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Knowledge-Humility-Excellence

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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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Editorial

True to its objectives and its international outreach, the second issue has been able to garner research papers from various disciples in the maritime domain and from the various geographies. The range includes Naval Architecture from Texas A and M University, USA; Marine Environmental Engineering from Singapore; Maritime Economics from Malaysia; Maritime Security from New Delhi; Maritime Social Sciences and Safety from Mumbai; Maritime Education from New Jersey City University, USA; and a ship design project from IIT Chennai to which self was a fortunate witness.

This journal aims to fill the void in maritime research so evident in the maritime domain. From providing a platform to highlight new knowledge and innovation in as much as bringing the same to the industry at large, this journal aims to inspire a culture of research in the domain and bridge the gap between academia and practitioners so that informed decisions can be taken to improve businesses.

As the maritime industry transforms from a skill-based, labour intensive industry to a highly capital intensive and sophisticated one, it becomes an illustrative example for bridging scientific knowledge and practical learning approach. For an increased professionalization of any sector, an underpinning of sophisticated knowledge base is critical. There is a need for the maritime industry to adopt a wider strategic view as opposed to a narrow, operational view.

At the diamond jubilee seminar of the Company of Master Mariners of India at Mumbai recently self-had the opportunity to put forth the proposal of encouraging Professional Doctorates in the maritime domain. Professional Doctorates have strong relationship with the workplace and 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.

And to which aim this journal also strives.

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AN EFFICIENT NONLINEAR NUMERICAL SCHEME TO PREDICT SHIP ROLL RESPONSES IN HEAVY SEAS

Rahul Subramanian[1]
Aishwarya Jayaraman[2]
Jyothish P V[3]

Abstract

Estimation of the roll motion of a vessel plays a vital role in the safe and efficient operation of a ship. It gives the designer prior knowledge of the limiting characteristics for transportation of cargo or passengers in a given sea-way. It is also crucial for the design of efficient, onboard roll control devices such as active fin stabilizer systems for both passenger and defense vessel applications. Traditionally, classification society based rules and empirical methods have been used to estimate the motion characteristics at the design stage. Although useful for the early phases of design, they tend to be inaccurate and conservative for more advanced design applications. Over the past couple of decades, computer based simulations have proven to be a more useful, efficient and robust tool for the designer. Typically based on linear theory, although they tend to be fairly accurate for moderate waves, the accuracy can quickly diminish for more realistic or severe sea states. This paper demonstrates the application of an efficient nonlinear computer program to predict the rolling of a ship. The computational model has been developed based on the direct time-domain body-nonlinear strip theory. The nonlinear theory is important to estimate ship motions in a severe sea-state. To model the viscous damping, the fully nonlinear form of the semi-empirical Ikeda-Kawahara method is employed.

In order to validate the computational predictions, a 1:12.5 scale model of a 200t fuel transport vessel has been fabricated and experiments carried out to evaluate decay characteristics and response in regular beam seas at zero forward speed. The comparisons of the numerical predictions with the experiments show generally good agreement. Detailed analysis of the hydro-mechanical force components helps in bringing out the importance of nonlinearities. The methodology thus promises to be a useful tool to designers to accurately predict the nonlinear roll behavior of ships at the early phase.

Key words - Seakeeping, Nonlinear Strip-Theory, Large Amplitude Roll Response, Roll Decay Tests, Body-Exact Time-Domain.

1. INTRODUCTION:

Accurate estimation of the dynamical responses and characteristics of a floating body in the presence of waves is crucial for the design of floating structures such as ships and offshore platforms. In particular, proper prediction of the roll motion is of significant practical importance. It is crucial in determining not only the stability and safety aspects of the floating system, but also in determining the comfort levels and its operational limits. There is great commercial interest in the theoretical understanding of the roll

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behavior from operators of containerships, heavy transport vessels and FPSOs. There exist several approaches to predict the roll behavior of vessels. They can broadly be classified into experimental and computational methods. Historically, scaled model tests carried out in the model basin have been used to predict the roll responses. A rigorously conducted experiment provides invaluable information and still remains as the most reliable tool to the designer. However, fabrication and labour costs can quickly rise if a large number of experiments are to be conducted to explore a variety of alternate designs. In addition, scale effects may affect the fidelity in extreme cases.

Over the last couple of decades, with the dramatic increase in computational power, computational techniques have evolved as a promising tool to the designer. They can be classified into ideal fluid and viscous methods. Ideal fluid potential flow theory has been the most popular approach to seakeeping. The method dates back to the 1950s starting with the work of (Korvin-Kroukovsky and Jacobs, 1957). The advantages of the method lie in the fact that it has proven to be fairly accurate, robust and computationally fast. Traditionally, the problems have been formulated in the frequency domain to solve the linearized Boundary value problem (BVP). Although, it can give fairly satisfactory results for small amplitude waves, the accuracy drops substantially for physical scenarios dominated by nonlinear behavior.

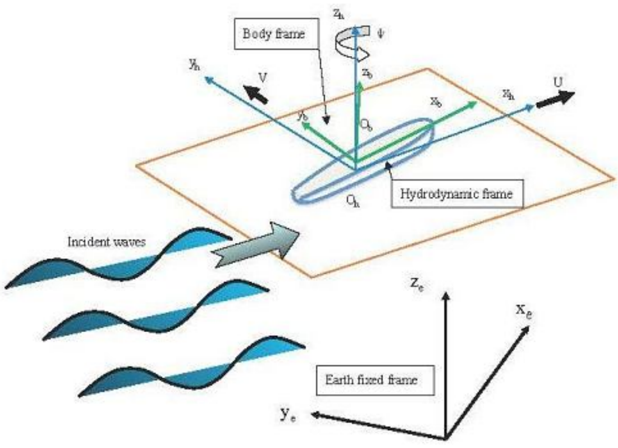
Since the early 2000s, viscous flow based CFD codes are being actively pursued to aid in the design of ships. These codes have shown to be capable of simulating highly complex fluid flows occurring in cases such as the roll motion. They can thus give very valuable insights about the local flow field to the designer. However, the enormous computational cost and time limit their application as a practical design tool. In addition, they also require accurate turbulence models and are known to be sensitive to the quality of geometry and grids. These factors affect their robustness and practicality. The direct time-domain approach has been receiving a lot of attention, following the pioneering work of (Longuet-Higgins and Cokelet, 1976), where the fully nonlinear water wave problem was solved using the Mixed Euler Lagrange (MEL) approach. Time-domain based methods have a major advantage in being able to model different degrees of nonlinearity, as reviewed in (Beck and Reed, 2001). The sophistication level of these so called "blended method" codes can be chosen based on the particular problem being solved, the required accuracy level and available computational resources. Validation studies have shown increased levels of accuracy and capability in handling large motions when compared with linear frequency domain methods; with the downside being increased computational effort.

This paper presents the application of an efficient "blended method" scheme to predict the roll behavior of a ship in a large sea-state. A computer program based on the body-nonlinear time-domain strip theory (cf. (Bandyk, 2009), (Subramanian, 2012) and (Subramanian and Beck, 2015)) has been developed to perform the numerical computations. The strip theory approach allows for faster computational times and simplified body geometry definition, when compared to fully three-dimensional methods. The body-nonlinear direct time-domain approach accounts for nonlinear dynamics attributed to the changing wetted surface of the body, thus accounting for higher order radiation and diffraction wave loads. This ensures the validity of the method for large roll amplitudes. In order to validate the computational predictions, a 1:12.5 scale model of a 200 tonne oil transport vessel has been fabricated and experiments carried out at the model basin in the Department of Ocean Engineering at IIT Madras. To this end, the free decay and seakeeping experiment in regular beam seas at zero forward speed have been carried out.

2. MATHEMATICAL FORMULATION:

The objective is to predict the motions and forces on a ship in a seaway. Three different coordinate systems are used for solving the fluid flow problem as in shown in Figure 1; an earth fixed inertial axis (x_e, y_e, z_e) is used to keep track of the position of the center of gravity of the ship and the Euler

Figure.1.: Schematic showing the different coordinate frames used



angles. A hydrodynamic frame (x_h, y_h, z_h) translates in the horizontal calm water plane with translational velocities U, V and rotational yaw rate $\dot{\psi}$. It thus follows the ship such that its origin O_h is always in vertical line with the origin of the body frame, O_b. This is the frame in which the boundary value problem is formulated. A body fixed frame (x_b, y_b, z_h) rotates and translates in all 6-DOF with the body. The frame is used to compute the forces acting on the ship and to solve for the equations of motions.

The velocities U, V and $\dot{\psi}$ are the instantaneous body velocities resolved in the hydrodynamic frame.

The fluid flow is considered inviscid, irrotational, incompressible and unsteady. For such a flow, a velocity potential Φ, representing the perturbation potential for the absolute fluid velocity in the earth fixed frame is defined. The fluid particle velocity $\mathbf{v}$ can be written as:

$$\mathbf{v} = \nabla\Phi \qquad (1)$$

From Equation (1), the continuity equation for the conservation of mass of the fluid reduces to the Laplace's equation

$$\nabla^2\Phi = 0 \qquad (2)$$

The linearized kinematic and dynamic free surface boundary conditions written in the moving hydrodynamic frame are,

$$\frac{\partial \eta}{\partial t} = \frac{\partial \Phi}{\partial z} + (\mathbf{U} + \dot{\mathbf{\Psi}} \times \mathbf{r_h}) \cdot \nabla\eta \qquad \text{on } z = 0 \qquad (3)$$

And

$$\frac{\partial \Phi}{\partial t} = -g\eta + (\mathbf{U} + \dot{\mathbf{\Psi}} \times \mathbf{r_h}) \cdot \nabla_{\Phi} \qquad \text{on } z = 0 \qquad (4)$$

Here, η and $\mathbf{r_h}$ represent the free surface wave elevation measured from the calm water surface, and the position vector in the hydrodynamic frame respectively.

The body boundary condition ensures no normal flow through the body surface:

$$\nabla\Phi \cdot \mathbf{n} = v \cdot \mathbf{n} \qquad \text{on} \quad S_B(t) \qquad (5)$$

where Φ is the total three-dimensional perturbation potential, v is the absolute velocity of a node on the body surface with respect to the earth fixed frame including velocities due to rotational effects; **n** is the unit normal vector positive out of the fluid (or into the body), and $S_B(t)$ is the exact wetted body surface.

The above formulations are defined for a fully three-dimensional flow field. If it is assumed that the ship is slender such that the slope of the body surface in the longitudinal direction is smaller than the slopes in the transverse direction, the gradient $\frac{\partial}{\partial x} \ll \frac{\partial}{\partial y}, \frac{\partial}{\partial z}$. This forms the basis for the strip theory approximation, where the three-dimensional problem is solved as a series of individual two-dimensional problems.

The strip wise two-dimensional potential satisfies the Laplace equation at each frame:

$$\nabla^2 \varphi(y,z,t;x) = 0 \qquad (6)$$

Here $\varphi = \varphi(y,z,t;x)$ shall henceforth refer to the two-dimensional potential for notational convenience.

The free surface boundary conditions take the following form from Equations (3) and (4):

$$\frac{\partial \eta}{\partial t} = \frac{\partial \phi}{\partial z} + V\frac{\partial \eta}{\partial y} + x_h \dot{\psi}\frac{\partial \eta}{\partial y} \quad \text{on } z = 0 \qquad (7)$$

$$\frac{\partial \phi}{\partial t} = -g\eta + V\frac{\partial \phi}{\partial y} + x_h \dot{\psi}\frac{\partial \phi}{\partial y} \quad \text{on } z = 0 \qquad (8)$$

Consistent with strip theory, the encounter frequency is assumed high such that, $\frac{\partial}{\partial t} \gg U\frac{\partial}{\partial x}$ and the downstream free surface effects are ignored.

The far field radiation boundary condition is satisfied by incorporating an outer damping beach and modifying the free surface boundary conditions. The details are given in (Subramanian and Beck, 2015). The free surface equations (7) and (8) are integrated in time using a 4^{th} order Adams Bashforth-Moulton predictor-corrector scheme. All simulations are carried out in deep water and so the gradient of the perturbation potential vanishes as $z \rightarrow -\infty$. This is automatically taken care of by the Rankine source function.

The perturbation potential can be broken down into different components for proper bookkeeping:

$$\varphi(y,z,t;x) = \varphi_I + \varphi_D + \varphi_R$$

where, φ_I, φ_D, φ_R refer to the incident, diffracted and radiated potential, respectively.

The incident wave potential and elevation are known at all time and the linear Airy wave theory is used. The analytical expressions for the potential and wave elevation with respect to the earth fixed inertial frame are:

$$\phi_I = \frac{iga}{\omega_0} e^{-ik(x_e \cos\beta + y_e \sin\beta)} e^{i\omega_0 t} e^{k(z-\eta)} \quad (9)$$

$$\eta_I = a e^{-ik(x_e \cos\beta + y_e \sin\beta)} e^{i\omega_0 t} \quad (10)$$

Here, a, ω_0, k, λ, and β refer to the wave amplitude, frequency, wave number, wavelength and the heading angle relative to earth fixed x-axis, respectively. The incident wave potential formulation also includes the Wheeler stretching term.

The body boundary condition (5) is re-written in terms of its individual components in the two-dimensional frame

$$\nabla\varphi_D \cdot \mathbf{N} = -\nabla\varphi_I \cdot \mathbf{N} \qquad \text{on } S_B(t) \quad (11)$$

$$\nabla\varphi_R \cdot \mathbf{N} = v \cdot \mathbf{N} \qquad \text{on } S_B(t) \quad (12)$$

Here the two-dimensional strip theory unit normal **N** is used. $S_B(t)$ denotes the surface formed by the intersection of the instantaneous wetted body surface with the mean water level. Algorithms have been developed to find the intersection of the body surface and cut panels at each time step. Computations are only performed for sections that are wetted. The free surface evolution can either continue or be reset to zero. Thus, the present method allows for changing wetted geometry and emergence of sections.

The velocity v used in Equation (12) is the velocity of a node on the body surface with respect to the earth fixed frame and includes all the three translational and rotational components, namely (u,v,w,p,q,r).

The mixed boundary value problem (Equations (6) - (12)) is solved for the perturbation potentials φ_R and φ_D and their derivatives. In the present work, a source distribution technique is used. Desingularised sources are placed above the free surface nodes and constant strength panels are used on the body. The desingularised method avoids complicated panel quadrature and can handle higher order derivatives in a straightforward manner ((Cao, Schultz, and Beck, 1991)). Details of the method are given in (Subramanian, 2012).

Once the potentials, pressure and forces acting on the body are determined, the equations of motion (EOM) are set up using the position and velocity of the body. The fully nonlinear 6-DOF EOM is used here. Details are given in (Subramanian, 2012). The velocities and displacements are time-stepped using a 4^{th} order Adams-Bashforth time-stepping scheme. The new values of the variables are used to continue the evolution of the flow variables.

3. IKEDA ROLL DAMPING MODEL:

The Ikeda method estimates the roll damping coefficient by breaking it down into various components. These components are then individually modeled taking into account the physics governing each of them. The total roll damping moment, F_4^d is given by:

$$F_4^d = -B_{44}^{(1)}\dot{\phi} - B_{44}^{(2)}\dot{\phi}|\dot{\phi}| \tag{13}$$

Here, the terms $B_{44}^{(1)}$, $B_{44}^{(2)}$ and $\dot{\varphi}$ denote the linear damping, quadratic damping, and roll velocity, respectively. To use with linear frequency domain codes, the quadratic term is typically linearized by assuming the dissipated energy over a cycle to be equal. This yields the following expression for the equivalent linear damping $B_{44eq}^{(1)}$,

$$B_{44eq}^{(1)} = \frac{8}{3\pi}\phi_a \omega B_{44}^{(2)} \tag{14}$$

Here, φ_a and ω denote the roll amplitude and encounter circular frequency respectively. Therefore, their product represents the roll velocity amplitude.

In the modified Ikeda method ((Kawahara, Maekawa, and Ikeda, 2009)), the ship hull geometry is represented by the Taylor Standard Series. Once the hull geometry is analytically represented, the integrations along the length can be carried out to obtain explicit expressions for the damping coefficients in terms of the hull main particulars. This approach is very useful to quickly estimate the roll damping coefficients at the preliminary phase of design when often the only details the designer has at his or her disposal, are the main particulars of the vessel. The damping coefficients consist of five components. These are the wave radiation, frictional, eddy, lift and bilge keel. A brief description and semi empirical formulas according to the modified Ikeda method are as follows.

3.1 Wave Radiation Damping:

The wave radiation component is the damping due to the radiated waves created due to roll. This is directly computed by the potential theory formulation. Therefore, the present method does not use this term. The detailed formulations are given in (Kawahara *et al.*, 2009).

