007-2012) average annual totals of 20.9 million and 113 million tonnes for NOx (as NO_2) and SOx (as SO_2) from all shipping, respectively {corresponding to 6.3 million and 5.6 million tonnes converted to elemental weights for nitrogen and sulphur, respectively). NOx and SOx play indirect roles in tropospheric ozone formation and indirect aerosol warming at regional scales. International shipping is estimated to produce approximately 18.6 million and 10.6 million tonnes of NOx (as NO_2) and SOx (as SO_2) annually; this converts to totals of 5.6 million and 5.3 million tonnes of NOx and SOx (as elemental nitrogen and sulphur, respectively). Global NOx and SOx emissions from all shipping represent about 15% and 13% of global NOx and SOx from anthropogenic sources reported in the latest IPCC Assessment Report (AR5), respectively; international shipping NOx and SOx represent approximately 13% and 12% of global NOx and SOx totals, respectively.

Over the period 2007-2012, average annual fuel consumption ranged between approximately 250 million and 325 million tonnes of fuel consumed by all ships within this study, reflecting top-down and bottom-up methods, respectively. Of that total, international shipping fuel consumption ranged between approximately 200 million and 270 million tonnes per year, depending on whether consumption was defined as fuel allocated to international voyage (top-down) or fuel used by ships engaged in international shipping (bottom-up), respectively.

Correlated with fuel consumption, CO_2 emissions from shipping are estimated to range between approximately 740 million and 795 million tonnes per year in top-down results, and to range between approximately 900 million and 1150 million tonnes per year in bottom-up results. Both the top-down and the bottom-up methods indicate limited growth in energy and CO2 emissions from ships during 2007 - 2012, as suggested both by the IEA data and the bottom-up model. Nitrous oxide (N2O) emission patterns over 2007- 2012 are similar to the fuel consumption and CO2 patterns, while methane (CH4) emissions from ships increased due to increased activity associated with the transport of gaseous cargoes by liquefied gas tankers, particularly during 2009 - 2012.

14. REDUCTION OF GHG EMISSIONS FROM SHIPS:

The IMO led MEPC 69 had agreed to discuss and work on further reducing GHG emissions from ships, taking into account the documents submitted and the related documents referred by MEPC 69 and onwards, *i.e.* MEPC 69/7/1 (ICS), MEPC 69/7/2 (Belgium *et al.*), MEPC 69/7/3 (CSC) and MEPC 69/7/4 (WSC *et al.*), as well as comments made at MEPC 69.

International shipping CO_2 estimates range between approximately 595 million and 650 million tonnes calculated from top-down fuel statistics, and between approximately 775 million and 950 million tonnes according to bottom-up results. International shipping is the dominant source of the total shipping emissions of other GHGs: nitrous oxide (N_2O) emissions from international shipping account for the majority (approximately 85%) of total shipping N_2O emissions, and methane (CH_4) emissions from international ships account for nearly all (approximately 99%) of total shipping emissions of CH_4. In continuation, MEPC 70 further considered in subsequent document MEPC 70/7/2 highlighting a perceived regulatory barrier to the use of non-petroleum fuel oils, related to the general application of regulation 18.3.2 of MARPOL Annex VI.

The Committee noted the information provided by Institute of Marine Engineering, Science and Technology (IMarEST) and invited Member Governments and international organizations to submit relevant proposals for a new output in accordance w this regard, the Committee also noted information provided by the observer from ISO with regard to a currently ongoing revision of ISO 8217:2012 related to specifications of marine fuels, including changes in its scope allowing it to include synthetic and renewable fuels and their blends.

15. FUEL RELATED EMISSION FACTORS:

The pollutants CO_2 and SO_2 are fuel related. The emission factors for CO_2 in this emission model are corresponding to IMO and IPCC published CO_2 emission factors.

The SO_X emission factors would be corresponding to IMO MARPOL Annex VI fuel oil Sulphur content requirements for MDO/MGO and HFO (380 Cst) globally and in "Sulphur Emission Control Areas (SECAs) governed by Regulation 14 of MARPOL Annex VI.

Table - 6: CO_2 and SO_2 emission factors (kg/ton fuel)
[Ref: MOPSEA Project EV43]

EF (kg/tonne)	Heavy Fuel Oil (HFO)	Diesel and Gas Oil (MDO/MGO)
CO_2	3110	3100
SO_2 (… -18/05/2006)	54	4
SO_2 (19/05/2006 – 2009)	30	4
SO_2 (2010 …)	30	4 or 2*

*2 kg of SO_2 /ton diesel or gas oil at berth (minimum duration of 2 hours)

15.1. Technology Related Emission factors for:

The technology related emission factors for NO_X, $PM_{2.5}$, HC and CO for 2-stroke SSD engines are those taken from EMS/ENTEC and other sources. The EMS emission factors are modelled as combination of basic emission factor and correction factors for the technology (age and NO_X Regulation) and the percentage of maximum continuous rate (MCR) of the ship engines.

Emission Factor (g/kWh) = Basic emission factor
(g/kWh) X CorrAge X CorrNO_X X CorrMCR

15.2. Correction for technology:

Two correction factors have to be implemented on the basic emission factor to take account into the technology of the sea-going vessels:

01. Emissions are dependent on the year of construction of vessels because of evolution in engine technology

02. Main engines built after the year 1999 have restrictions for their NO_X emissions (IMO MARPOL Annex VI Chapter 2)

16. CORRECTION FACTOR FOR % OF MCR:

The basic emission factors are based on a test cycle. This is an average of all stages of navigation. Therefore, they are not representative for the individual stages of navigation (expressed in % of MCR). A correction factor has to be implemented on the basic emission factor to get emission factors for the individual stages.

Table – 7: Basic emission factors (g/kWh) for a 2-stroke SSD engine

EF (g/kWh)	Heavy Fuel Oil (HFO)	Diesel and Gas Oil (MDO/MGO)
HC	0.60	0.60
CO	3.00	3.00
NO_X	16.00	16.00
PM	1.70	0.50

Table – 7(a): Correction factor for the NO_X Regulation (IMO MARPOL Annex VI)

Date of Building	g/NO_X/kWh	RPM	g/NO_X/kWh	CorrNO_X
>2000	14.5	290 - 2000	$45*n^{-0.2}$	$3.10*n^{-0.2}$
>2000	14.5	>2000	9.8	0.68

Table – 7(b): Correction factors for the age of the 2-stroke SSD engine

Date of Building	Heavy Fuel Oil (HFO)				MDO /MGO			
	HC	CO	NO_X	PM	HC	CO	NO_X	PM
<1974	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 – 1979	1.00	1.00	1.13	1.00	1.00	1.00	1.13	1.00
1980 – 1984	1.00	1.00	1.19	1.00	1.00	1.00	1.19	1.00
1985 – 1989	1.00	0.83	1.25	1.00	1.00	0.83	1.25	0.80
1990 -1994	0.83	0.67	1.13	1.00	0.83	0.67	1.13	0.60
1995 – 1999	0.67	0.67	0.94	0.88	0.67	0.67	0.94	0.60
>2000	0.50	0.67	0.91	0.88	0.50	0.67	0.91	0.60