3.2 Frictional damping:

The frictional damping is attributed to the hull skin friction. This is estimated based on Kato's formula from experimental results for cylinders.

3.3 Eddy damping:

The eddy component of the roll damping is created by small separation bubbles or shed vortices generated at the bilge of the midship section and large vortices generated at the relatively sharp bottom of bow and stern sections. Although vortex shedding from oscillating bluff bodies is usually governed by the Keulegan-Carpenter number (K_C number), it was found by (Ikeda, Himeno, and Tanaka, 1978) that the viscous forces created by such small separation bubbles or small shedding vortices do not significantly depend on the K_C number. In Ikeda's prediction method, the distribution of the pressure created on a hull surface by such separation bubbles is assumed as a simple shape for each shape of cross sections on the basis of experimental results of pressure distribution on hull surfaces.

3.4 Lift damping:

The lift damping occurs due to lift forces generated by the hull surface when the ship has a non-zero forward speed. The present study is restricted to zero forward speed; hence this component is not considered at present.

3.5 Bilge keel damping:

It is quite typical to fit a bilge keel to most ocean going vessels. A well designed bilge keel can be an effective solution to reduce the roll response, where it can contribute more than 50% of the total roll damping. Vortices shed from the sharp edges of the bilge keels are responsible for the large viscous forces. Two primary mechanisms have been identified for the generation of quadratic damping moments. The first part is due to the normal force acting on the bilge keel, and the second sub-component, is due to the pressure on the hull surface created by the bilge keel.

4. EXPERIMENTAL SET-UP:

In order to validate the computational predictions, experiments have been carried out in the model basin in the Department of Ocean Engineering, Indian Institute of Technology Madras, India. A model of a 200 t oil vessel has been fabricated to a scale of 1: 12.5 using fiberglass. In addition to the geometric similarity, the dynamic similarity is ensured by properly distributing weights to obtain the correct inertia properties of the prototype. Superstructure and deck-house have been added to simulate correct mass distribution and account for dynamic effects due to deck-wetting and spray.

An inclining test was initially conducted to ascertain the GM of the loaded ship. All the model tests have been conducted for the fully loaded condition. After correctly loading the model, the free roll decay tests were conducted to access the roll natural period and damping characteristics. The ship model was given an initial roll displacement and released and allowed to settle down while undergoing damped oscillations. Care was taken to ensure that the initial velocity was zero and displacement was only in roll. The measurement system uses conductivity-type wave probes for wave measurements and ORE Motion Reference Unit (MRU) for measuring the roll. The MRU is placed on the deck level on the centerline of the vessel at the LCG position. The tests were performed in the wave flume measuring 90*m* in length, 4*m* in width, and 2.8*m* in depth; with facilities for computer controlled wave generation. To evaluate the roll response of the vessel, regular waves of constant wave slope were generated for a range of frequencies. The model was oriented perpendicular to the wave fronts and placed beyond the region of transient waves and many wavelengths away from the parabolic wave absorbers at the far end to minimize effects of wave reflection. After each run, the model was reoriented to the beam sea configuration using two guide lines.

5. NUMERICAL SET-UP:

The geometry of the vessel is imported using the offset data of the ship. The strip theory formulation allows for effortless input and panel modeling. A cubic spline interpolation is used to obtain smooth contours on each of the sections. On the hull surface, an average of 60 flat panels are used per station. To accurately model the free-surface, 30 nodes are used per wavelength. To ensure mesh-independent solutions, the free-surface extends two wavelengths away from the body on each station. To enforce the far field boundary condition, a numerical beach is implemented extending two wavelengths. A time-step size of $T/100$ is used for the numerical integrations; T referring to the wave period. These values are chosen to minimize computation time and maximize accuracy, ensuring optimum numerical efficiency. These parameters have been set based on the extensive convergence studies performed in (Subramanian, 2012). To avoid large transients in the beginning of the simulations, a smooth ramp is used to ramp-up the incident wave amplitude. The ramp period duration is set to 2.5 wave periods.

6. RESULTS AND DISCUSSION:

The main particulars of the 200t oil vessel are given in Table 1. The body plan is shown in Figure 2. A photo of the model being prepared is shown in Figure 3. The outcome of the experimental roll decay test is shown in Figure 4. Multiple lines on the graph indicate multiple test runs, with different initial displacements. The roll decay has also been simulated numerically by giving the vessel a specified initial roll displacement and allowing the equations of motion solver to predict the behavior. The comparison of the two approaches is shown in Figure 5. The results show good agreement of

Figure.2.: Body plan, 200 t oil vessel

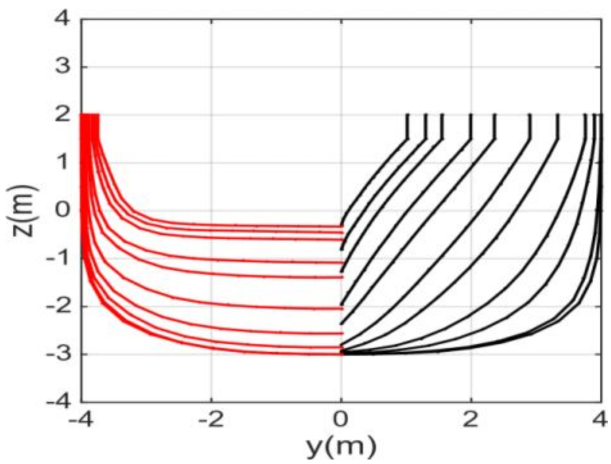


Figure.3.: Model of the oil vessel (Scale 1:12.5)

Table.1.: Main particulars of 200 t oil vessel

Main Particulars	Full Scale	Model Scale
Scale	1.0	1 : 12.5
LBP $[m]$	31.200	2.496
Beam $[m]$	8.000	0.640
Draft $[m]$	3.094	0.247
Displacement ∇ $[m^3]$	493.500	0.253
LCG $[m]$ (wrt midship)	−1.739	−0.139
KG $[m]$	3.034	0.243
k_{xx}/**B** (wrt CG)	0.312	
k_{yy}/**L** (wrt CG)	0.229	
C_B	0.639	
Cm	0.890	
l_{BK}/**L**	0.3800	
b_{BK}/**B**	0.0285	
Design Froude Number	0.349	

the numerical prediction with the experimental results. The natural period predicted by the numerical method is 1.65 s, compared to the experimental value of 1.64 s. This also indicates that the added mass term, A_{44} is correctly predicted. Assuming linear behavior, the non-dimensional damping coefficient, k, given by $\frac{B_{44}^{(1)}}{2\sqrt{(I_{44}+A_{44})C_{44}}}$, can be estimated assuming an exponential decay of the roll oscillations. Here I_{44}, C_{44}, and $B_{44}^{(1)}$ refer to the roll moment of inertia, hydrostatic stiffness and total linear roll damping term including viscous effects, respectively.

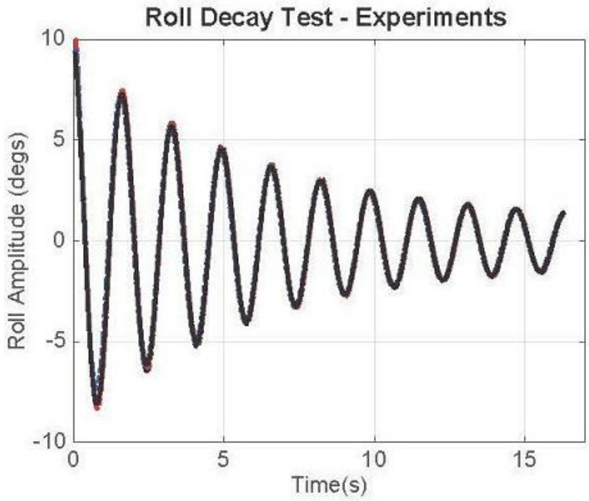
The plot of successive peaks is shown in Figure 6. The numerical results show good agreement with the experimental data. The smaller roll angles show small deviations, with excellent match at higher amplitudes. In reality, because of the nonlinear nature of roll, the damping coefficient varies with the amplitude. This is illustrated in Figures 7 and 8, which show the various roll damping coefficients of the 200 t oil vessel at the roll natural frequency using the modified Ikeda method. The linearized damping coefficient, $B_{44}^{(1)}$ is non-dimensionalised by

$$B_{44}ND^{(1)} = \frac{B_{44}^{(1)}}{\rho \nabla B^2}\sqrt{\frac{B}{2g}} \qquad (15)$$

Figure 7 shows the linearized damping coefficient is not constant but increases rapidly with increasing roll amplitude, indicating the nonlinear characteristic. The nonlinear (quadratic) coefficients are shown in Figure 8. It is seen that the coefficients are nearly constant for $\theta > 5$ degs. As amplitudes get smaller, the damping coefficients increase rapidly. This is attributed to the dependence of these viscous components to the Reynold's number and K_C number. The plots also give a picture on the relative contribution of these components in damping the roll motions. It is evident that the bilge keel plays a major role in controlling the roll motion.

It is important to note that the only inputs to the computational program are the main particulars of the vessel including the bilge keel geometry. Typically, the amount of roll damping is "tuned" using the experimental results. In the present method, the roll damping is completely modeled using the nonlinear form of the semi-empirical Ikeda method described in Section 3.

Figure. 4.: Experimental roll decay test. Multiple lines indicate multiple runs.



The roll response in regular incident waves at 90 degs is shown in Figure 9. The incident wave slope is set to a value of H/λ = 1/60. H and λ denote the wave height and wavelength, respectively. The comparisons are favorable, with excellent agreement at and near the roll natural period. Good agreement is seen for larger wave periods. There is some deviation at smaller periods. The reason for this is unknown at present, and will be further investigated. Figure 10 presents the non-dimensionalised roll response computed for different incident wave slopes. The dramatic changes near the resonance

Figure.5.: Comparison of numerical and experimental roll decay test.

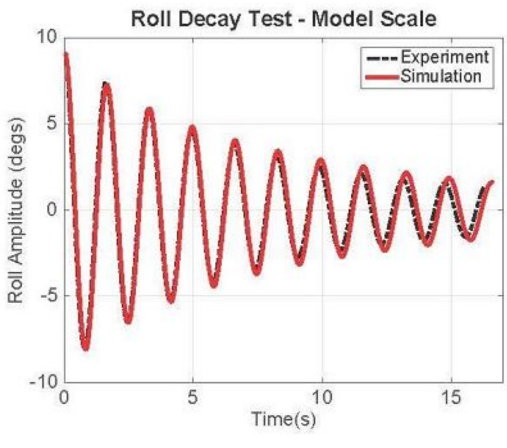


Figure.6.: Comparison of exponential decay characteristics

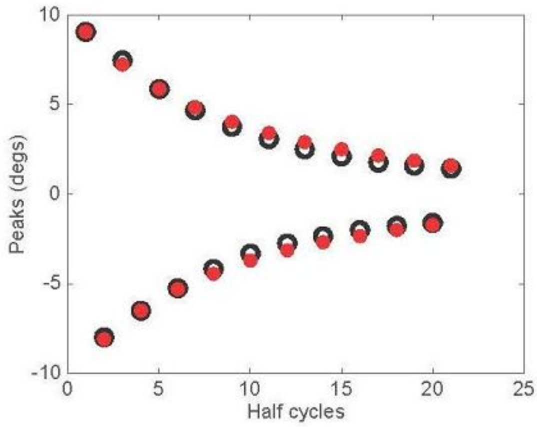


Figure.7.: Linear and linearized roll damping components using Ikeda method

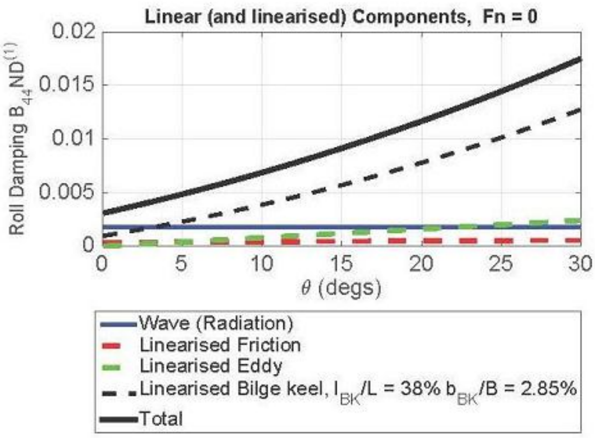


Figure.8.: Nonlinear roll damping components using Ikeda method

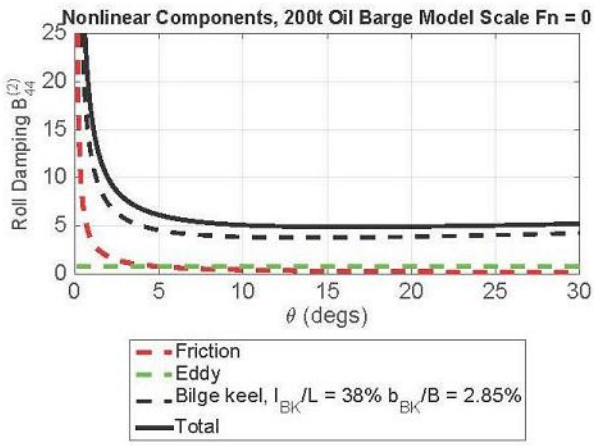


Figure.9.: Roll response in regular waves, $H/\lambda = 1/60$

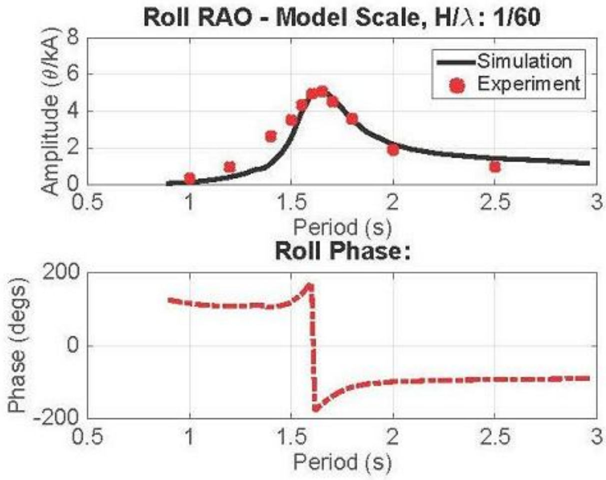


Figure.10.: Variation of roll response with incident wave slope

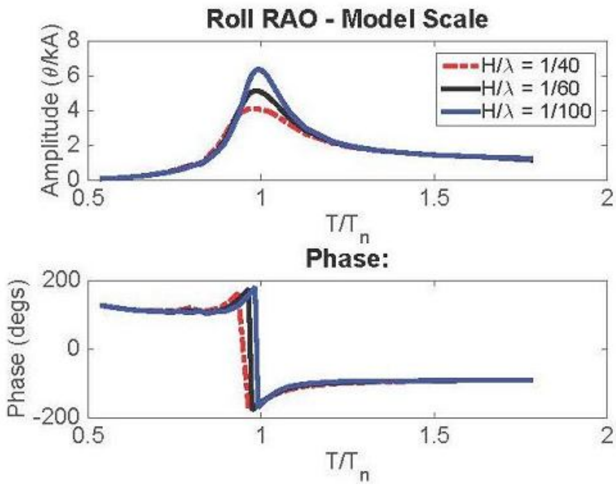


Figure.11.: Roll motion time history

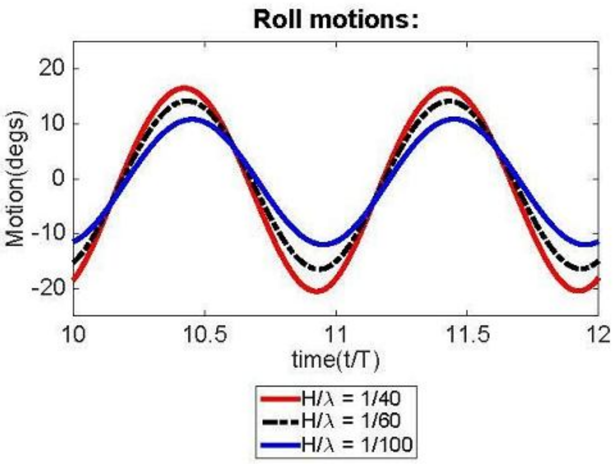


Figure.12.: Roll moment (Incident and Diffraction) time history

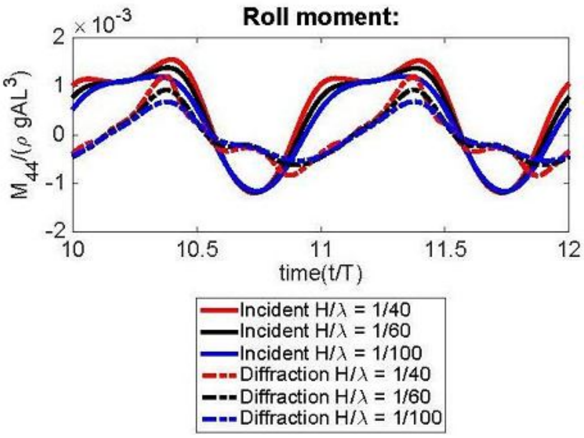


Figure.13.: Roll moment (Radiated and Hydrostatic) time history

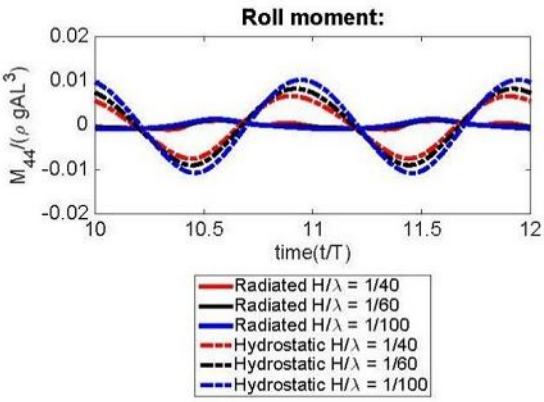
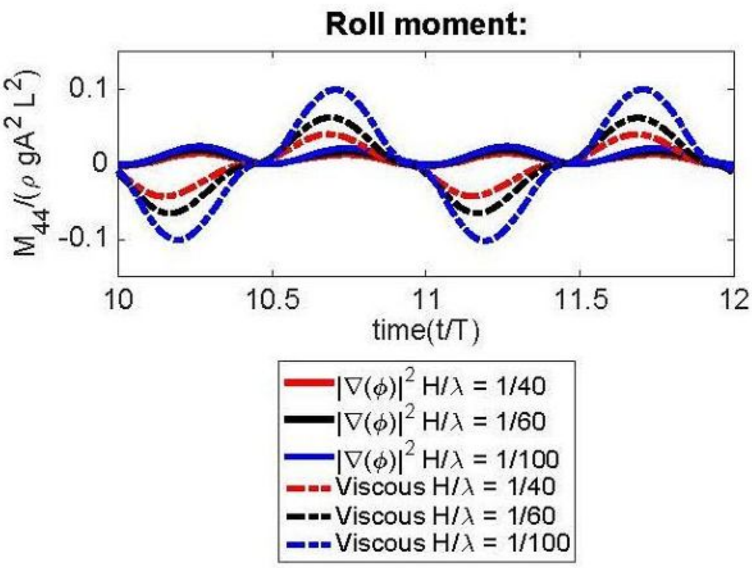


Figure.14.: Roll moment (Viscous and $|\nabla\varphi|^2$) time history



period highlights the strong nonlinear behavior. The nonlinear approach is capable of capturing this phenomenon. It is also interesting to note that the peak response shifts slightly, shifting towards lower period as the wave slope increases. The response also gets flatter as the wave slope increases. The time-history of the roll response for incident wave period, $T = 1.66$ s is shown in Figure 11. It is observed that the mean roll is non-zero due to the effect of higher order loads. As expected, this is more pronounced for the higher wave slope of $H/\lambda = 1/40$. Examining the roll moments acting on the vessel gives a better picture of the underlying dynamics.

The breakdown of the roll moment components is shown in Figures 12 through 14. It is clear that all components exhibit nonlinear characteristics, which can be attributed to the changing wetted surface of the body. The radiated component includes the damping due to potential wave radiation. The incident wave and hydrostatic forces are computed up to the exact incident wave surface. The viscous moments represent the contribution from the roll damping model. Although the damping coefficient is quadratic in nature, roll velocity varies with wave slope. This implies that the viscous moments can exhibit non-quadratic variation with wave amplitude (Figure 14). The term $|\nabla\varphi|^2$ refers to the v^2 term contribution in the Bernoulli (pressure) equation.

7. SUMMARY AND CONCLUSIONS:

A computer program based on the time-domain body-nonlinear approach has been developed. Implementation of the strip-theory formulation allows for computational efficiency and simplified body geometry definition. It also allows for vastly efficient algorithms for dealing with dynamic wave-body intersection and panel cutting. The fully nonlinear form of the modified Ikeda-Kawahara roll damping method has been implemented to accurately predict the roll behavior. The combination of a higher-order time-domain approach and fully nonlinear damping technique allows for accurately predicting large amplitude roll response without the need for linearizing the coefficients.

In order to validate the numerical predictions, experiments have been conducted on a 200t fuel vessel at the model basin in the Department of Ocean Engineering at IIT Madras. The free decay simulations show excellent agreement with the experimental results. The roll natural frequency matches closely with the measured value. The predicted roll responses for incidence angle of 90 degs also show good agreement with the measured values. The simulations are able to accurately predict the peak responses. There exists some deviation at higher wave frequencies. The exact reason for this is unknown at present and further studies will have to be done. The responses have been computed for various values of the wave slopes. The roll responses show the expected nonlinear behavior, including a mean component due to higher-order mean loads. Closer examination of the wave loads shows nonlinear contribution from all the components. This is attributed to the changing wetted body geometry, inclusion of exact Froude-Krylov and hydrostatics, and the nonlinear viscous damping.

The methodology promises to be beneficial to not only ship designers, but also offshore platforms such as FPSOs and FLNGs. The modified Ikeda method is particularly useful to estimate the roll response at the early stages of design, since the only inputs required are the main particulars of the vessel.

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BENCHMARKING OF MALAYSIAN SHIPPING COMPANIES USING STOCHASTIC FRONTIER ANALYSIS APPROACHES

Saravanan Venkadasalam[1]

Abstract

The purpose of this study is to benchmark selected shipping companies in Malaysia by evaluating their technical efficiency particularly for the financial year 2015-2016. The secondary data of the selected companies were retrieved from the database of Kuala Lumpur Stock Exchange. Based on a Stochastic Frontier Analysis model, the data was analyzed using Frontier 4.1 and STATA 13.0 software. It was found that Malaysian Shipping Companies were operating at average of 92 percent. The hypothesis testing reveals both Cobb-Douglas production frontier and Translog production frontier models are significant at 1%. There is a strong relationship between the variables.

Key words: Company Efficiency, Benchmarking, Shipping Company, Stochastic Frontier Analysis.

1. INTRODUCTION:

The concept of measuring an organization's efficiency has its roots in the fields of education and healthcare, but has been adopted by other industries also. The measurement of technical efficiencies is seen as an effective index in measuring a company's performance (Sowlati, 2005) as an alternative to financial pointers. This enables companies to benchmark themselves within the industry and enhance their reputation (Brønn and Brønn, 2005). Besides, measuring efficiencies, such indices would assist the managers in stabilizing the company's finances (Gokgoz and Çandarli, 2011). However, not many studies have been conducted in this field, especially for the shipping industry. Recent global economic downturn has weakened the performance of the shipping companies. The prelude to this was the drop in demand for commodities as an impact of the 2008/09 global crisis (Grama, 2012). Scholars indicated that shipping company continues to operate even though required to be pure technology inefficient (Odeck, 2008) or scale inefficient (Chang and Liao, 2012) in order to sustain in this industry.

Studies on efficiencies of shipping companies are limited and those available have measurements related to smaller companies involved in fishing and management of ferries. Works by Kim *et al.* (2011), Pascoe *et al.* (2013), Gutierrez *et al.* (2014) and Pinello *et al.* (2016) are few of the studies worthy of mention. Kim *et al.* (2011) studied

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on the cost reduction variables to assist the fishery industry, while Pascoe *et al.* (2013) stated that the technical and the scale inefficiencies as business exit indicators. However, there are no studies in the region which have measured efficiencies of large shipping companies engaged in international trade. In this study, the efficiencies of few big Malaysian shipping companies have been measured and a benchmarking exercise has also been completed.

2. METHODOLOGY:

The key aspect of this research is the use of the stochastic frontier analysis (SFA) for benchmarking the efficiency of the selected shipping companies. Even though, there are few other methods such as least square econometric production models, total productivity indices and data envelopment analysis to analyze the efficiency, the SFA was considered for this study. SFA uses the maximum likelihood estimation, which encompasses desirable statistical properties like unbiasedness, efficient and consistent in a small sampling (Radam, Yacob, and Muslim, 2010). Also, the pure random noises are excluded in the SFA approach. SFA approaches have been employed in cases where estimations have been affected by unpredictable noises (Martín, Román, and Voltes-Dorta, 2009). Since, the shipping companies vary in operation, size and nature of the business activity, and presence of unpredictable noises are foreseen, SFA would effectively exclude them and measurements would be precise. Hence, SFA was selected as the best tool for the study.

Malaysia is the 3rd largest ship owner country within the ASEAN states. As per the Review of Maritime Transport 2016, Malaysia have 1660 registered vessels with a total carrying capacity of 9,616,000 dead weight tonnage.

In this present study, a total of 17 shipping related companies located in Malaysia were tested. These companies were limited liability companies listed on the Kuala Lumpur Stock Exchange (KLSE). Table 1 displays the list of companies considered in this study. While some are noticeably big in capital and international operations, the others are within the set of related industries such as oil and gas sector and shipping-support service sectors. The audited annual reports of these companies were extracted from the KLSE website for the purpose of gathering the required data. Factors indicating the financial strength and performance were considered primarily. Information on revenues, paid in capital, general and administration expenses and cost of goods sold for the year 2015-2016 *etc*., were used as the input and output variables.

Table.1.: Malaysian shipping companies (all listed in KLSE)

No.	Company	Stock Name
1	Alam Maritime Resources Berhad	ALAM
2	Bumi Armada Berhad	ARMADA
3	Complete Logistics Services Berhad	COMPLET
4	Harbour- Link Group Berhad	HARBOUR
5	6 lmn off:stoe-	HUBLINE
6	Hubline Berhad	ICON
7	Icon Offshore Berhad	MAYBULK
8	Misc Berhad	MISC
9	PDZ Holdings Bhd	PDZ
10	Petra Energy Berhad	PENERGY
11	Sapura Energy Berhad	SKPETRO
12	Scomi Energy Services Berhad	SCOMIES
13	Sealink International Berhad	SEALINK
14	Shin Yang Shipping Corporation Berhad	SYSCORP
15	T7 Global Berhad	T7GLOBAL
16	TAS Offshore Berhad	TAS
17	Yinson Holdings Berhad	YINSON

All these variables were tested on the stochastic frontier production function. The basic SFA for panel data was developed by Battese and Coelli in (1995; 1992) as expressed in the equation (1). This model has two components, one estimating the random effect and another estimating the inefficiency. The Frontier 4.1 and Stata 14.0 software were utilized for this analysis.

$$Y_{it} = X_{it}(\beta) + V_{it} - U_{it} \qquad \text{Eq. (1)}$$

Where, Y_{it} is the logarithm of the production of the i^{th} firm in t^{th} time period, X_{it} is the vector of the input quantities of i^{th} firm in t^{th} time period, β is vector of the unknown parameter to be estimated, V_{it} represents the random errors $N(0, \sigma_v^2)$, which were independently distributed of the U_{it}, while U_{it} represents the non-negative random variables $(z_{it}\delta + W_{it})$ associated with the production technical inefficiency. Two models were tested in this study. The first model is the Cobb-Douglas production frontier using panel data and assuming a half normal distribution as shown in equation

(2). The second model was the Translog production frontier using panel data and assuming a truncated normal distribution as shown in equation (3). The model specifications are expressed below:

$$Ln(RV_{it}) = \beta_0 + \beta_1 Ln(VC_{it}) + \beta_2 Ln(FC_{it}) + \beta_3 Ln(TE_{it}) + (V_{it} - U_{it})$$

Eq. (2)

$$Ln(RV_{it}) = \beta_0 + \beta_1 Ln(VC_{it}) + \beta_2 Ln(FC_{it}) + \beta_3 Ln(TE_{it}) + \beta_4 Ln(VC)_{it}^2 + \beta_5 Ln(FC)_{it}^2 + \beta_6 Ln(TE)_{it}^2 + \beta_7 Ln(VC_{it})Ln(FC_{it}) + 8Ln(FC_{it})Ln(TE_{it}) + \beta_9 Ln(VC_{it})Ln(TE_{it}) + (V_{it} - U_{it})$$

Eq. (3)

$$i = 1, 2.3, \ldots\ldots, n$$

Where,

RV = Revenue

VC = Variable costs (sales of goods sold)

FC = Fixed costs (administrative and general)

TE = Total equity

Two hypothesis is developed. The first proposition with test the relationship between the variables under the Cobb Douglas production frontier model. The first null hypothesis as stated;

$$H_{o1} = There\ is\ no\ relationship\ between\ the\ variables\ in\ Cobb\ Douglas\ production\ frontier\ model$$

$$\beta_0 \neq \beta_2$$

Eq (4)

The second hypothesis is testing the relation between variables under the Translog production frontier model. The second null hypothesis to be tested will be;

$$H_{o2} = There\ is\ no\ relationship\ between\ the\ varibles\ in\ Translog\ production\ frontier\ model$$

$$\beta_0 \neq \beta_2$$

Eq (5)

3. RESULTS AND DISCUSSION:

Table 2 presents the ordinary least squares (OLS) estimates of the stochastic frontier analysis for both models. Based on the results, both models are significant at 1%. Thus, both nulls are rejected. There is a strong relationship between the variables. For the model 1, there is a strong positive relationship within the revenue and the variable costs and the equity. This was further proven in the model 2 where similar variables show a significant relationship. High R^2 and increased adjusted R^2 in this test shows that this model is reliable and perfectly fit. In this estimation, over 99% of the fractions between the variables can be explained and only less than 1% were uncounted as the error term. The Wald Chi2 indicates that the dependent variable is attributed by the change in the independent variables. For example, in the model 1, any changes in the variable cost leading to change in the revenue by 85%. Meanwhile, the changes in the total equity affect the revenue by 14%. The outcome from the second part of this study is shown in the Table 3 where the efficiencies of selected shipping companies for the year 2015-2016 were measured. In the Cobb-Douglas production frontier model, all shipping companies appear efficient. This has resulted from the assumption that all firms have similar or same production elasticity. This drawback of the Cobb-Douglas model being simplistic indicates the positive normalization of all companies being equally efficient. Hence this outcome was not considered for final analysis.

Table.2.: Ordinary Least Square estimations

Ln(RV)	**Model 1'**	**Model 2'**
Intercept	0.9353 (0.63)	16.7681'' (2.22)
Ln(FC)	-0.0086 (-0.16)	-0.8612 (-0.88)
Ln(VC)	0.8515+ (13.7)	-2.2433 (-1.63)
Ln(TE)	0.1423' (2.87)	2.2883 (3.34)
$Ln(FC)^2$		-0.0419 (-1.21)
$Ln(VC)^2$		0.2305— (2.53)
$Ln(TE)^2$		0.0878 (3.25)
Lm(FC)*Ln(VC)		0.0593 (0.85)
Ln(VC)*Ln(TE)		-0.3459+ (-4.31)
Ln(FC)*Ln(TE)		0.0586 0.85
R^2	0.9909	0.9937
Adj. R^2	0.99806	0.9914
Wald chi^2	1012.92	1709.69

Note: ' and ' represent the significance level at 1% and 5% respectively.