Table – 7(c): Correction factor for the % of MCR for 2-stroke SSD engine

% of MCR	HC	CO	NO_X	PM
85	0.84	0.70	0.97	0.97
80	0.87	0.76	0.97	0.98
75	0.89	0.82	0.98	0.98
70	0.92	0.88	0.98	0.99
65	0.95	0.94	0.99	0.99
60	0.98	1.00	0.99	1.00
55	1.00	1.06	1.00	1.00
50	1.03	1.12	1.00	1.01
45	1.09	1.23	1.01	1.01
40	1.16	1.38	1.02	1.03
35	1.27	1.56	1.03	1.05
30	1.42	1.80	1.04	1.08
25	1.65	2.14	1.06	1.12
20	2.02	2.66	1.10	1.19
15	2.74	3.51	1.17	1.32
10	4.46	5.22	1.34	1.63
0	0.00	0.00	0.00	0.00

17. TECHNOLOGY RELATED EMISSIONS FACTORS FOR 4-STROKE MSD ENGINES:

The technology related emission factors for HC, CO, NO_X and PM for 4-stroke engines are taken in same way from EMS/ENTEC and other sources as mentioned for 2-stroke engines. They are modelled just like for a 2-stroke engine, as a combination of a basic emission factor and correction factors for the technology (age and NO_X regulation) and the percentage of the maximum continuous rate (MCR), which is same as for 2-stroke engine.

Table – 7(d): Basic emission factors (g/kWh) for a 4-stroke MSD engine

EF (g/kWh)	Heavy Fuel Oil (HFO)	Diesel and Gas Oil (MDO/MGO)
HC	0.60	0.60
CO	3.00	3.00
NO_X	12.00	12.00
PM	0.80	0.50

Table – 7(e): Correction factors for the age of the 4-stroke MSD engine

Date of Building	Heavy Fuel Oil (HFO)				MDO /MGO			
	HC	CO	NO_X	PM	HC	CO	NO_X	PM
<1974	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 – 1979	1.00	1.00	1.17	1.00	1.00	1.00	1.17	1.00
1980 – 1984	1.00	1.00	1.25	1.00	1.00	1.00	1.25	1.00
1985 – 1989	1.00	0.83	1.33	1.00	1.00	0.83	1.33	1.00
1990 -1994	0.83	0.67	1.17	1.00	0.83	0.67	1.17	0.80
1995 – 1999	0.67	0.67	0.92	0.88	0.67	0.67	0.92	0.60
>2000	0.50	0.67	1.21	0.88	0.50	0.67	1.21	0.60

The use of different emission factors influences the emission figures. For the purpose of sensitivity analysis, MOPSEA model has been run with the widely used ENTEC (2005) emission factors. Emissions for the year 2004 have been calculated by using the ENTEC average emission factors per ship instead of the detailed EMS emission factors per individual ship. This resulted in emission figures which are higher than those calculated with the EMS factors.

18. ILLUSTRATION ON THE EF MODEL FOR A SHIP TYPE BY EF ESTIMATION:

Development of Emission Factor (EF) Model for a ship type would be based on methodology which covers emission during activities of all the phases (cruising, maneuvering, hoteling, berthing/anchorage). The basic algorithm for the technology related emission calculations for each activity is adopted from MOPSEA model with a different approach and innovative inputs.

My Literature Review is consistent with ongoing research studies and to be continued…

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Lyyränen et al. 1999; Cooper 2003; Fridell et al. 2008; Winnes and Fridell 2009;

Winnes and Fridell 2010

Whall *et al*. 2002; Agrawal *et al*. 2008; Winnes and Fridell 2009; Winnes and Fridell 2010.

Eyring *et al*. 2005a; Eyring *et al*., 2005b.

IPCC 2000

Aircraft Emissions - Kristin Rypdal (Statistics Norway).

Martinez and Marcel

M. Vangheluwe, J. Mees and C. Janssen

Jalkanen *et al*. (2009, 2012 and 2013)

Transport impacts on atmosphere and climate: Shipping: Veronika Eyring, Ivar S.A. Isaksen, Terje Berntsen, William J. Collins, James J. Corbett, Oyvind Endresen, Roy G. Grainger, Jana Moldanova, Hans Schlager, David S. Stevenson.

[1]Global comparator represents CO_2 from fossil fuel consumption and cement production, converted from Tg Cy^{-1} to million metric tonnes CO_2, Sources: MEPC 67, Boden *et al*. 2013 fur years 2007-2010; Peters *et al*. 2013 fur years 2011-2012, as referenced in IPCC (2013)

[2]Global comparator represents N_2O from fossil fuels consumption and cement production. Source: IPCC (2013).

MEPC 69/7/1 (ICS), MEPC 69/7/2 (Belgium *et al.*), MEPC 69/7/3 (CSC) and MEPC 69/7/4 (WSC *et al.*), MEPC 70, MEPC 70/7/2

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Being a proactive ocean and maritime environmental activist, Jai has keen interest in maritime consultancy projects, maritime education and training (MET) with an emphasis on maritime environmental awareness and protection of oceans.

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EFFECTIVENESS OF A NEW INITIATIVE IN TEACHING AND LEARNING AS IMPLEMENTED IN INTEGRATED TRAINING CENTRE

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Abstract

This research aims at studying the effectiveness of new innovative initiative implemented in a higher education institution. The study comprised of qualitative research and included interviews of head of department (HoD, manager), expatriate (trainers) and student (future technician). The various categories investigated are importance of initiative, implementation, effectiveness, challenges, sustainability and ethical considerations. The analysis of interview responses of HoD reveal that the new initiative is landmark transformation in teaching and learning of skill based training which is very risky and dangerous in real world. One of the major challenges faced is to find the right people for the right job. According to the expatriate, the new initiative of integrated training center is safe and close to reality in teaching and learning experiences which are important for competency-based training. Student views indicated that the integrated training center is a once in the life time opportunity to prepare for pre-employment and his, employability marketability and adaptability to job is high. This finding is in agreement with global trends of pre-employment learning. This study is important to highlight the important of integrated training centre in quality teaching and learning. It is also useful in policy making in training institutions of technical and vocational education in Malaysia.

Keywords: initiative, teaching-learning, employability, interview, skill training

1. INTRODUCTION:

In the beginning of the 20th century, the position of stakeholders in higher education has received more attention in policy making (Bjørkquist, 2009; Mainardes *et al*., 2010). Both students and staff of higher education institutions are given more decision making power as compared to the previous times. This power however induced challenges in administrating the higher education institution in the form of quality teaching and learning, be accountable to parents and sponsors. Stakeholders in this study include students, sponsors and administrators. This study is concerned with the two types of stakeholders which are student and administrator. To better understand the major concerns of stakeholders, it is vital to conduct students' performance assessment in terms of knowledge and skills as a key to their employment success.

Manpower demand especially skilled technicians in developing country industries are increasing day by day. To address this need, a competence based vocational training is very crucial. The common issue faced by most of the employers is the lack of skills in available applicants that they do not possess relevant qualifications for specific jobs. This issue is even more asserted in three major age groups like young semi-skilled and skilled technicians;

successful applicants who have been hired but are not yet fit for the job; and experienced technician who are looking for promotion in performing complex jobs (GIZ, 2013).

Emerging countries around the world including Malaysia realized that the potential of the economic growth is significantly contributed by the higher education. It is known that other than contribution in economic and industrial development, higher education is also promoting cultural diversity, enhancing democratic values and business. Current trends in education is going through great evolutions such as from general education to work oriented learning, from national level to global, from teachers centred to student orientated, from fewer opportunities to lifelong training, from campus based education to online distance education and from reality to virtual training (Rena, 2010). Due to the evolutions, numerous challenges are faced by the higher education in developing countries. These challenges include management, operation, administration and academic.