Table.3.: Malaysian shipping companies: Technical Efficiencies

Estimated Technical Efficiency			
	Model 1	Model 2	Ranking
ALAM	0.9999	0.8934	15
ARMADA	0.9999	0.9309	10
COMPLET	0.9999	0.9672	2
HARBOUR	0.9999	0.9744	1
HUBLINE	0.9999	0.9397	9
ICON	0.9999	0.9658	3
MAYBULK	0.9999	0.9099	12
MISC	0.9999	0.9590	4
PDZ	0.9999	0.8954	13
PENERGY	0.9999	0.8943	14
SCOMIES	0.9999	0.8917	16
SEALINK	0.9999	0.9498	7
SKPETRO	0.9999	0.7613	17
SYSCORP	0.9999	0.9518	5
T7GLOBAL	0.9999	0.9503	6
TAS	0.9999	0.9258	11
YINSON	0.9999	0.9433	8
Mean	0.9999	0.9238	

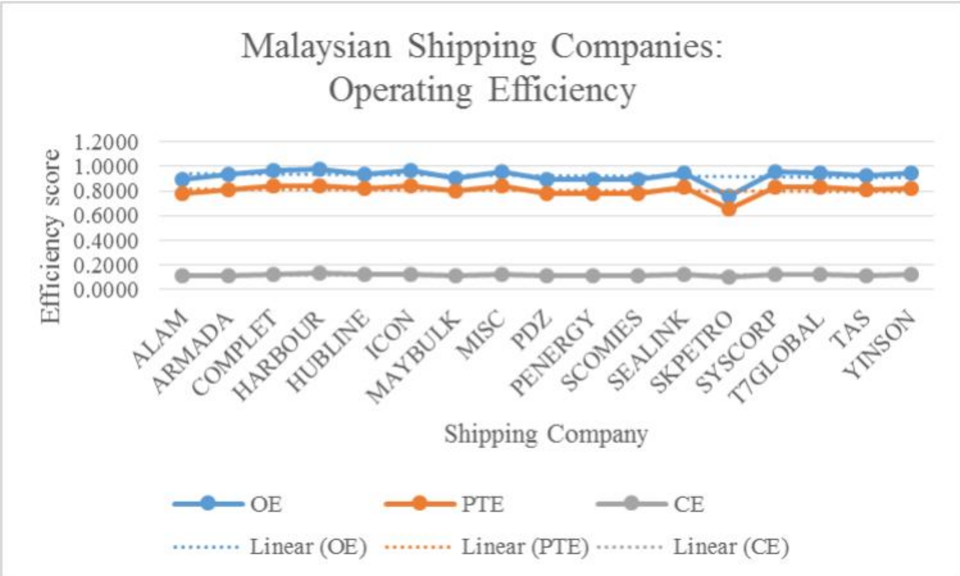
This drawback of Cobb-Douglas model is overcome by the generalization using the Translog Frontier function. The Translog production frontier generalizes the Cobb-Douglas function. The flexible functional form provides a second order estimation. From the study, the most three efficient firms were 'HARBOUR', 'COMPLET' and 'ICON' with an efficiency level of 97.44%, 96.72% and 96.58%, respectively. The least three efficient firms identified were 'ALAM', 'SCOMIES' and 'SKPETRO' with operating efficiencies at 89.34%, 89.17% and 76.13%, respectively.

The mean represents the shipping industry's efficiency as a whole in Malaysia, which worked to 92.39% for 2015-2016. Previous studies by Gutierrez (2014) to measure the efficiency of international container shipping lines in 2009 indicated that the shipping companies' efficiency at 74%. The results from this study indicates the performance of the companies have improved as compared to the earlier study by Gutierrez (2014).

Further, the results show that all shipping companies in Malaysia were operating above 89%, with the exception of 'SKPETRO' with an efficiency of 76.13%. This results are a good index and reason to investigate into the performance of the company.

Figure 1 exhibits the breakdown of the pure technical efficiency (PTE), cost efficiency (CE) and the overall efficiency (OE).

Figure.1.: Malaysian shipping companies: Comparison of Efficiencies



From Figure 1, it is seen that all the companies are operating at the same level of cost efficiency, which is about 11%. The cost efficiency can be taken as an indication of the optimization of the inputs by the management (Iliyasu and Mohamed, 2016) while a low score of pure technical efficiency would indicate failure of maximizing resource utilization (Sufian, 2007). Considering pure efficiencies, it is seen that all companies except 'SKPETRO' are equally efficient. The pure technical efficiency is the deciding factor for the overall efficiency. Fail in maximizing the use of the resources (equity) will lead to pure technical inefficiency. This is supported further by the hypothesis testing. The revenue is strongly dependent to the equity.

4. CONCLUSION

This study has analyzed the efficiency of the shipping companies in Malaysia using the stochastic frontier analysis approach. From the exercise, it is seen that the Malaysian shipping industry is performing well. The study had relied on inputs from the reports provided in public domain by the companies and reliability of the data was assumed. The scope for validation of the data was as such limited. Further, the reporting format of the companies being non-uniform, some of the fixed cost elements (*e.g.*, labour costs) could not be ascertained. Withstanding these limitations, the study has provided an index to assess a shipping company's performance for identifying areas requiring improvements. Further studies are recommended wherein other factors such as fixed costs (*e.g.*, insurance), unexpected costs (*e.g.*, port fines, pollution damages *etc.*) can be considered. Future studies may be undertaken which can enhance this study by analyzing the actual labour cost as the fixed cost.

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WI-FI ENABLED AUTONOMOUS SHIP MODEL TESTS FOR SHIP MOTION DYNAMICS AND SEAKEEPING ASSESSMENT

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Abstract

Captive model testing for ship motions, sea-keeping and dynamic effects has been always a challenge due to the large amount of channels of data, the need for continuous data communication for effect feedback control, and in the case of extended studies relating to fleets, the methodology for group fleet control. For the first time a solution is offered by designing a free self-propulsion, self, on-board controlled, surface ship model. The design incorporates Wi-Fi enabled robust communication and control and protocols for data storage, exchange, multiple device control and communication to fleet sister surface ships for fleet control. The design is described in this paper with details of implementation on a demonstration oceanographic research vessel. It illustrates the excellent communication between shore station computer and the on-board system on a wire-free model with robust control and exhibiting all the motion behavior and dynamic effects.

Keywords: Free-running, self-propulsion, WiFi enabled, PD controller, group control, autonomous ship model, surface vehicle, remotely operated.

1. INTRODUCTION:

The assessment of ship motion characteristics and dynamic effects require testing in simulated sea conditions in a large laboratory wave basin. The challenges of such a test are met with the development of a state-of-the art system based on Wi-Fi linked control and autonomous corrective action of the surface ship model. The development represents a first time national effort and reports a new methodology whereby the ship model on suitable scale has its own command and control on board without communication from the ground station computer. The system has two modes of operation; one is the autonomous mode and the other is the remotely controlled mode of operation. In the autonomous mode the on-board computer follows a prescribed path using closed loop feedback control in an externally disturbing environment. The controller executes all manoeuvres such as straight-line path, zig-zag or steady turn in the autonomous mode. In the remotely operated mode the base computer sends

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command to change the course in real time. In the autonomous mode the on-board controller provides necessary controlling actuator signals to the propulsion motor and steering motor. The on-board controller receives continuous heading data from the Motion Reference Unit (MRU) and sends continuous feedback corrective signals. The paper describes a new methodology for motion control and measurement and in the Wi-Fi environment extendable to autonomous group control. This in itself is a first time ever concept development. The present development describes surface ship model control. The methodology is demonstrated in the case of a candidate oceanographic research vessel to perform ship manoeuvre simulation in different wave condition and sea-states. High fidelity track and trajectory control of a high order with robust signal irrespective of distances in the laboratory environment has been achieved, demonstrated by full speed motion tests simulated in a restricted wave basin area (30m x 30m x 3m depth). The main components of the on-board system are (i) single-board programmable controller, (ii) data acquisition system which consists of the MRU and the portable data recorder (iii) BLDC motor with controller (iv) twin rudder system with stepper-motor controller and (v) the Wi-Fi based communication system. The controller integrates the functioning of all the above units and commands the ship based on a Proportional Derivative (PD) control algorithm. The surface ship model has power packs for all the power requirements. This system has the advantage of a number of protocols available, high bandwidth and making the set up independent of the operating system.

2. MODEL DESCRIPTION:

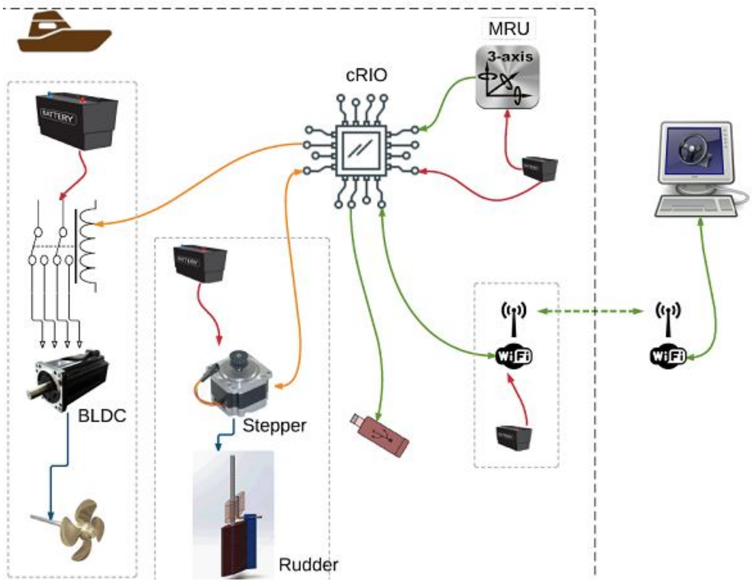
The objective of this effort is to design a self-supporting ship model for free running ship motion studies at design speed. The basic requirements in model preparation are geometric, kinematic and dynamic similarities. The model is built to a suitable geometric scale and floated to its correct draught and with mass distributions so as to conform to the natural oscillation characteristics of the prototype vessel. The candidate vessel has a scaled down displacement of approximately 125kg (Refer Fig.1). The model is built complete with all features of the superstructure and fitted with twin skewed five bladed propellers and twin Becker rudder system. The prime mover for the propulsion system is a 440W BLDC motor and the power is transmitted through single input twin output 1:1 counter-rotating gearbox. The rudder prime mover consists of a stepper motor with 1.26Nm holding torque.

Figure.1: Ship model in wave basin

3. ON-BOARD SYSTEM LAYOUT:

The main components of the on-board system (Refer Fig.2) are (i) single board programmable controller, (ii) data acquisition system which consists of the MRU and the portable data recorder (iii) Propulsion system which includes BLDC motor with controller (iv) twin rudder system with stepper The main components of the on-board system are (i) single board programmable controller,

Figure.2: System Layout

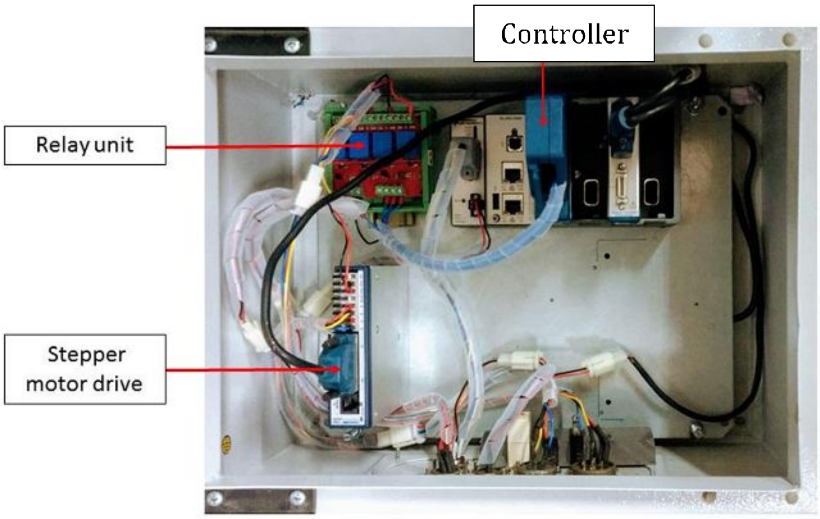


(ii) data acquisition system which consists of the MRU and the portable data recorder (iii) Propulsion system which includes BLDC motor with controller (iv) twin rudder system with stepper-motor controller and (v) the Wi-Fi based communication system. The controller integrates the functioning of all the above units and commands the ship based on a Proportional Derivative (PD) control algorithm. -motor controller and (v) the Wi-Fi based communication system. The controller integrates the functioning of all the above units and commands the ship based on a Proportional Derivative (PD) control algorithm.

3.1. Single Board Programmable Controller:

Single board programmable controller (Refer Fig.3) It is the heart of the entire control and command system and generates computed control signals for control of the main propulsion motor as well as the stepper motor to operate the twin rudders.

Figure.3: Controller and its sub-modules



Single board programmable controller also interfaces with the motion measurement and heading angle sensor unit *i.e.*, the Motion Reference Unit (MRU). A 4-channel 24V relay module is the interface between the propulsion motor and the Electronic Speed Controller (ESC) and also for the steering stepper motor and data acquisition.

3.2. Data Acquisition System:

The roll, pitch, heave and heading are measured electronically using a Motion Reference Unit (MRU). The MRU is placed at the center of gravity of loaded ship model. The MRU data is stored in a USB flash drive on board and at the same time data is transferred from the ship model to the base station through a wireless communication. The two-way data acquisition storage *i.e.* via USB and Wi-Fi gives data redundancy for safety. Secondly when data from multiple controlled platforms is required for group control, this is a minimum requirement.

3.3. Propulsion System:

The main propulsion system consists of a 440 watt BLDC motor, a pair of transmission shafts, 1:1 counter-rotating gearbox and twin skewed five bladed propellers (Refer Fig.4). The BLDC motor is interfaced with the main controller through an electronic motor drive. The drive gets the control signals from the main controller through a switching relay circuit. The RPM of the BLDC motor is controlled through the analog voltage generated by the controller. These analog voltage values can be changed using a virtual knob placed on a Graphical User Interface (GUI) window on the base station.

3.4. Twin Rudder Steering System:

The steering system consists of a twin rudder installed with a stepper motor with the help of timing belt and pulleys (Refer Fig.4). A stepper motor actuates the rudders with a holding torque capacity of 1.26N-m. The stepper motor is interfaced with the main controller through a stepper drive. The stepper motor operates in open loop as well as in closed loop. In open loop the rudder deflection commands are given by the user from the base station over wireless communication to carry out course correction in real time. In closed loop the system is set to follow the desired path where the steering control takes real time position data from the MRU and the control law generates the actuator signal to perform heading correction to keep the desired course. In the event of external disturbances only closed loop control will work.

Figure. 4: Propeller and Becker-rudder

3.5. Communication System

The on board system and the base station computer communicates over wireless link. This end-to-end communication uses client- server model, where the onboard system works as server, which share its resources to the base station, which acts as a client. This architecture provides the operating system independency and scalability of the whole setup. A wireless dual band router is used for the wireless communication. The router uses the latest high-speed wireless technology to bring lightning-fast Wi-Fi speeds of up to 433 Mbps on the 5 GHz frequency band and 300 Mbps on the 2.4 GHz frequency band.

3.6. Power:

All the components onboard are powered by three sets of lead acid batteries.

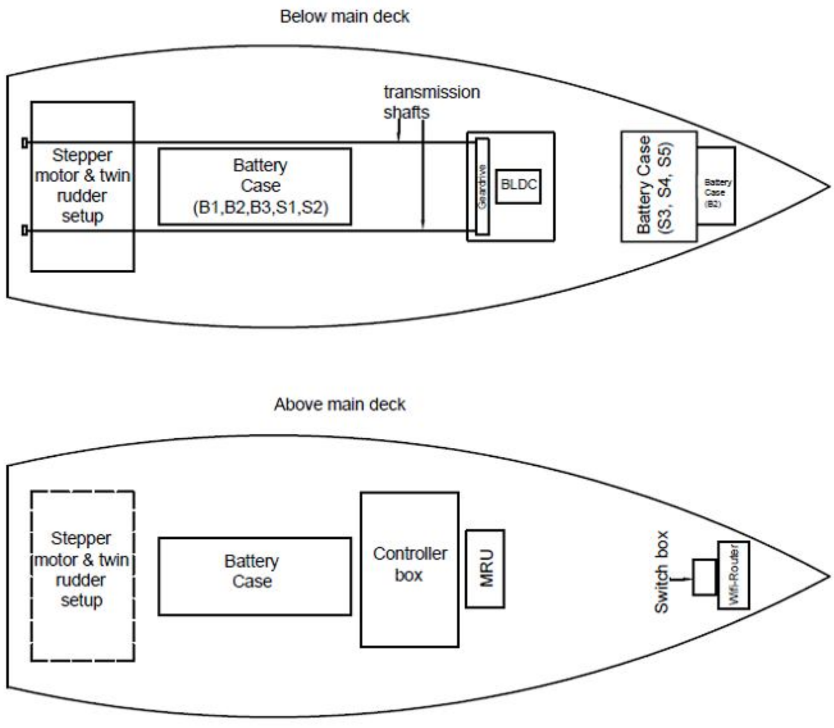
i. 12 Volt 26Ah batteries: A set of 4 batteries is connected in series to power the BLDC motor.

ii. 12 Volt 7Ah batteries: A set of 4 batteries is connected in series which powers the Stepper motor, Controller unit and MRU.

iii. 12 Volt 7Ah batteries: A single battery is used to power the Wi-Fi Router.

3.7. General Arrangement of Components:

Figure.5: Hardware arrangement in the model.



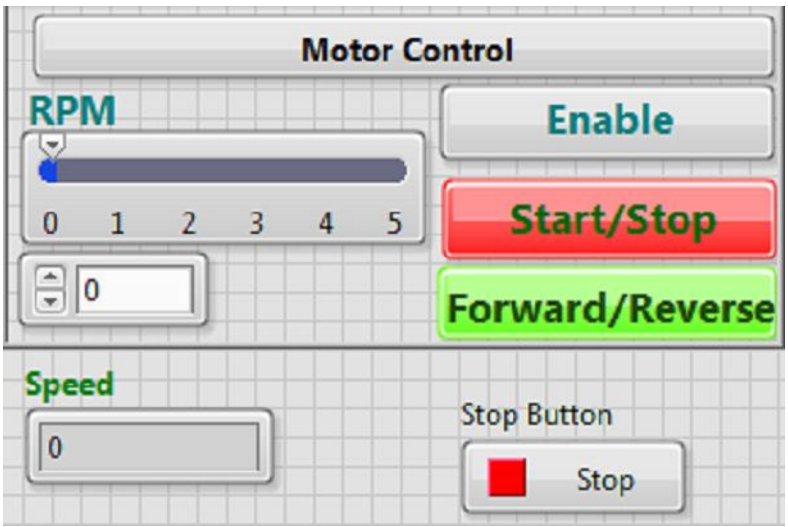
4. BASE STATION:

The base station includes a computer with LabVIEW software and a control algorithm with user interface.

A data flow programming language is used to develop a graphical user interface on the base station computer, which allows user to input the command to the on board system over wireless link. The BLDC drive receives logic signal generated from main controller, which controls the direction of rotation. On-chip ADC generates analog signal corresponding to the digital command generated by virtual knob on base station, to control the rpm of the main propulsion system. Under the motor control tab, different buttons are assigned to set different commands. Setting command in terms of heading angle and rotation velocity controls the stepper motor. The heading angle is converted to position signal, which further compares with the current position of the motor and allows stopping the motor if set position is achieved. The GUI provides control buttons to send command to the BLDC and stepper motor.

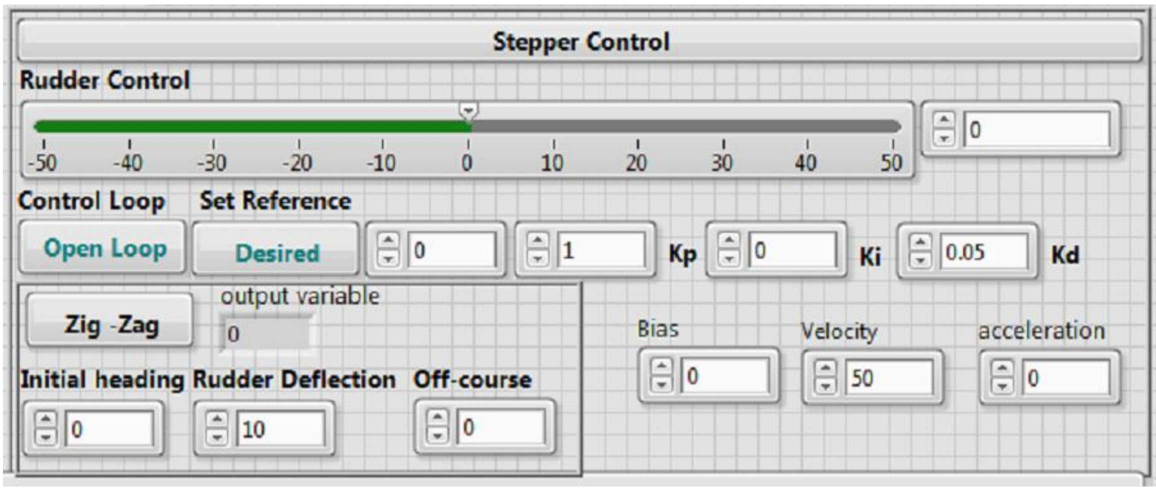
The BLDC Motor control panel is shown in the Fig. 6. The speed control is achieved by setting the rpm to a constant value by generating an analog signal from main controller. There are numerous virtual knobs to control the BLDC motor. The 'Start/Stop' knob is used to activate and de-activate the motor. The 'Forward/Reverse' knob is used to change the direction of rotation of motor shaft. 'RPM' knob helps to adjust the speed of BLDC motor.

Figure.6: BLDC control panel



Steering Control: To perform motion tests and station keeping it is essential to keep the model in desired course when subjected to external disturbances. The stepper motor control panel is shown in Fig. 7. This panel allows user to operate the steering mechanism. The 'Rudder Control' knob is used to input the required rudder angle. The stepper motor can be operated in Open loop or Closed loop with the help of 'Open Loop' knob (shown in Fig. 7). The 'Zig- Zag' knob is used to maneuver ship in a Zig-Zag pathway. GUI also allows user to store the data in USB flash drive and at base station for further analysis to quantify the ship motion in different wave conditions. The MRU data integrated with proportional controller is used to keep the model in a desired course while doing the straight-line test. The model is commanded to a desired heading and difference with MRU heading data goes to the proportional controller.

Figure.7: Stepper control panel



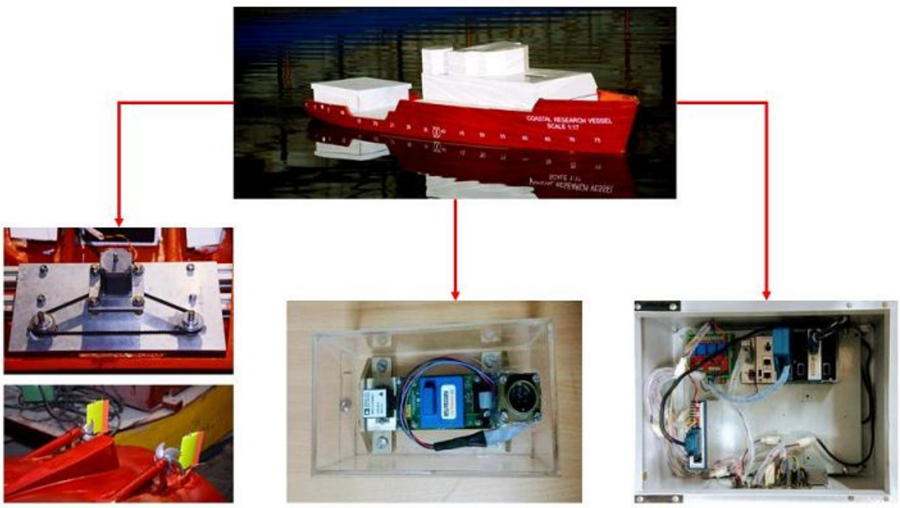
5. EXPERIMENTAL SETUP:

The experimental setup consists of three main components i) a twin Becker rudder steering system and propulsion system ii) MRU and power source and iii) main controller with its sub modules with a Wi-Fi router. The above-mentioned setup is implemented on a scale ship model of 2.5m length with superstructure as shown in Fig.8. All required ship motion tests to obtain the direct motion characteristics as well as dynamic effects are effectively simulated with this new design set up. The tests cover stationary condition regular and irregular wave responses in different directional waves – head sea, beam sea, oblique sea as well as at speed conditions. The robust autonomous control allows quick starting, stopping and manoeuvring and therefore full speed tests are also conducted effectively. The superior control characteristics make it possible to quantify speed loss in head sea condition, dynamic roll responses in beam sea condition at forward speed and seakeeping test in 3-D irregular sea-states from moderate to heavy sea conditions.

To minimize reflection effects the following procedure is adopted.

a. Model is set to full rpm and held restrained.
b. Waves are generated.
c. When waves reach the model, the model is released. Hence the waves head into undisturbed incident waves.
d. When the model approaches close to the wave maker, the propeller is stopped and reversed, effectively braking the model and making it stationary.

Figure.8: Experimental Setup



The model is equipped with a power source, propulsion and steering motor. When the waves are generated using the Multi-element wave maker (MEWM), the shore station computer generates the signal to activate the propulsion motor. An on-board computer with chassis sends signals for the control of the propulsion motor. Heading angle sensed by the MRU is fed back to the on-board computer and knowing the deviation as compared with the desired heading angle, appropriate correction signal is generated and sent to the appropriate device such as steering motor. The MRU data is transmitted over Wi-Fi to the ground station computer, where all post processing and data analysis are performed.

Figure.9: Ship in irregular moderate and heavy sea condition

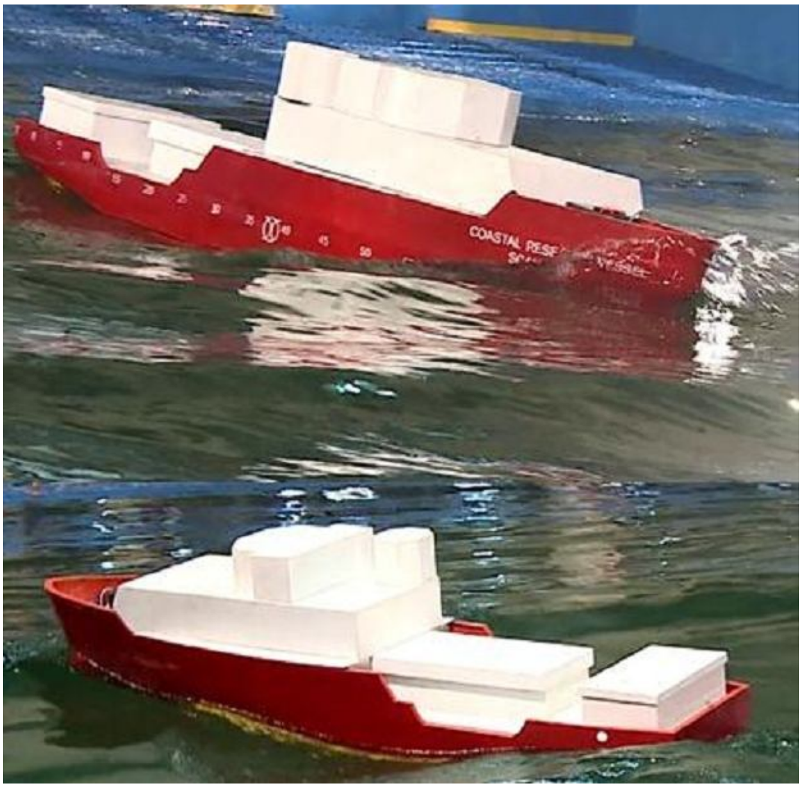
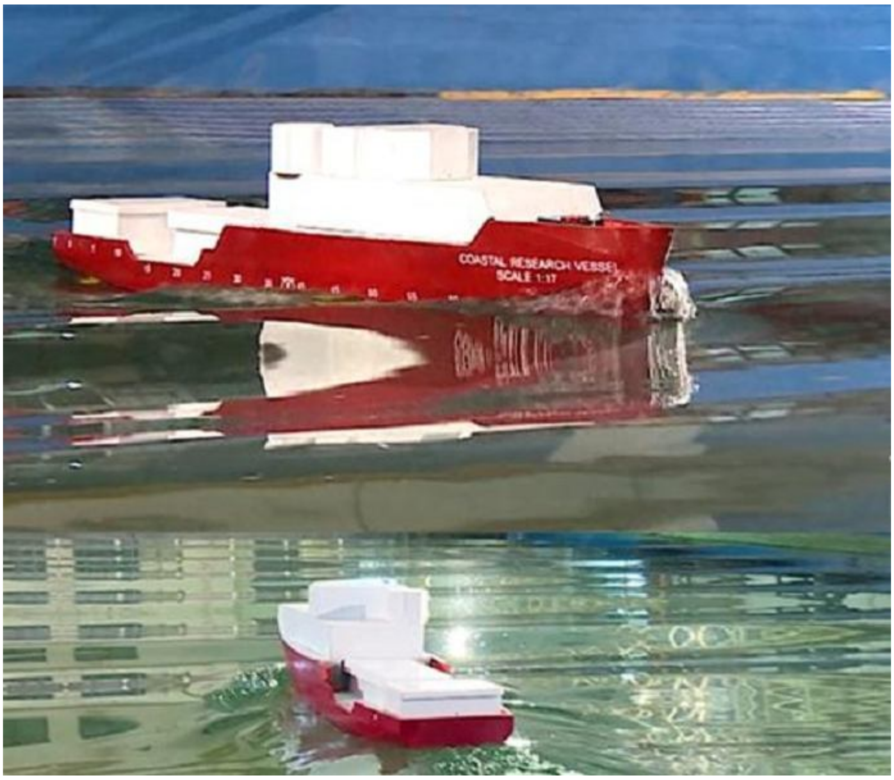


Figure.10: Dynamic effects in different sea conditions

Figure.11: Ship in head sea condition



Figurc.12: Bow emergence at speed in head sea condition

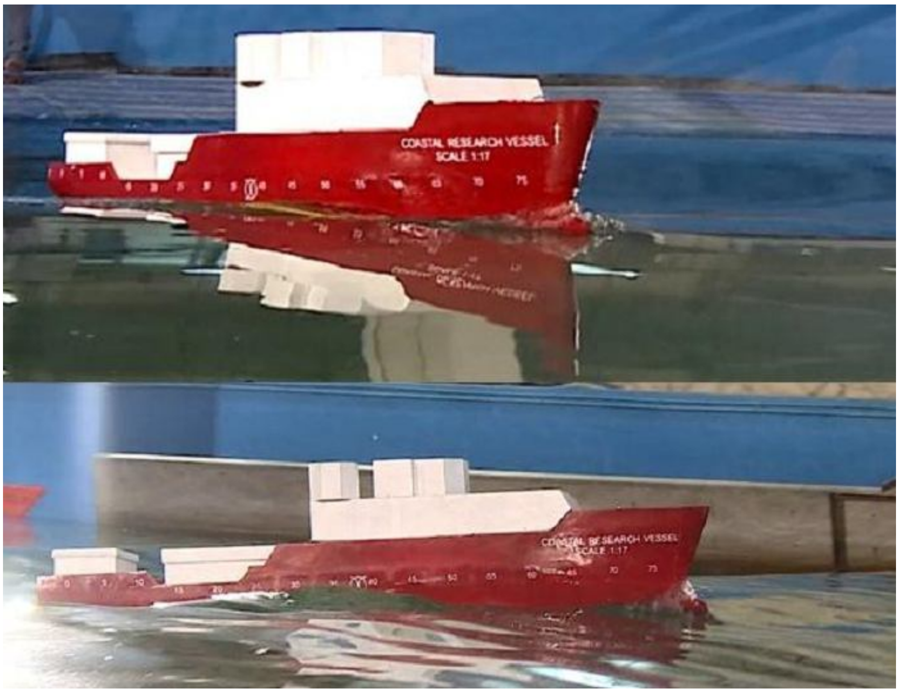


Figure.13: Steady turning manoeuvre in calm water

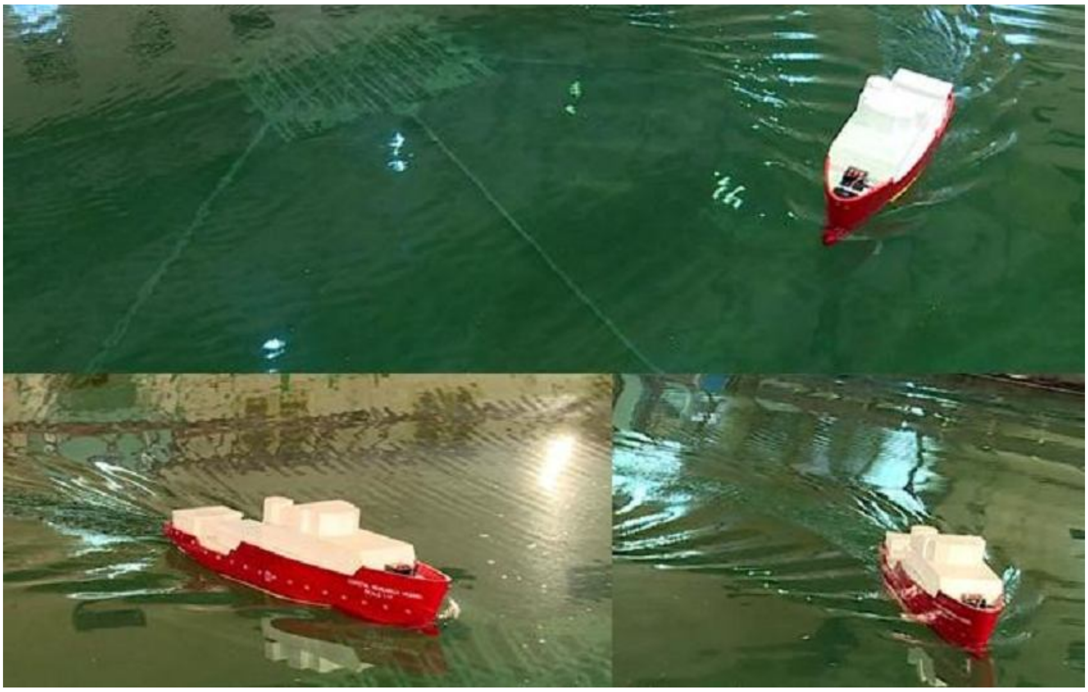
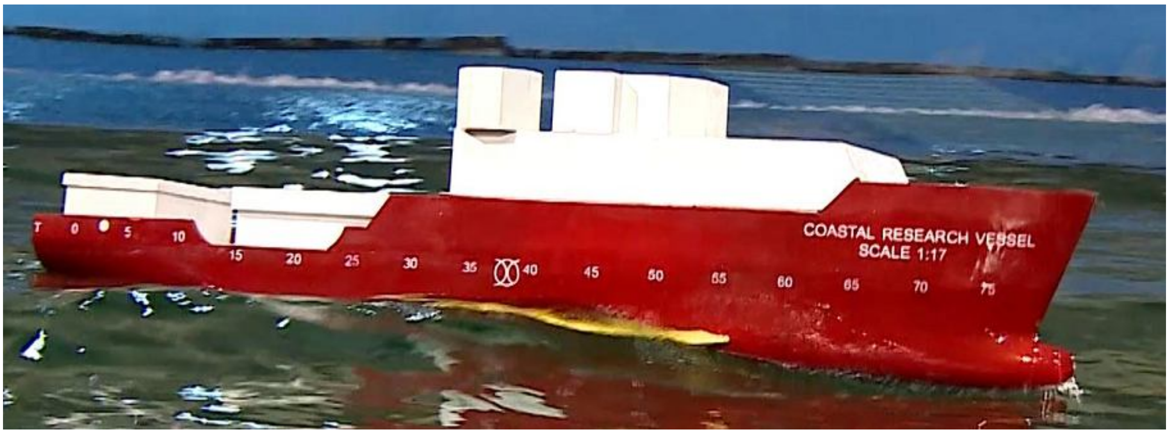


Figure.14: Bow emergence in head sea condition



6. CONCLUSION

This paper reports the development of a state-of-the-art full free self-propulsion maneuvering simulation system in a laboratory environment using robust, hi-fidelity wireless enabled Wi-Fi based communication protocol, extendable to autonomous group control of surface ships. The illustration photographs above amply demonstrate the versatility achieved in free model running. This is a national first time breakthrough development. The development makes captive controlled model testing obsolete and provides an exciting tool to perform simulations, which were hitherto cumbersome if not impossible. The development has been implemented in a significantly scaled down model, keeping in consideration generation of wave frequencies and amplitudes on model scale, and with the challenge of working with limited payload capacity of the model.