In higher education institutions, quantity and quality to produce job ready graduates is the greatest challenge. Therefore, this study is important to address the selected higher education which deals with innovative initiative teaching, learning and assessment. The teaching, learning and assessments techniques under this study are designed to provide students with knowledge and skills needed as the first step into their employment. Thus, it is a job related training and qualification which will develop the students' understanding, knowledge and skills in performing the service and maintenance according to procedures and safety guidelines. The teaching, learning and assessment are focused on measuring the students' comprehension of work related skills and provide confidence needed for performing the task at hazardous areas (Jones, 2005).

2. BACKGROUND OF STUDY:

Education is one of the main components of Malaysia's transformation into a high-income nation by 2020. Thus, National Key Economy Area (NKEA) launches various initiatives to introduce wide range of education in Malaysia, from early childcare to professional skills training (ETP, 2014). In education and training institutions, quality education and services provided by institutions have received substantial attention nationwide (Yaacob, 2015). Also stakeholders' expectations and requirements needed to be identified because the main influence is skills training with the target of employability (Ibrahim *et al.*, 2012). Thus, the human capital enhancement is an important factor to obtain Economic Transformation Program goal. Higher education institution which can provide the skilled profession is needed to fulfil national requirements (ILO, 2000 and 2010; Wildavsky *et al*., 2012).

The chosen training centre (referred as "ETC", Engineering Training College in this paper for preserving confidentiality of data) aspired to train skilled maintenance workforce for industries. The courses offered are competency-based training. The teaching and learning facilities in ETC are modernised and aligned with industry requirements. For productivity and safety, it is important to provide students with knowledge and skills needed as the first step into their employment. Hence, ETC had launched the industry-scale training centre. It is an integrated live operation training plant equipped with numerous state-of-art facilities includes simulator, manufacturing plant, process plant and workshop. The significance investment provides students with real-industry hands-on experience and enables them to attain competencies via structured self-learning activities in production-technological learning environment. The students also trained with skills in problem solving and able to continuously enhance the manufacturing and maintenance process. This is in line with Tisch *et al*. (2013) findings that with the current speed of technology advancement, transformation of technical training is required by improving the scientific-founded and competency-based approach.

3. METHODOLOGY:

The aim of this study is to investigate the effectiveness of the innovative teaching, learning and assessment strategies at ETC. Thus, a qualitative research method of study is selected. This method is interpretative and enable researcher to extract the details about implementation of initiative and its impacts from small group of people (Lane 2011). Furthermore, this method allows the researcher to explore the perception of individuals from different angles and perspectives.

This design of this research comprises of interviews and detailed analysis. In conducting this study, one Head of Department (HoD), one foreign trainer, (expatriate) and one future technician (student) were interviewed. The descriptions of the three interviewees (sample size, n = 3) are tabulated in Table 1. They comprised of different level, work experience and responsibility and are one of the important stakeholders of this study.

Table 1: Description of selected four interviewees along with the detail of task

Interviewee	Administrative level	Work Experience	Role and Responsibility
HoD	Managing	20 – 30 years	Monitor the implementation of initiative
Expatriate	Trainer	More than 30 years	Deliver and assesse in class
Student	Future technician	None	Learn and perform according to standards and procedures

Semi-structured interviews were conducted upon obtaining the permission all parties to discover their perspectives, expectations and challenges about the new initiative. The participation is voluntary and they may stop at any time if they feel uncomfortable. The planned interview was to last no longer than fifteen to twenty minutes. All information was held confidential. This includes personal data and the name of institution to protect and maintain the anonymity and confidentiality. The interviewees were interviewed with open-ended questions the effectiveness of initiative. The interviews were begun with building up the rapport between interviewer and interviewee and followed by discussion. The questions are both predetermine and subsequently emerging from discussion. Data collected from interview transcripts were reorganized systematically and classified according to codes and themes for analysis.

4. RESULTS AND DISCUSSION:

The change initiative and its importance in the institution and wider context

HoD, the manager who has experience in various sectors varied from government to private and later education. He is appointed as one of the managers and assessors in the department. He is also the subject matter expert. According to his statements, the new initiative is important to equip the students with required knowledge and skills for employment. The classical competency-based training mainly is classroom based training, hands-on radical at workshop with additional industrial attachment. However, this new initiative involves students' experiences working in the live industrial plant to gain skilled based knowledge to be a job ready technician. It is vital to produce competent technicians who have skills in problem solving and able to continuously improve the manufacturing process. This is in line with Tisch *et al*. (2013) finding that with the rapid advancement of technology, reformation of current training is needed by adding scientific-founded approach. Based on their study, it is crucial for the employer to catch up with the rapidly changing of social, economy and technology in order to move forward to the future oriented-production and compete with others in global market.

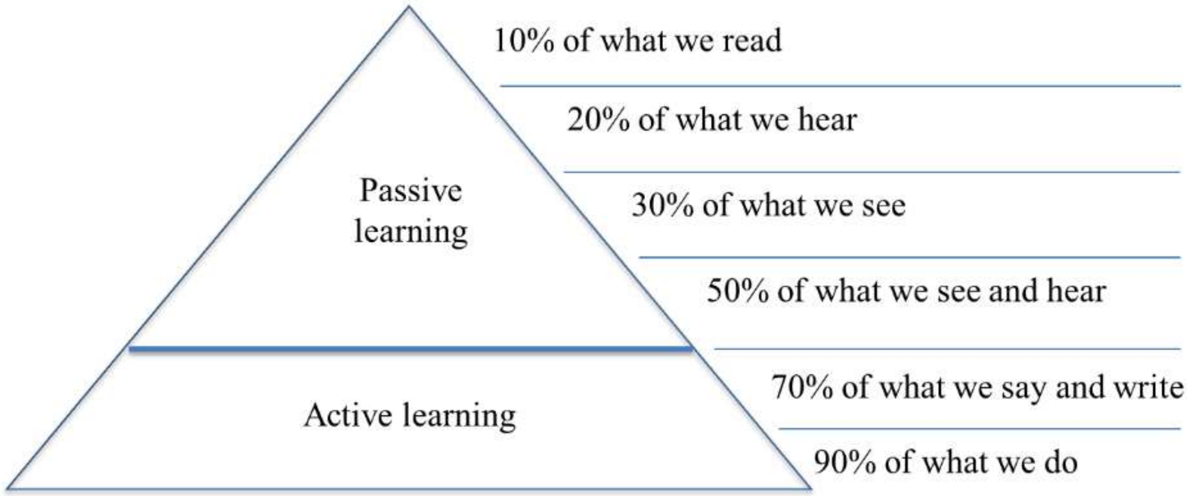
ETC is an established institution in providing technical training. However, to be a preferable regional training services provider, this new initiative plays an important role. Baumann *et al*. (2014) presented that workers with knowledge and specific skills are limited in US to cater the needs of manufacturing sectors which is well furnished with advanced and modern technologies to produce innovative product and process. The current available education system is unable to produce the skilled workers with required standards. Skills and development training are shortage too. Thus, the new initiative at ETC is a potential avenue to merge the education and private sectors to achieve a mutual educational method which includes industry-defined and innovative teaching, learning and assessment. The expatriate, who is a retiree also agreed with this transformation.