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A LITERATURE REVIEW ON CONCEPTS RELATED TO A 'DISTRIBUTED APPROACH TO SAFETY LEADERSHIP' AND ITS ROLE IN INSTILLING SAFETY CULTURE ON-BOARD MERCHANT SHIPS.

Delna Shroff[1]

Abstract

This conceptual paper explores 'distributed approach to leadership' and its role in instilling safety culture on-board merchant ships. The paper reviews literature pertaining to (a) recent developments in safety leadership and its observed safety outcomes, and, (b) how safety culture has been conceptualized over the years. With such underpinning knowledge it then intends to understand how leadership is distributed across different levels of the maritime system thus adopting a multi-level perspective to understanding the phenomenon of leadership and its role in safety culture using a qualitative approach.

Making a shift from the traditional approaches of understanding individual behaviours and personal characteristics where the unit of analysis is the individual to a more practice based perspective; the focus of the proposed research is on understanding patterns of interaction among leaders, followers and their situation with the organization as the unit of analysis. This is an attempt to explore the emerging patterns of distribution despite the existing vertical hierarchical structure on-board ships.

Keywords: Distributed Leadership, Safety Culture, Shipboard Safety

1. INTRODUCTION:

1.1 Adaptive Safety:

Safety as in emerging safety science is regarded as a dynamic and emerging property of the organization, including both the social and technological aspects of it. According to Reiman, Rollenhagen, Pietikainen and Heikkila (2015) the way safety is managed in a safety critical organization depends heavily on the beliefs and assumptions the management and personnel have concerning organizational behavior and safety. Safety critical organizations are complex adaptive systems which operate in high hazard industries such as aviation, oil and chemical industry organizations (Oedewald and Reiman, 2007) and seafaring (Smedley *et al.* 2013). A 'complex adaptive system' (CAS) is a collection of individual agents with freedom to act in ways that are not always predictable, and whose actions are interconnected so that one agent's actions change the context for other agents (Plsek and Greenhalgh, 2001). As the agents are interdependent on each other, relationships among agents can be considered to be the essence of such a system. The ship may be conceptualized a constituent unit of a safety

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critical organization where seafarers are subject to a combination of risk factors, for example, rough weather conditions, navigational equipment failure or accidents during routine maintenance or cargo work (as quoted in MacLachlan,2017, p.25). Almost all jobs at sea are safety critical; where decline in performance as a result of any cause, including psychosocial ones may put seafarers and their vessel at significant risk (Carter, 2005).

Table.1.: Key Features of Complex Adaptive Organizations

Key features of complex adaptive organizations.

Feature	Description
Non-linearity	Inputs are not necessarily proportional to outputs. Small changes in local conditions can have major effects on the overall system. Systems are (composed of) highly responsive and interconnected feedback loops that can reinforce or attenuate inputs. Moreover, all effects have several parallel contributing factors, instead of one or few causal chains as in linear systems. There are 'spiralling, iterative cycles of cause and effect' (Eoyang and Holladay, 2013, p. 63) instead of one root cause for each effect. On the other hand, complex adaptive systems also exhibit time delays between 'causes' and 'effects', which can lead to overshoots in interventions
Emergence	Emergence is a result of the pattern of connections among diverse agents. As a consequence of these interactions, new patterns of relationships, new system level properties and structures emerge. Emergent properties forming from the interaction of the agents cannot be traced back to those individual agents. Yet these patterns have an effect on the agents. The irreducible nature of emergent properties means that the properties of the whole are distinctly different from the properties of the parts. Examples of emergent properties include consciousness in a brain, norms or climate in a work group
Self-organization	*Self-organization* denotes the emergence of new structures, patterns and new forms of behaviour in the system as a consequence of agent interaction and connections (Prigogine and Stengers, 1984). Organizations are continually self-organizing through the processes of emergence and feedback. Thus, the phenomenon of self-organization is the collective (emergent and ever non-permanent) result of local yet non-linear interactions among agents. Complex adaptive systems (CAS) can thus self-organize into even greater states of complexity. Yet, self-organizing creates order in the system: in a CAS, order is a result of the properties of the system itself rather than an intentional achievement of an external controller
Far-from-equilibrium conditions	'Complex living systems … seek to exist in a balance between order and disorder, regularity and irregularity, stability and instability, equilibrium and non-equilibrium' (McMillan, 2008, p. 54). This is sometimes called the edge of chaos, the condition of high requisite variety and creativity. It is also the edge of order or the edge of stability. Being far from equilibrium also means that the system is in a continuous process of flux and change. Change in these systems is a natural tendency, not something initiated by an outside force. This capability also allows these systems to self-organize and adapt to changes in their environment
Coevolution	A complex adaptive system exists within its environment, but it is also part of that environment. Environmental changes require a change in the system. However, since the system is part of its environment, change in a system changes its environment, creating a process of mutual change and evolution. Further, the environment including the organization can be considered a CAS of its own, which also learns and adapts (see nested systems)
Nested systems	Complex adaptive systems are sometimes called 'systems within systems'. For example, organizations are composed of individuals who themselves are complex adaptive systems (and their brains can each be considered to be a CAS). These nested systems increase the diversity and uncertainty inherent in the 'parent system'
History-dependence	A CAS cannot be rewind back to its earlier form and state. Actions are thus irreversible, and the past helps to shape present behaviour. Agents learn from their previous experiences and change their actions accordingly. History dependence also means that solutions can seldom be copied from one system to another: what works in one organization cannot be replicated in another organization, since they each have their own distinct histories (McMillan, 2008, p. 112). It has also been pointed out that, in general, a CAS is highly sensitive to its initial conditions (the butterfly effect). However, Cilliers (1998) reminds us that such chaotic behaviour results from the non-linear interaction of a relatively small number of equations. In complex organizations, however, there are always a huge number of interacting components making the sensitivity to initial conditions of lesser importance than general history dependence

Note: Retrieved from Reiman, T., Rollenhagen, C., Pietikäinen, E., and Heikkilä, J. (2015). Principles of adaptive management in complex safety–critical organizations. *Safety science*, *71*, 80-92.

Table 1 summarizes the general features of organizations as complex adaptive systems. Self- organization and emergence signify two key concepts for understanding the dynamics of complex adaptive organizations. The phenomenon of self-organization necessitates that control in complex adaptive systems is always distributed rather than centralized. Moreover, leaders have an active role in creating emergence in complex systems. Adaptability emerges if there are constraints or boundaries that consistently operate on the choices and actions of the individuals in the system (Goldstein *et al.*, 2010, p.14; cf: Reiman *et al.*, 2015).

1.2 Safety Criticality and role of human factors in Shipping:

According to Roberts, Nielsen, Kotlowski and Jaremin (2014) shipping is one of the most dangerous industries in the world wherein between 2003–12, the fatal accident rate in British merchant shipping was 21 times that of the general British workforce, 4.7 times of that in the construction industry and 13 times of that in manufacturing. The nationalities of the deceased were British (31; 47%), other European (17), Asian (16), other and unknown (1 each). In the late 1990s, in the Indian merchant fleet, the number of deaths from accidents was 26. Refer to Table2 below.

Table.2.: Fatal accident rates among seafarers employed in merchant fleets worldwide, 1945–2012: studies ordered by fatal accident rate

Merchant fleet	Time period	No. of deaths from accidents	Fatal accident rate per 100 000 seafarer-years (95% CI)	Study reference
Sweden	1945–54	847	370 (346, 396)	[1]
Norway[a]	1957–64	1027	276 (259, 293)	[11]
Germany	1954–63	827	199 (186, 213)	[12]
Singapore	1986–95	253	180 (159, 204)	[2]
Greece	1990–94	339	162 (145, 180)	[9]
Hong Kong	1986–95	82	159 (126, 197)	[13]
UK	1945–54	2280	140 (134, 146)	[4]
Germany	1964–72	485	126 (113, 138)	[12]
Iceland[c]	1966–76	67	108 (84, 137)	[14]
Norway[b]	1990–94	156	102 (87, 119)	[9]
Poland	1985–94	49	100 (74, 132)	[15]
Germany	1974–76	[d]	92	[16]
Poland	1996–2005	52	84 (63, 110)	[10]
UK	1955–64	1571	80 (76, 84)	[4]
UK	1965–74	854	77 (72, 82)	[4]
Iceland[c]	1977–86	65	76 (59, 97)	[14]
UK	1975–82	512	75 (68, 81)	[4]
Denmark	1986–93	74	67 (53, 82)	[17,18]
Belgium	1990–94	3	63 (13, 184)	[9]
Japan[b]	1990–94	121	58 (48, 69)	[9]
Hong Kong	2000–05	44	56 (41, 75)	[10]
Denmark	1994–2001	64	55 (42, 70)	[18]
Iceland[c]	2001–05	14	54 (30, 91)	[19]
Poland	1960–69	48	51 (38, 68)	[20]
Isle of Man	2000–05	17	45 (26, 72)	[21]
Isle of Man	1988–99	16	43 (25, 70)	[21]
UK	1983–92	135	41 (17, 49)	[4]
The Netherlands	1990–94	15	39 (22, 64)	[9]
Germany	1990–94	35	39 (27, 54)	[9]
Poland	1970–79	57	39 (30, 51)	[20]
Sweden	1984–88	27	37 (24, 54)	[22]
Finland	1982–86	15	37 (21, 61)	[23]
Poland	2003–11	6	33 (12, 72)	Current study
Denmark	2002–09	31	27 (18, 38)	[18]
Canada	1996–2005	16	22 (13, 36)	[10]
France	1990–94	6	20 (7, 44)	[9]
Germany	2004–08	13	20 (10, 34)	[24]
India	1996–2005	26	18 (12, 26)	[10]
UK	2003–12	53	16 (11, 20)	Current study
Spain	1990–94	7	16 (6, 33)	[9]
UK	1993–2002	41	16 (10, 21)	[4]
Sweden	1996–2005	19	13 (8, 20)	[10]
Australia	1990–94	3	10 (2, 29)	[9]
Sweden	1990–94	9	10 (5, 19)	[9]

For improved comparability across studies, deaths from drowning of undetermined intent are included as accidental deaths.
[a]Includes deaths from suicide and homicide as well as accidents.
[b]Includes deaths from maritime disasters but not deaths from personal accidents.
[c]Includes deep sea fishermen as well as merchant seafarers.
[d]Not available.

Note: Retrieved from Roberts, S. E., Nielsen, D., Kotłowski, A., and Jaremin, B. (2014). Fatal accidents and injuries among merchant seafarers worldwide. *Occupational Medicine*, *64*(4), 259–266.

According to Bergheim, Nielsen, Mearns and Eid (2015) the shipping industry has a high potential for accidents. The nature of the working environment in the confines of a ship poses a number of challenges for seafarers; crew members are exposed to various hazards in handling dangerous machinery, conducting heavy lifting and material handling in connection with loading/unloading operations. Adverse weather conditions further increase the probability of accidents in such situations (Soares and Texeira, 2001; cf: Fenstad *et al.*, 2016)

Besides the environmental factors (related to the physical and technical environment), human factors play a crucial role in maritime accidents. A recent analytical study by Chauvin, Lardjane, Morel, Clostermann and Langard (2013) used a systemic approach to analyze the role of human and organizational factors in maritime accidents (collisions). The analysis revealed that most collisions are due to decision errors. At the leadership level, the analysis revealed frequent planning of inappropriate operations and non-compliance with the Safety Management System (SMS). In other words, instructions given by the 'leader' to the bridge team were inappropriate given the situational requirements of poor visibility or heavy traffic. They may have been in direct contradiction with the SMS; in that case constituting supervisory violations. They may reveal some difficulty for leaders to adapt their instructions to a changing situation. They may also reveal a poor safety culture. Chauvin *et al.*'s study (2013) also stressed the necessity to examine the master's decisions in critical conditions. These decisions not only concern bridge manning and vessel speed, misuse of instruments and attention deficit but also relate to the notion of Efficiency-Thoroughness-Trade Offs; though such principles have not yet been discussed in the maritime context (Schroder-Hinrichs,2010). These decisions also relate to the Safety Management System, the International Safety Management (ISM) Code and more commonly, to the company safety culture. In the light of the above, addressing both human and organizational factors can bring about a change in the way one looks at maritime accidents, that will help identify the right causes to be addressed and help improve maritime safety.

1.3 Maritime Leadership Today:

When it comes to leadership in the maritime industry, it can be considered at different levels. While the direct 'leader' of the crew is the ship's master, in the connected world of today the master himself receives orders and resources for supervisors located ashore. However, in accident reports unsafe supervision appears to be related to the master's choices. It is then crucial to differentiate between different leadership levels. Different leadership behaviors are effective in safety depending on the hierarchical position of the leader (Flin and Yule, 2004).

Traditional hierarchical views of leadership then are regarded as less useful in complex adaptive systems. Managing such systems is often said to require adaptive leadership, which can be seen as a complex dynamic process that emerges in the interactive spaces between people and ideas (Lichtenstein *et al.*, 2006).

While there is a need felt to examine the master's decisions, in the light of the IMO Casualty Investigation Code, the master is just a part of a wider system and it is the system that needs to be improved. Further, isolated discussions about single actors and single causes in a system, no matter how important they are, will not lead to sustainable system improvements. (Schroder-Hinrichs, Hollnagel, and Baldauf, 2012).

It would seem then that a single individual leader's behavior alone does not result in safe operations on board the ship; but it is the involvement of multiple leaders – ship owners, regulators, *etc.* that makes the intended output of systems and procedures a reality. Hence there is all the more a need to adopt a multi-level perspective and consider different levels of leadership and how it operates to affect maritime safety.

Another factor that influences the leader's behavior onboard is *efficiency demands* from ship operators; they can be major contributor to negative safety climate. In particular, compliance with procedures for safety is perceived as a challenge when ship-owners also want efficient operations. The compromising of safety to cut costs or to keep to a timetable is in essence procedure short-cutting, which is one important starting point for accidents. The balancing between efficiency and safety could vary between ship-owners and result in different consequences for the crews. It is reasonable to assume that the *efficiency–safety trade-off* could influence the amount of work pressure that the crews experience, how the management onboard prioritize safety, and the inclination of non-compliance to procedures. In other words, efficiency demands could have a negative impact on the safety climate on board the vessels (Fenstadand Kongsvik, 2016).

Fenstad *et al.*'s study (2016) thus revealed that shipboard safety can be influenced by internal crew-related factors, as well as external factors involving the ship owners and regulatory authorities. Simultaneous involvement of various levels of the maritime system (crews, ship-owners, regulators) can be effective for safety improvements.

1.4 Summary:

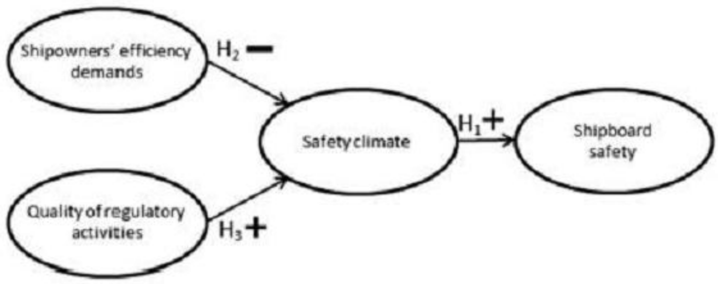
As evident from the above, seafarers are subjected to multiple risk factors when working aboard the ship. They operate in hazardous working conditions, which pose a threat to their lives as well as threat to the safety of the vessel. Both human and organizational factors play a crucial role in maritime accidents. Often the leader's actions / behaviors are under scrutiny in most accident investigations. However, these very decisions and behaviors also relate to various other factors – efficiency thoroughness tradeoffs, regulations, organizational influences and thereby affect the safety culture. External actors (both ship owners, regulators) also have the power to influence working conditions onboard. It is time to move away from the unitary view of the leader onboard the ship (the master) and explore the construct of leadership holistically. In other words, there is a need to explore how leadership is distributed across different levels of the maritime system and its influence on safety culture taking the organization as the unit of analysis.

2. SAFETY CONCEPTS:

In shipping operations, the time and the measures taken to ensure safety operations have to be balanced with economic considerations in the commercial operation of a ship. Hollnagel (2009) refers to these as *trade-offs between efficiency and thoroughness.* The dilemma facing *sharp end operators (i.e.* people who are directly involved in a specific activity and are responsible for the hands-on control of what is going on) is that more often work demands of them to be efficient rather than thorough, except in cases where the outcome shows that they should have been thorough rather than efficient. Making these efficiency-thoroughness trade-offs is routinely essential for the efficacy of overall performance, but can also lead to accidents. (Schroder-Hinrichs *et al.*, 2012). The model in Figure 1 below also illustrates an expected relationship between the ship operators' efficiency demands and the safety climate. Fenstad *et al* (2016) in their study revealed that higher demands for efficiency from the ship operator were associated with more negative levels of safety climate on board.

Fierce competition is one of the several hallmarks of a modern market economy in which the ships operate today and decision-makers constantly need to make short-term decisions in order to fulfil demands related to profitability. These decisions are usually made to optimize performance in one part of a system without reference to how they collectively will influence long-term goals regarding safety (Rasmussen 1997).

Figure.1.: Theoretical Model and Expected Relation Between Factors



Reference: Fenstad, J., Ø., and Kongsvik, T. (2016). Shipboard safety: exploring organizational and regulatory factors. *Maritime Policy and Management*, *43*(5), 552–568. https://doi.org/10.1080/03088839.2016.1154993

Prominent scholars like Rasmussen (1997) and Hollnagel (2009) point to the possible conflicting driving factors inherent in efficiency and safety. Cost reductions that are introduced to enable to be economically viable in a competitive environment (*e.g.* reductions in maintenance budgets), might reduce safety margins in the longer run. Also, efficiency demands might introduce time pressure that could go at the expense of thoroughness (Hollnagel 2009). In 2016 Fenstad *et al* conducted a survey which focused on concrete efficiency measures that compromised safety. (see Table 3 below)

Table.3.: Descriptive statistics for variables used in the study—mean and standard deviation on a scale from 1 ('totally disagree') to 5 ('totally agree') (V1–V18) and from 1 ('very bad') to 10 ('very good') (V19). N = 244.

Variable	Mean	SD
V1: My captain appreciates that the employees take up safety issues	4.26	1.13
V2: I am sure to get support from my captain if I prioritize safety in all situations	4.31	1.13
V3: My captain sets a good example regarding attention to safety	4.18	1.14
V4: The shipowner compromises on safety to cut costs	2.20	1.23
V5: The shipowner compromises on safety in order to keep to the timetable	2.09	1.25
V6: Owing to the shipowners' demand for efficiency, we sometimes have to violate procedures	2.94	1.44
V7: Following the safety procedures is not rewarded in the shipping company where I work	2.94	1.42
V8: On my vessel, we strive to achieve zero harm to people, prevent accidents, and reduce negative effects on the environment	4.56	0.85
V9: Safety is well taken care of on my vessel	4.46	0.96
V10: Captain's judgment of when it is safe to conduct a voyage is respected by the shipowner	4.45	0.96
V11: I find it difficult to know which procedures are applicable	2.09	1.20
V12: The procedures are difficult to understand/vaguely formulated	2.13	1.19
V13: The procedures on board are too general and are not adapted to the vessel I work on	2.23	1.24
V14: We have sufficient time to train employees on board	3.80	1.22
V15: New employees receive sufficient training to work safely	3.91	1.18
V16: We always perform the emergency exercises which we are ordered to perform	4.09	1.05
V17: The Norwegian Maritime Authority's inspection of seafarers' working and living conditions is good	3.19	1.21
V18: The Norwegian Maritime Authority does a good job of motivating the industry to take responsibility for safety themselves	3.30	1.09
V19: Overall, how would you evaluate safety in your work situation?	8.16	1.48

Note: Retrieved from Fenstad, J., Ø., and Kongsvik, T. (2016). Shipboard safety: exploring organizational and regulatory factors. *Maritime Policy and Management*, *43*(5), 552–568. https://doi.org/10.1080/03088839.2016.1154993

A number of very serious accidents occurring in the 80's was shown to be a result of human errors, with management faults also identified as contributing factors. Thus the need was felt for a safety management system, leading to the development and implementation of the International Safety Management Code (ISM) in 1998. The American Bureau of Shipping (ABS, 2012) states that "the goal of the ISM Code, and of Safety Management Systems (SMS's) is the attainment of peak safety performance (i.e., no operational incidents, no personal injuries, and no harm to the environment), but the maritime industry is still some way from achieving this goal. These tools undoubtedly aid compliance with regulation, but they do not necessarily improve safety culture". Importantly, they also point out that "there is a general recognition in the industry that encouraging safe working practices does not require more rules, regulations, and procedures. Instead, the industry needs a better understanding of social and organizational factors that foster professionalism in the seafarer in routine and emergency situations". It is in this context that the relevance of an effective safety culture becomes the key to improving occupational safety on board ships. The promotion of such a preventative culture is very much a leadership matter (International Labour Office, 2003). For many years' leadership as a construct was examined at the individual level of analysis, but rarely at the group or organizational level.

The challenge for the researcher is to explore the emerging patterns of distribution despite the existing hierarchical structure on-board ships. How individuals and groups act and collaborate during day to day activities play an important role in shipboard safety.

3. LEADERSHIP:

Before exploring leadership as a construct and understanding it more holistically it is important to understand its theoretical underpinnings:

At the beginning of the 20th century, during the emergence of psychology, there was a large amount of research on leadership and a variety of theories were proposed. Leadership was also influenced by sociology, management, history political science, social anthropology, economics and studies of religion and ethics. As such it has never rested on one academic principle. In a recent article Jon Aarum Andersen (2016), identified two broad groups of leadership theories – organizational effectiveness theories and process descriptive theories. Refer to Table 4 below.

One question that's worth considering is whether the purpose of any research is to explain or to understand the emergence of, existence of, or consequences of leadership? Taking elements from both the groups of theories, the purpose of the proposed research is to provide a holistic understanding of leadership practice. Taking from the organizational effectiveness theories, the '*ship*' may be considered a private enterprise / organization. The 'ship master' (the formal leader) in this research will be referred to as a '*manager'*. A formal leader (manager) is a person who is responsible both for the subordinates and for the results.

Table.4.: Main differences between 'organizational effectiveness theories' and 'process description theories'

Organisational effectiveness theories		Process description theories
Organisations are contrived by owners. The owners' goals are the organisations' goals. Goal-attainment is the purpose of the organisation.	*Organisational concept*	Social, political or religious movements and organisations. Stakeholders and leaders. The goals are the goals of the leader or common goals.
Leaders, subordinates and tasks are the properties that must exist for *managerial* leadership to exist. Leaders and subordinates are employed by the organisation. The manager is the owners' extended arm.	*Leadership concept*	Leader and followers are the properties that must exist for *political* leadership to exist (no tasks). Leaders and followers are not employed. The manager is performing a balancing act.
The purpose is to explain causal relationships between leadership behaviour and organisational effectiveness.	*Research focus*	The purpose is to describe and understand relationships and perceptions of leadership.
Leadership research addresses many different study objects, thus there is no best method. The methods are characterised by strict definitions and quantitative measurements and the use of statistical analyses.	*Methods*	Few study objects are researched. A preference for methods like participant observation (ethnographic method), case studies, metaphors and interviews.
Likert (1979): data from more than 20,000 managers on all levels and responses from more than 200,000 subordinates in 350 organisations. Smith et al. (2011): data from 7,701 managers from 56 nations. Center for Creative Leadership (2012): data from 17,300 managers in 951 organisations in 58 countries.	*Empirical data (examples)*	Mintzberg (1973): data from 5 managers. Smircich and Morgan (1982): data collected during 6 weeks by observing and interviewing 10 top managers. Kotter (1986): interviews with 15 managers. Alvesson and Sveningsson (2003): 40 interviews with managers plus observations of management team meetings.

Note: Retrieved from Andersen, J. A. (2016). "Leadership scholarship_ all bridges have been burned." *Leadership and the Humanities*, *4*(2), 108–125.

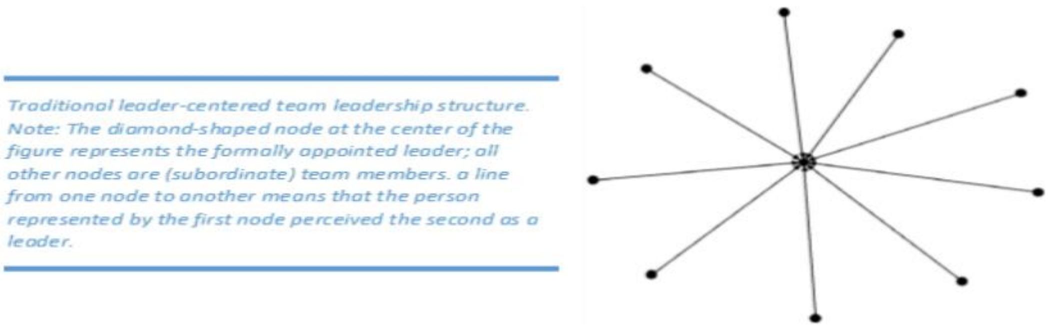
Leadership is a process while management is a position (Hughes at al. 1999; cf: Andersen, 2016).Keeping the three elements - manager, subordinates and the taskintact, while the focus of the proposed research is not so much on causal explanations between leadership behaviors and organizational effectiveness, it is more about understanding the internal perspective of the leaders themselves, perceptions of leadership, patterns of interaction, and the dynamic processes at work within the organization; and how it affects and is in turn affected by other processes or organizational systems.

3.1 Understanding Leadership?

According to Pearce and Conger (2003) leadership is *"a dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals or both. This influence process often involves peer, or lateral, influence and at other times involves upward or downward hierarchical influence"* (as quoted in Pearce and Conger, 2002, p. 1). It is described as an activity, process or phenomenon that occurs in groups rather than a skill possessed or task executed by a single leader. (Barnett and Weidenfeller, 2016)

Yammarino, Salas, Serban, Shirreffs and Shuffler (2012) in their study provided a view of leadership as a collective phenomenon, in both formal and informal relationships, that cannot be viewed as static but rather as fluid and dynamic in nature depending on organizational and environmental demands and requirements. A lot of studies on leadership in the past have looked at traditional top-down models taking a leader focused view. (See Fig. 2)

Figure.2.: Traditional leader-centered team leadership structure.



Reference: Mehra, A., Smith, B. R., Dixon, A. L., and Robertson, B. (2006). Distributed leadership in teams: The network of leadership perceptions and team performance. *The Leadership Quarterly*, *17*(3), 232–245. https://doi.org/10.1016/j.leaqua.2006.02.003

In the western economies, in particular, there had been a focus on individualism (*e.g.* Bauman 2001; cf: Thorpe *et al.*, 2011). The unit of analysis in most of the studies in the past has been the *'individual'*. (Yammarino *et al.*, 2012). This individualistic culture and non-systemic worldview limits one's understanding on leadership (Senge, 2002) Studies of safety leadership in the past have used quantitative methods viz. self-report measures. (Pilbeam, Doherty, Davidson and Denyer, 2016)

In 2009, Avolio, Walumba and Weber examined recent theoretical and empirical developments in leadership literature. They found there was a shift from the transactional models (based on how leaders and followers exchanged with each other) to models that might enhance transactional leadership and were termed as charismatic, inspirational, transformational and visionary or what Bryman in 1992 termed as the new-genre leadership theories. While charismatic /transformational leadership is positively associated with leadership effectiveness and other organizational outcomes, these new- genre models primarily adopted a unitary view of the leader which serves to limit one's understanding of leadership. Studies largely utilized survey based designs, with research lacking at the organizational level.

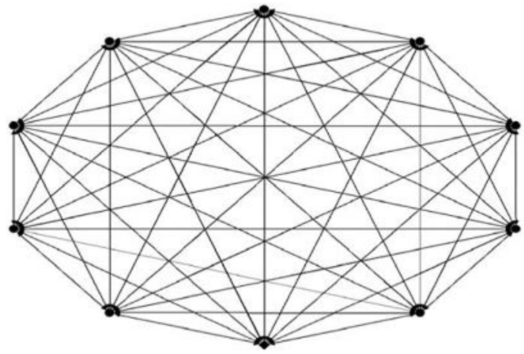
Similarly, the Leader –Member Exchange (LMX) Theory that has focused on the relationship between the leader and the follower, has again utilized LMX scales ('developed on an adhoc, evolutionary basis, without the presentation of any clear logic or theory justifying the changes which were made' (Schriesheim *et al.*, 1999, p.100; cf: Avolio *et al.*, 2009). Further, most of the LMX literature is based on correlation designs; a lack of research on more objective measures of performance (Erdogan and Liden, 2002). Research was carried out at the dyadic level with dearth of research at the group level. (Hogg *et al.*, 2004) The studies failed to take account of the context, as noted in a recent meta-analysis of leadership styles as antecedents of safety behaviors (Clarke, 2013).

In a more recent literature review by Pilbeam *et al* in 2016 on safety leadership practices and observed safety outcomes, similar findings were noted. They found that out of 25 empirical studies, a majority have measured leadership using generic scales – MLQ and LMX, providing a quantitative assessment of the leader's behavior. The general concept of transformational – transactional leadership, being along a continuum, had been critiqued both conceptually and methodically (van Kippenberg and Sitkin, 2013; cf: Pilbeam *et al.*, 2016), measuring them using tools that did not correspond to the dimensions specified by theory, accounting for contradictory finding between studies.

However, both reviews (Avolio *et al.*, 2009 and Pilbeam *et al.*, 2016) have highlighted important trends in leadership research: Research focus has shifted to adopting a more holistic view of leadership; a shift from traditional approaches of understanding individual behaviors and personal characteristics to a more relational and practice-based perspective, it being viewed as a complex and emergent dynamic, increasingly being distributed and shared in organizations. The follower is becoming an integral part of the leadership dynamic system. Particularly, leadership roles are dispersed across organizational levels over time (See Fig. 3)

Figure. 3.: Distributed team leadership structure.

Distributed team leadership structure. Note: The diamond-shaped node (at 6 o'clock) represents the formally appointed team leader; all other nodes are (subordinate) team members. A line from one node to



Reference: Mehra, A., Smith, B. R., Dixon, A. L., and Robertson, B. (2006). Distributed leadership in teams: The network of leadership perceptions and team performance. *The Leadership Quarterly*, *17*(3), 232–245. https://doi.org/10.1016/j.leaqua.2006.02.003

In 2007, Carson, Tesluk and Marrone attempted a more complete conceptualization of the emergent and relational nature of the shared leadership construct; the findings indicated that an *internal team environment and coaching by an external leader* are positively related to the level of shared leadership in a team. However, the approach they used (social network approach) neither specified the meaning of leadership nor primed specific behaviors for respondents. The study nevertheless highlighted an important area to be explored:

Shared leadership can occur in a team with a designated formal leader or in a team without one; implying both vertical and shared leadership should be studied in combination (Kozlowski and Bell, 2003)

4. DEVELOPMENT OF DISTRIBUTED LEADERSHIP:

Distributed leadership literature emerged primarily within the educational sector; it was in 2002 that Peter Gronn integrated team-based shared leadership and distributed leadership, now quoted widely in managerial team based shared leadership literature. Most of the literature on distributed leadership is less theoretically diverse than team based literature and is centered on the conceptual model developed by Spillane, Halverson and Diamond (2004) using longitudinal designs. The unit of analysis in Spillane's study was the school rather than the team.