The implementation and effectiveness of the initiative

Integrating the competency-based training requires a complex and tedious process. A holistic approach is needed to match every element in the system to produce an initiative which makes eligible to all the students from every level of workforce (Hodge, 2007; Kodiappan, 2011). Thus, for this initiative, steps were taken to eliminate the problem inherited from the previous system and encouraged proficiency and mastery of tasks with opportunities provided.

Both HoD and expatriate have identified significant improvement in the students' performance from the new initiative which emphases on field based training. This might be an advantaged of the new initiative, job oriented training which provide students with hands on practical. This type of learning can increase the retention. The Edgar Dale's "Cone of Learning" stated that we remember only 10% after two weeks we read, but we remember 90% of what we do.

Figure 2: Cone of learning showing the various stages of learning.



Both HoD and expatriate believed that students were trained in competency and soft skills will be more productivity. This is an important remark and Esa *et al*. (2013) presented those employees who have soft skills and sociological attribute are preferred for the fast rising in human capital demand. McClarty and Gaertner (2015) urged in their research work that achieving mastery of tasks by an individual is a must to indicate the performance level. Absence of mastery can bring damages and putting society at risk. A non-robust and lenient approach performed during training will only result in non-competent individuals. Thus, it is essential to validate the assessments and interpret the results with regards to employability and marketability of students. Various researches have been performed to recognise the best method for assessment and identified which industry standard to refer. This has been highlighted by Rahman *et al*. (2014) and Schoonenboom *et al*. (2007).

In this initiative, students were assessed based on the task assigned which they perform according to standards and procedures with required knowledge, skill and attitude under the observation of certified assessor. Feedback, collection of evidence, questioning, formal reports, *etc*. are the approaches used in the assessment. The assessments used are rational, consistent and reliable. A good assessment has four principles such as reliability, fairness, validity and flexibility (GIZ, 2011).

The critical factors for the sustainability of the initiative

The new initiative is an outcome-based learning which driven by demand and industry. It is a complex training system and it faced various challenges in ensuring the value, validity, relevance and responsiveness as the global economy continuously drive the changes in society, schools and industry (Anane, 2013). The job-oriented training is established with reference to occupational standards and regulations. When designing the training, few keys characteristics were identified like competency specifications, instruction, assessment, governance and management (Tuxworth, 2005). However, ETC still faced challenges to recruit the right expertise in delivering the training.

In this new initiative, foreign trainers were engaged to deliver the training. However, students found difficulty in understand the teaching. But the expatriate fund students are having deficiency in English language and learning behaviour. The above situation happened probably due to the early school training. Students have fear that they might be laughed at for speaking incorrect English in front of other students. Juhana (2012) reported that the key psychological factors like lack of confidence, shyness, anxiety, and *etc.* obstructed the students from speaking English language in public. Both trainers and students have to take initiatives to engage and interact for effective learning.

Personal interaction between students with trainer will improve the achievement in learning. Nugent (2009) presented that that the main variable in classroom is the trainer. If they spend time to build the relationship, students will be motivated to learn. Trainers have to be conscious of students' needs such as both academic and emotional assistance. The competency based training is to coach the students with knowledge, skills and right attitude. Thus, sufficient resources, facilities, quality trainers are required to sustain the initiative. For that, ETC introduced different types of skill gap training to address the shortage of skilled workface in industries. Currently, it cost higher to train personal at the real plant.

However, there are still lack in infrastructure and resources for the initiative. Abdullahi (2003) reported that that insufficient workshop facilities and support will unable trainers to deliver the training effectively and productively.

The ethical considerations used in the initiative

CIHE (2015) presented that there are several reasons for an educational institution to hold the ethical responsibilities namely continuance of institution 's mission and values, administration, support for both staffs and students, legislation, reputation, pressure from stakeholders and business strategies. At ETC, the learning environment are friendly and pleasant.

The above finding motivated students to be part of the lively training atmosphere. This is in agreement with Goleman (2001) who reported that the emotional intelligence (EI) is the skill to engage with others and it demonstrated by empathy, social skill, and self-awareness. The EI showed the level of bonding, teamwork and leaderships.

At the moment there is a huge maintenance cost (electricity, manpower, financial environmental *etc*.) due to the 24-7 operations. ETC must have enough students to be trained to recover and justify the return of investment. Adequate financial and wellbeing (health and safety) of the staff must be considered and monitored continuously (London, 2014). Overall maintenance is cost massive but it will benefit the society and individual on the long term. Usually such facilities as this one has large ecological foot print on natural resources which include water, electricity, fuel and others. Gender discrimination and equal participation of all ethical groups have to be address.

Couch and Alexander (2009) reported that educational institutions are accountable to prepare ethical teaching and learning environment. Education provides students with opportunities to access the knowledge and skills which have long term and life changing impacts. At ETC, the new initiative in teaching and learning has significantly impacted the pedagogy in skill development. Students have benefited from the state-of-art integrated training plant without risking their live which the case in real plant. The overall employability of the students is depending on the capability and capacity of individual. It is important for the students to be ready for employment with both competency and soft skills which bring productivity. Students who have soft skills and sociological attribute are preferred. This initiative is important in building human capital demand for the nation.

5. CONCLUSIONS:

Several conclusions can be drawn from this study. New initiative significantly contributed to teaching and learning system of competency-based training. HoD is optimistic in implementation of new initiative here students can master skills in performing the service and maintaining at high risk environment. Expatriate believed significant change in teaching skill on demand is extremely required in current industries like petrochemical process was not possible over classical teaching and learning methodology. Student found that the opportunities to learn and practice are high. He is able to visualize the future career that he is going to undergo.

There are however, issues pertaining to the high running cost of 24-7 operational stress and sustainability of this new start-of-art facility. Finding expert who can train students is the major challenge for the plant management of this new initiative. In this study, author also identified that students struggled in comprehending English language delivered by native speakers. Foreign trainers realized their problems and encouraged students to be active in learning activities.

In Malaysia, this is a unique initiative in teaching and learning methodology and therefore, students can be trained for global high tech market in the region. The job oriented or work integrated leaning are well accepted by stakeholders since it is a pre-employment training. This training is preferable as it is a task based learning and assessed based on knowledge, skills and attitude which are the three main elements required as a competent technician.

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APPLICATION OF RELIABILITY CENTERED MAINTENANCE TECHNIQUES TO A DYNAMICALLY POSITIONED VESSEL USING FAILURE MODE EFFECT AND ANALYSIS – A CASE STUDY

Ulhas S. Kalghatgi

Abstract

Reliability Centered Maintenance (RCM) is a systematic approach to ensure that a system maintains its functional capability through optimum maintenance activities. One of the key step in implementing RCM is to carry out Failure Mode Effect Analysis (FMEA). FMEA is an engineering technique used to define, identify and eliminate known and/or potential failures. FMEA is a proactive method to analyze possible failures before the failure has occurred. Such failures cause interruption in the operation of the vessels, leading to cost implications, besides loosing precious time in restoring the system. The consequences of such failures could be disastrous too. FMEA is a study of any system's functioning and anticipating probable failures and then taking suitable corrective actions to prevent them from occurring.

Dynamic positioning (DP) is a system to automatically maintain a vessel's position and heading by using its own propellers and thrusters. Position reference sensors, wind sensors, motion sensors and gyro compasses, provide information pertaining to the vessel's position and environmental forces affecting its position. It enables operations at sea where it is difficult to moor or anchor the vessel. Some of the common applications of the DP systems are ships and semi-submersible mobile offshore drilling units (MODU), oceanographic research vessels and cruise ships. These vessels are usually engaged in critical operations, where position keeping of the vessel remains a key function of the **DP System.**

The aim of FMEA study was to identify the single point failures in any system in the vessel which would lead to loss of position keeping of the vessel. The causes and effects of any such failures were analysed and possible corrective actions recommended in the FMEA report.

The vessel, for which the FMEA was carried out, is fitted with diesel driven main propellers and electrically driven tunnel and bow thrusters. The findings of FMEA were used to identify functional failures and plot P-F curves using failure rate data from OREDA. This was used to structure the RCM framework to develop a maintenance plan that will provide an acceptable level of operability, with an acceptable level of risk, in an efficient and cost-effective manner. In the end, Cost-benefit analysis was carried out to determine which systems would benefit from RCM and which were better off with traditional maintenance practices.

Key words: Reliability Centered Maintenance, FMEA, and Dynamic Positioning System

1. INTRODUCTION:

Dynamic Positioning system has been widely accepted as a primary method of position keeping of ships engaged in oceanographic research and oil exploration activities. The complexity of the system demands a reliability study to ensure safe position-keeping for prolonged operations. Through this paper an attempt has been made to apply principles of Reliability Centered Maintenance on a DP vessel through Failure Mode Effect Analysis (FMEA)

1.1. Reliability Centered Maintenance (RCM):

RCM is a systematic approach to establish the maintenance strategies of a plant and its equipment's. It is the optimum mix of reactive, periodic, condition based and proactive maintenance practices.

The primary objective of RCM analysis is to provide a comprehensive, systematic and documented investigation which establishes important failure conditions of the machinery system(s), maintenance tasks or redesigning of system/equipment. The analysis helps in reducing the frequency of such occurrences, and the rationale for maintaining spares inventory.

RCM integrates Preventive Maintenance (PM), Predictive Testing and Inspection (PTandI), Repair, and Proactive Maintenance to increase the probability that a machine or component will function in the desired manner over its design life-cycle with a minimum amount of maintenance and downtime.

RCM analysis should answer the following seven questions:

1. What are the system functions and associated performance standards?
2. How can the system fail to fulfil these functions?
3. What can cause a functional failure?
4. What happens when a failure occurs?
5. What might the consequence be when the failure occurs?
6. What can be done to detect and prevent the failure?
7. What should be done if a maintenance task cannot be found?

The first six of these questions can be answered by one of the most widely used techniques towards implementation of RCM i.e. **Failure Modes and Effects Analysis (FMEA)**. The information required to perform FMEA is as follows:

- Consequences of failure
- Probability of failure
- Historical data
- Risk tolerance (Mission Criticality)

2. FAILURE MODES AND EFFECTS ANALYSIS (FMEA):

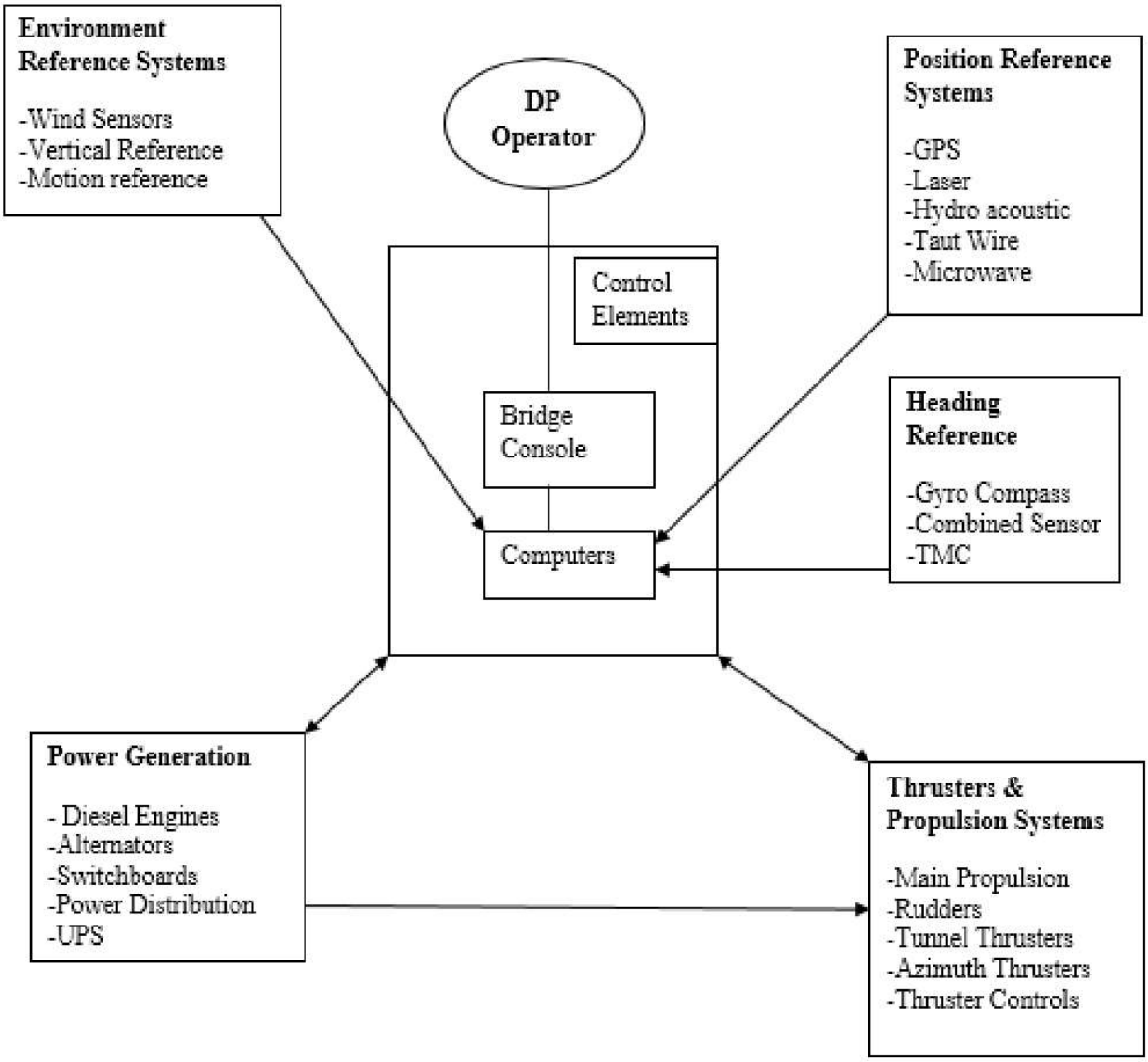
FMEA is an engineering technique used to define, identify and eliminate known and/or potential failures. FMEA is a proactive method to analyze failures before the failure has actually occurred. A crucial step is in anticipating what might go wrong with a product. Failure Modes and Effects Analysis (FMEA) is applied to each system, subsystem, and component identified in the boundary definition. For every function identified, there can be multiple failure modes. The FMEA addresses each system function, all possible failures, and the dominant failure modes associated with each failure. The FMEA then examines the consequences of failure to determine what effect the failure has on the mission or operation, on the system, and on the machine. Even though there are multiple failure modes, often the effects of failure are the same or very similar in nature to each other. From a system function perspective, the outcome of any component failure may result in the system function being degraded. Similar systems and machines will often have the same failure modes, but the system use will determine the failure consequences.

3. DYNAMIC POSITIONING (DP) SYSTEM:

Dynamic positioning (DP) is a computer controlled system to automatically maintain a vessel's position and heading by using its own propellers and thrusters. The information regarding vessel's position and the magnitude and direction of environmental forces affecting its position is fed to the computer by using position reference sensors, combined with wind sensors, motion sensors and gyro compasses.

Figure 1 below gives a visual description of the inter-relation of the various elements of a DP system

Figure 1.: Block Diagram of DP system Components



DP System Description:

Figure 2.: Schematic Diagram of a DP System

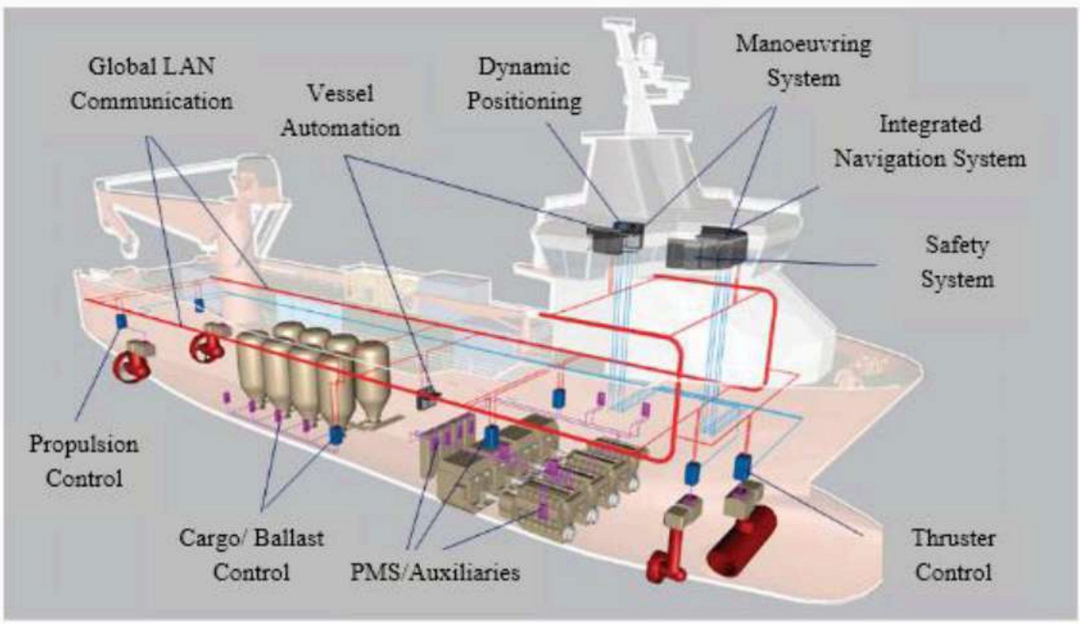
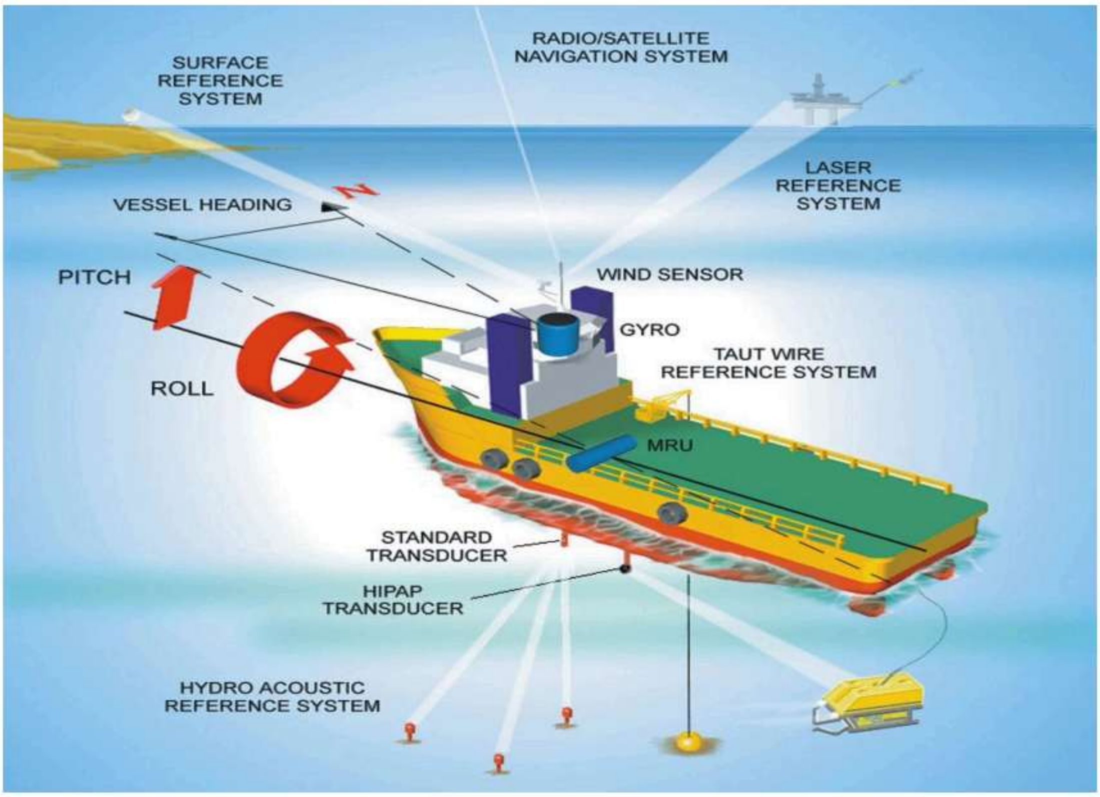


Figure 3.: Components of a DP System



Dynamic Positioning of a vessel is achieved by using thrusters at the aft (rear) end (also called as stern thrusters), fitted with / without controllable pitch propeller (CPP) and bow thrusters at the forward end.

3.1. Thrusters:

The vessel is fitted with following thrusters and propellers.

a) Bow Thrusters - 2No, 600 kW each

b) Stern Thruster – 1 No, 600 kW

c) Two Aft Propellers coupled through single reduction gearing to diesel propulsion engines together developing 8000kW

3.2. Operator Station and Controller:

The vessel is fitted with one DP Operator Station including operator joystick and LCD monitor. All logic with respect to safety, control and monitoring is located in a single DP controller. The DP controller receives input signals from gyro compass, DGPS and vertical reference unit and computes the required thruster output for each thruster for position keeping. Two wind speed units mounted on the vessel provide environmental reference to DP control system.

3.3. Digital Global Positioning System (DGPS):

The basic requirement for DP system to function satisfactorily is the information regarding reliable and continuous position of the vessel. DGPS has become the most commonly used position reference for DP operations. The system using positioning satellites and differential correction signal provides accurate position reference to the DP system. The system consists of GPS antenna, central processing unit and antenna for receiving the differential corrections. The vessel is provided with two DGPS units. One is supplied from power GMDSS console power distribution board panel and the other is powered from the UPS.

3.4. Motion Reference Unit (MRU):

The MRU measures the accelerations by the use of linear accelerometers and calculates inclination angles. The system provides accurate values of roll and pitch to the DP system and accordingly the position calculations for vessel positions are corrected. The vessel is provided with one MRU unit.

3.5. Gyro Compass:

Gyro compass is interfaced with DP system to provide a reference for controlling and monitoring the Tugs heading. The vessel is provided with two numbers Gyro units.

3.6. Wind Sensors:

The vessel is provided with two wind sensors to provide wind speed and direction to the DP System. The wind sensors are important as significant changes in the wind speed or direction can affect the vessel position unless compensated. The feed forward mode of the above information to the DP system allows for corrective thrust from the DP system to counter act the disturbances produced by the wind.

3.7. Power Supply:

The vessel is provided with a UPS unit. The UPS system which is powered from 220V Emergency supply, feeds power to one of the DGPS, Fanbeam, Alarm Printer, Operator Station, DP Controller. The status of the power supplies and the 230V AC UPS supply is monitored with an alarm output to the DPC.

3.8. Dynamic Positioning Software (Software Control in the DP system):

In this version of the Dynamic Positioning Control System there is no redundancy of the controller apart from the manual backup operation of the thrusters. Within the controller computer there is no software module redundancy. The required reliability is achieved by the implemented diagnostics system that monitors all input signals to the system and checks for lost or abnormal signals

4. FAILURE MODES:

Following major failure modes were identified during the study:

1. Power failure to Operator Station (115/230V AC)
2. Operator Station Computer Faulty
3. DP Operator Joystick Faulty
4. Power failure to UPS
5. Power Loss to Controller
6. Remote Control Unit Faulty
7. Power Loss to DGPS Unit
8. DGPS Faulty
9. Power Loss to MRU
10. Motion Reference Unit Faulty

5. RELIABILITY AND AVAILABILITY CALCULATION OF DP SYSTEM:

After determining probable failure modes in the DP system, its reliability and availability were calculated.

The following basic mathematical equations pertaining to the above said parameters were used in the analysis.

Reliability (R) = $e^{-\lambda t}$ .... (5.1)

Failure Rate (λ) = 1/MTBF .... (5.2)

Availability (A) = MTBF / (MTBF + MTTR) .... (5.3)

Maintainability (M) = 1- $e^{-\mu t}$ .... (5.4)

where μ = Repair Rate

5.1. Subsystems and device – MTBFs":

To calculate the system reliability, a reliability block diagram (RBD) as shown in figure 5.1 was first constructed to logically connect the different components of the DP system.

Figure 4.: Reliability Block Diagram (RBD) of the DP-1 system

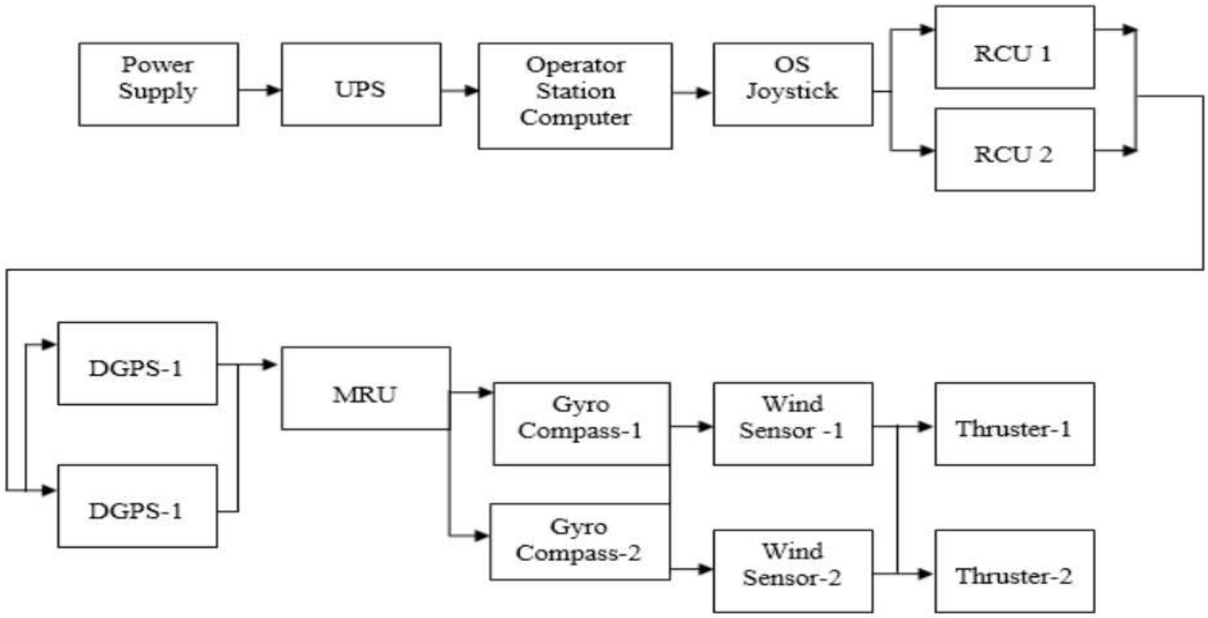


Table 1 below gives the information based on data collected from different DP vessels, available literature and operational experience

No	Equipment	MTBF	MTTR	λ (/10^6 hours)	μ	Reliability (For 1 equipment)	Combined Reliability
1	Thrusters	50000	9.4	0.00002	0.1	0.83929	0.9742
2	Operator Stations	92000	1	1.08696E^{-5}	1	0.909176	0.9092
3	Controllers	92000	7	1.08696E^{-5}	0.1	0.909176	0.992
4	DGPS	50000	5	0.00002	0.2	0.83929	0.9741
5	Motion Reference Unit	50000	10	0.00002	0.1	0.83929	0.83929
6	Gyro Compass	50000	30	0.00002	0	0.83929	0.9741
7	Wind sensors	151285	2.7	0.0000061	0.4	0.94374	0.9969
8	Power Supply	25000	24	0.00004	0	0.7044	0.9741
9	Engines	40000	23	0.000025	0	0.8033	0.9613
10	Software Control	40000	5	0.000025	0.2	0.8033	0.9613
						System Failure Rate	**5.31325E^{-5}**
						System MTBF ($MTBF_s$)	**18820**
						System Reliability	**0.6279**

Based on the RBD and the calculations in the above table, Reliability of the DP system was obtained as 0.6279 (62.79 %)

To calculate the Availability of the system, the mean time to repair (MTTRs) for the DP system was calculated as below:

$$MTTR_s = \frac{\sum \frac{MTTRi}{MTBFi}}{\sum \frac{1}{MTBFi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.5)$$

Using the above relation $MTTR_{system}$ is obtained as **14.39 hours**

Availability of the system was calculated based on system mean time between failures and mean time to repairs using the equation 5.3.

$A = MTBF_s / (MTBF_s + MTTR_s)$

= 18820 / (18820 +14.39)

= 0.9992

= **99.92 %**

Down time of the system in operating time between failures was calculated as below:

$$\text{Downtime} = MTBF * \left(\frac{1}{A} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.6)$$

= **15.06 Hours**

Average Downtime cost rate = **10000 $ / hour**

Total Downtime cost = **150600 $**

If we use only a single gyro compass and wind sensor, the reliability of the system drops significantly to 51.21%. In such a scenario, the system failure rate would be $7.6397E^{-5}$ and the $MTBF_s$ would be 13090 hours.

This would result in a drop of availability to **0.9985,** leading to a downtime of **19.664 hours** Therefore, total downtime cost would be **196645 $**

5.2. P-F Curves:

The benefit of using tools of Reliability Centered Maintenance as described above can be proved in the form of P-F Curves as shown below:

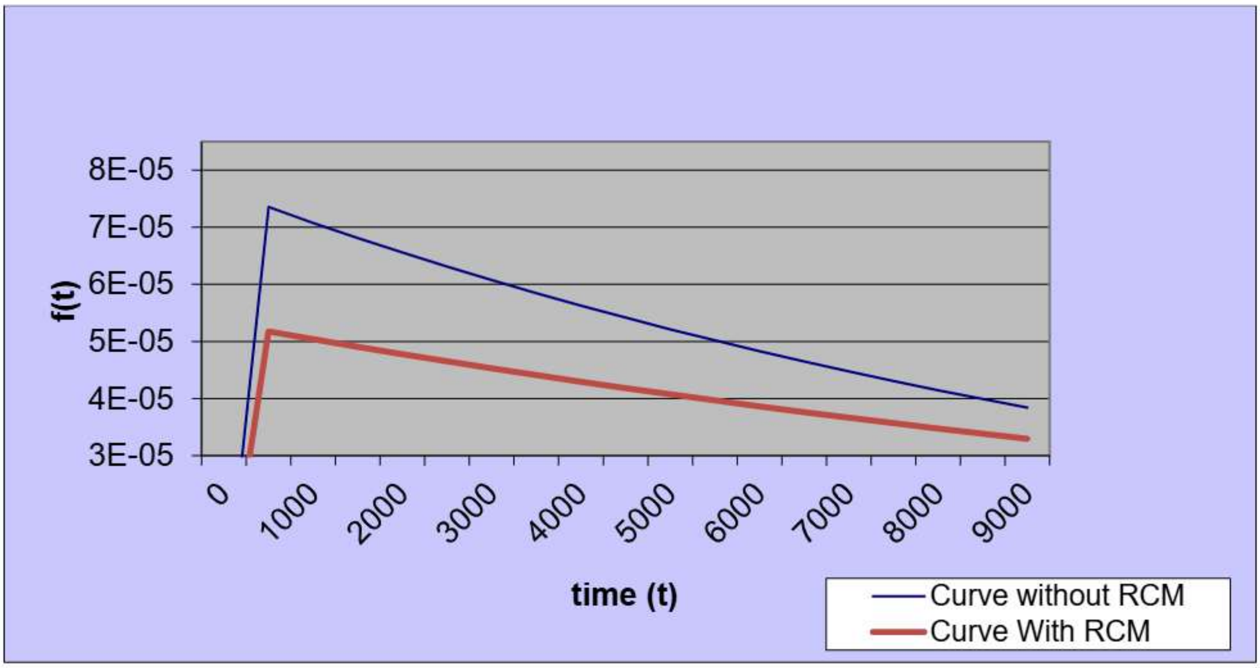
Table 2.: PDF (Without RCM)

Value of λ (Without RCM)	Time	Probability Density Function [f(t)]
7.6393E-05	0	0
7.6393E-05	500	7.35305E-05
7.6393E-05	1000	7.07749E-05
7.6393E-05	1500	6.81225E-05
7.6393E-05	2000	6.55695E-05
7.6393E-05	2500	6.31122E-05
7.6393E-05	3000	6.07470E-05
7.6393E-05	3500	5.84704E-05
7.6393E-05	4000	5.62791E-05
7.6393E-05	4500	5.41700E-05
7.6393E-05	5000	5.21399E-05
7.6393E-05	5500	5.01859E-05
7.6393E-05	6000	4.83051E-05
7.6393E-05	6500	4.64948E-05
7.6393E-05	7000	4.47523E-05
7.6393E-05	7500	4.30752E-05
7.6393E-05	8000	4.14608E-05
7.6393E-05	8500	3.99070E-05
7.6393E-05	9000	3.84115E-05

Table 3.: PDF (With RCM)

Value of λ (Without RCM)	Time	Probability Density Function [f(t)]
5.31325E-05	0	0
5.31325E-05	500	5.17396E-05
5.31325E-05	1000	5.03831E-05
5.31325E-05	1500	4.90623E-05
5.31325E-05	2000	4.77760E-05
5.31325E-05	2500	4.65235E-05
5.31325E-05	3000	4.53038E-05
5.31325E-05	3500	4.41161E-05
5.31325E-05	4000	4.29596E-05
5.31325E-05	4500	4.18333E-05
5.31325E-05	5000	4.07366E-05
5.31325E-05	5500	3.96686E-05
5.31325E-05	6000	3.86286E-05
5.31325E-05	6500	3.76159E-05
5.31325E-05	7000	3.66298E-05
5.31325E-05	7500	3.56695E-05
5.31325E-05	8000	3.47343E-05
5.31325E-05	8500	3.38237E-05
5.31325E-05	9000	3.29370E-05

Figure 5.: P-F Curves



6. ANALYSIS:

1. In view of redundancy designed for 415 V and 220 V systems and duplication of essential pumps, failure of one section of MSB does not lead total loss of propulsion.
2. In the event one of the BUS sections of the switch board fails, the essential pumps can be powered from the second section. The thrusters can be still powered from the auxiliary bus as long as there not affected.
3. In the event of failure of aux bus system, the vessel can continue to operate, however there would be degradation in performance as all the thrusters would not be available for station keeping. However, for DP-1 class the above failure mode is not critical. Moreover, as the auxiliary bus is in two sections interconnected by a breaker there would be only partial loss of thruster's power.
4. This DP-system is a Class 1 non – redundant system. For this system there are several single failures that may result in the **DP-system not functioning**. Examples of such failure are:
    - Loss of main power from the UPS
    - Functional failure of the Operator Station

In such cases the DP-system cannot be operated and the manual control of the thrusters (by joystick) should be used.

5. Further complete functional failure of Remote Control Unit no.1 (RCU 1) and failure of Motion Reference Unit (MRU), which has no redundancy, will significantly reduce DP system capability.

7. RECOMMENDATIONS:

1. Preventive maintenance procedure and operational check lists are to be formulated
2. Calibration of circuit breakers and protective devices to be carried out regularly.

8. CONCLUSION:

Through this paper, an attempt was made to apply Reliability Centered Maintenance (RCM) techniques to a DP vessel. One of the widely used RCM techniques - FMEA was conducted for the DP vessel which revealed critical failure modes. Another important RCM tool, Reliability Block Diagrams (RBD) was constructed to logically arrange the DP system to analyse its failure. Using the RBD, reliability and availability calculations were performed. These calculations showed that the system reliability is 62.79% and the availability is 99.92 %. Downtime for the vessel was determined as 15.06 hours. As the vessel goes off-hire during downtime, it results in added cost. This cost due to downtime was found to be **150600 $**.

In the absence of RCM, the downtime increases to 19.67 hours and the downtime cost increases to **196645 $**.

Thus, it is evident that judicious application of principles of RCM results in achieving higher reliability of the system as well as it helps in reducing downtime cost.

A comparative statement (table 8.1) shown below clearly brings out the benefits of using RCM Technique.

Table 4.: A comparative Statement

Parameters	With RCM	Without RCM
Reliability	62.79	51.85
Availability	99.92	99.85
$MTBF_s$	18820	13090
Downtime	15.06 hours	19.67 hours
Downtime cost	150600 $	196645 $

Thus, it is evident that judicious application of RCM results in achieving higher reliability of the system as well as in reducing the downtime cost.

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