Leadership practice centers not only on what people do but how and why they do it. It is viewed as a product of the interactions of school leaders, followers and their situation. Leaders have interactions with others as well as with aspects of the situation – tools, routines and structures. These routines, tools and structures define leadership practice; the situation both enables and constrains leadership practice. These interactions are critical in understanding leadership practice and the situation defines leadership practice in interaction with leaders and followers. It is worthwhile to explore emerging structural patterns of distributed leadership; in other words, how leadership is distributed in a safety-critical context how leadership is distributed in contexts other than school.

4.1 Three forms of Distributed leadership

1. Collaborated distribution involves leadership practice stretched over the work of two or more individuals working in the same space and time.
2. Collective distribution is similar to collaborated except that individuals are working separately but interdependently.
3. Co-ordinated distribution refers to leadership practice that has to be performed in sequence.

Peter Gronn (2002) construes distributed leadership as *concretive action* implying a more holistic view in which leadership is demonstrated through synergies achieved by joint action. Later in 2009, Peter Gronn proposed a revised unit of analysis in leadership referred to as '*configuration*' as an aggregated understanding does not explain different levels of leadership and does not account for qualitative differences among leadership units.

Despite the reaction to individualistic approaches to leadership, solo leaders continue to figure prominently in accounts that purport to be distributed and that distributed leadership supporters have not adequately clarified the role and contribution of individuals as continuing sources of organizational influence within a distributed framework. Gronn feels that a term such as hybrid would be a more accurate description of situational practice that includes both individual leaders and holistic leadership units working in tandem than distributed, because the notion of hybrid signals a mixture of types. This term seems to be a more advantageous means of characterizing situations. Secondly the unit of analysis should be broadened slightly from distributed to leadership configuration.

A key challenge for the researcher then is to try to determine the range of hybrid patterns or configurations of practice and to delineate them despite the existing vertical hierarchical structure on-board ships. For example, in 2006 in a study, Mehra, Smith, Dixon and Robertson examined distributed leadership in teams and found that certain kinds of decentralized leadership structures are associated with better performance than others i.e. a distributed coordinated structure was associated with higher team performance than traditional leader-centered leadership networks and distributed – fragmented leadership networks. It also matters whether or not the leaders see each other as leaders.

In work groups with a formally appointed leader, informal leaders can emerge for a variety of reasons; however, when formal and emergent leaders do not recognize one another's leadership, the group can literally be torn apart. By contrast when formal and emergent leaders recognize one another as leaders, they should be better able to synchronize their leadership efforts so that decision making and action are more effectively channeled within the group. The kind of distributed and coordinated leadership that Mehra *et al* are describing is similar to what Gronn has described as 'conjoint agency' in which few individuals emerge as leaders within a group and are able to synchronize their actions through reciprocal influence. The study suggests that it is important to recognize and model different structural patterns of distributed leadership within teams rather than merely assessing the extent to which distributed leadership is present. Different forms of distributed leadership can have different consequences for team performance.

Frameworks for leadership activity are scarce; new conceptual frameworks need to be developed, 'frameworks built out of concepts that speak directly to practice (Pickering 1992:7; cf: Spillane *et al.*, 2004)

How individuals and groups act and collaborate during day to day activities play an important role in shipboard safety. Distributed leadership is a product of the interactions of leaders, followers and their situation. Practice takes shape in the interactions of leaders, followers and their situation. It is these interactions that are so critical that it is worthwhile to understand the dynamics of leadership practice. Shipboard safety is influenced by the way individuals and groups act and collaborate during day to day activities.

5. SAFETY CULTURE:

According to an extensive review by Guldenmund in 2000, a theoretical model of safety culture marks the start of any scientific enterprise. No review of safety climate or safety culture is complete without a summary of those aspects of the discussion on organizational culture and climate. Looking at high risk industries, where safety culture is the dominant characteristic of corporate culture, the dominant culture and the prevailing context will influence its development and vice versa as both interrelate and reinforce each other (Williams, A. *et al.*, 1993). Culture affects and is in turn affected by other processes or organizational systems (Cooper, 2002). The idea of a safety culture is predated by extensive research into organizational culture and climate, where culture embodies values, beliefs and underlying assumptions (Gonzalez- Roma *et al.*, 1999, cf: Flin, Mearns, O'Connor and Bryden (2000))

Research on organizational climate developed primarily from a social psychological framework, while culture is rooted firmly in anthropology (Glick 1983, as quoted in Harris, 2017). Evidently both disciplines contribute different paradigms; the former a more quantitative approach while the latter uses mainly qualitative techniques to study its research objects. Research on culture is much more focused on the dynamic processes at work in an organizational culture, continuously creating and shaping it.
Taking from the above, the way both concepts are operationalized, organizational climate is commonly conceived of as a distinct configuration with limited dimensionality surveyed through self-administered questionnaires. Organizational

culture is often determined phenomenological, *i.e.* through observations and interviews, through trial and error, mutual comparison and the like. Such measures are regarded as qualitative and thus difficult to quantify. (Guldenmund, 2000). Taking from anthropology, the term 'safety culture' will be used in the proposed research, distinct from the concept of 'safety climate' as the focus is on the dynamic processes at work within the organization; and how it affects and is in turn affected by other processes or organizational systems.

Many definitions of safety culture have been attempted in the past; in many definitions, safety culture is viewed as an emergent property (set of values, beliefs and attitudes) reflecting an "interpretative view' favored by academics and social scientists. Other definitions reflect a functionalist view that culture has a predetermined function (implementing controls and policies to improve safety) favored by managers and practitioners (Cooper, 2002).

A definition that incorporates both views is the one by the U.K. Health and Safety Commission in 1993. They defined safety culture as "the product of individual and group values, attitudes, competencies and patterns of behavior that determine the commitment to and the style and proficiency of an organization's safety and health programs. Organizations with a positive safety culture are characterized by communications founded on mutual trust, shared perceptions of the importance of safety and confidence in the efficacy of preventive measures." (Cooper 2002). The "product of values, attitudes, competencies, patterns of behavior" element of the definition reflects the interpretative view, while the functionalist view is reflected by its stated purpose – it determines people's commitment to safety, and the style and proficiency of safety programs (Cooper, 2002). It is apparent that over the last 25 years of research conducted on safety climate, there is no universal consensus about a key set of underlying factors for the concept of safety climate (Coyle, Sleeman, and Adams, 1995).

Even though there is no full consensus, Flin, Mearns, O'Connor and Bryden *et al.* (2000) point to six organizational themes that are often addressed in safety climate studies: (1) management; (2) safety systems; (3) risk; (4) work pressure; (5) competence; and (6) rules/procedures.

In the shipping industry, a literature searches (Bibsys, 2004; ISI, 2002; cf: Havold, 2005) indicates that no such research has been done in shipping. Havold (2000) found that no safety climate / culture research has been reported in the maritime sector and a more recent SINTEF report (2003) confirmed Havold's conclusions. The study revealed that management attitudes / influence on safety is a factor appearing most frequently in papers dealing with safety climate/culture. Flin *et al* (2000) report that senior management as a factor influencing safety appears in 13 out of 18 reviewed papers. Thus the factor structure used to measure safety climate/culture in a shipping company seemed to confirm factors identified in other studies. While one may agree that there is some consensus regarding the dominant themes, particularly 'management attitudes' or 'management commitment', it is evident from the above that most of the studies have relied on self-reported data. Guldenmund's review (2007) shows that majority of the studies on safety climate rely on questionnaires. Furthermore, Reichers and Schneider (1990) describe the mere reliance on surveys as an ''insufficient source of information about the inner workings of an organization'' (p. 27, cf: Fruhen, Mearns, Flin and Kirwan, 2013). This suggests an investigation into the deeper, often unconscious aspect of organizational culture might require research methods that more directly relate to such inner workings. (Fruhen *et al.*, 2013).

A lot of prior research has found that safety climate and cultures are related to better safety performance indicated by criterion measures such as occupational accidents, safety compliance, injuries, or safety participation, higher safety motivation (Griffin and Neal, 2000) and lower underreporting rates of injuries (Probst *et al.*, 2008). However, reduction in accident rates and injury rates, are not sufficient in themselves to indicate the presence or quality of a safety culture. More in-depth research is required to be undertaken to explore the relationship between safety climate and actual safety behavior rather than a reliance on self-report measures. Looking at the above, a number of challenges lie ahead for the researcher:

- What are the key features of a good safety culture that can be assessed using a qualitative approach?
- Is there any evidence that these features are indicative of the state of safety, for instance do they relate to other safety measures (*e.g.* accident rates?)

- How does one determine the presence of an ongoing safety culture?
- How would the findings of this study generalize to other industries or countries?

Following three decades of safety climate research, Zohar (2008, 2010) had proposed that safety climate should be understood within a multi-level framework that identifies organization and group -level safety climates. Both, organization and group level items need to be assessed to attain a comprehensive understanding of safety climate. In other words, perceptions must be measured separately for the organization and group level safety climates.

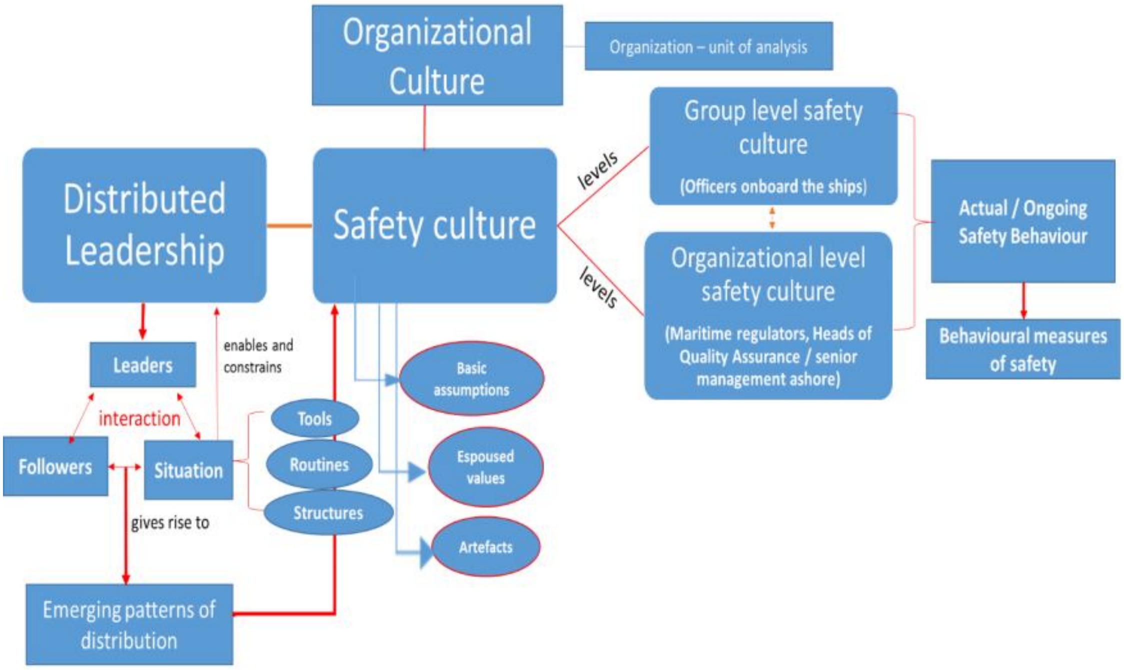
Guldenmund (2000) offers a holistic understanding of safety culture in terms of three levels:

1. Basic assumptions – general assumptions that form the core, they are unspoken, inherent, unconscious and shared throughout the organization.
2. Espoused values – attitudes of the organization's members that are safety specific; viz. attitudes towards management systems (*e.g.* safety systems), hardware (*e.g.* plant design), people (*e.g.* senior management) and behavior (*e.g.* risk taking).
3. Artefacts – the outermost layer is the outward expression of safety culture such as equipment (*e.g.* personal protective equipment), behaviors, (*e.g.* using appropriate safety equipment or managers conducting safety tours), physical signs (*e.g.* posting number of days since last accident publicly) and safety performance (number of incidents).

Safety culture is conceptualized as having three layers or levels at which it might be studied separately. The core is assumed to consist of basic assumptions, which are unconscious and relatively unspecific and which permeate the whole of the organization. The next layer consists of espoused values, which are operationalized as attitudes. Attitudes have specific objects and therefore this layer is, necessarily, specific with regard to the object of study. For safety culture four categories of objects are suggested; hardware, software, people and behavior. Finally, the outermost layer consists of particular manifestations, which are also specific to the object of study.

6. CONCEPT MAP:

Figure.4.: Concept Map



The proposed research is a practice-based perspective to understand leadership, taking account of the context which will provide deeper insights into the enactment of safety leadership. This is an attempt to view leadership as an emergent dynamic in a safety critical context where processes are standardized and relationships are hierarchical in nature. The objective is to explore **"how"** the phenomenon of leadership evolves and how it is distributed and shared across levels in an organization. Leadership is viewed as a product of the interactions of leaders, followers and their situation. Leaders have interactions with others as well as aspects of the situation – tools, routines and structures. These aspects of the situation define leadership practice; the situation both enables and constrains leadership practice.

The intent is to adopt methods that focus directly on the leader and their actions, which examine leadership 'in the moment' and take account of context including relationships with others so as to provide deeper insights into the emergence and enactment of safety leadership.

7. RESEARCH QUESTIONS:

Taking the organization as the unit of analysis, this is an effort to involve higher levels of analysis – various levels of the maritime system – seafarers, management on-board and external actors.

1. How is leadership distributed on-board the ship and what are the emerging patterns to distribution?
2. How do these patterns affect group-level and organizational-level safety culture?

Sub questions:

- What are the conditions that influence the emergence of distributed leadership and what are the conditions that inhibit the enactment of distributed leadership?
- How does interaction with external actors (ship owners, regulators, and heads of quality assurance) impacting safety culture? How external team leaders affect the team's ability to and motivation to be self-directed and share in leadership?
- What are the possible disturbances to established role relations when a shift to distributed leadership takes place?
- How does vertical and shared leadership work in combination and how does it impact group-level and organizational –level safety culture?
- Which team leadership functions are most frequently shared, with whom and at what points in the team performance process would be beneficial?

7.1 Further Challenges Envisaged for the Researcher:

- An understanding of the broader philosophical assumptions needs to be identified.
- Participants need to be chosen carefully – those who have experienced the phenomenon in question.
- As a researcher one would need to bracket out his her own views before proceeding with experiences of others.

It would be worthwhile to use grounded theory to capture different dimensions of the same phenomenon. Grounded theory develops explanatory theories of basic social processes studied in context. Descriptive theory building is essential before causal links can be established. Frameworks for leadership activity are scarce; adapting the

distributed perspective to a safety critical context and taking the organization as a unit of analysis will provide rich descriptions of leadership practice onboard the ship.
The researcher's intention is to move beyond description and to generate a theory, an abstract analytical schema of an action or practice. Assuming all participants in the study have experienced the phenomenon, development of the theory will further help explain practice or provide a framework for further research. Both phenomenology and grounded theory each have their own philosophical underpinnings that may be challenging to reconcile. Charmaz's constructivist grounded theory is closer to phenomenology, especially heurist/interpretative phenomenology where researcher and participant co-construct meanings and the researcher's agency is considered as important in the co-creation of conceptual frames or indeed meanings. The constructivist grounded theory lies directly within the interpretative approach to qualitative research with flexible guidelines, learning about the experience within embedded hidden networks, situations, relationships and making visible hierarchies of power, communication and opportunity. (Charmaz, 2006)

As literature on distributed leadership is fragmented and represents an emerging set of ideas, and since these ideas were tested on samples and populations largely within the educational sector, exploring the construct of leadership within the maritime context how it affects safety culture is indeed challenging. The theory that emerges may later be tested for its empirical verification with quantitative data to determine if it can be generalized to a sample and population within safety critical organizations.

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BEST PRACTICES FOR UNDERGRADUATE EDUCATION IN TRANSPORTATION

Amit Mokashi[1]

An hourglass model is proposed here for undergraduate education in transportation. This model is based on the generic hourglass model suggested by Indira Nair[1]. A student starts his/her undergraduate education with a broad foundation in professional and general skills such as personal development, study skills, research skills, business communication, project management, decision making, *etc.* These skills are necessary for the students to develop the maturity to appreciate what they will be exposed to not just academically during their education but also professionally during a possible internship or their eventual careers in the industry. Study done by Wong *et al.*[2] has found a greater demand for these skills than subject knowledge amongst employers for entry level logistics positions in UK.

The exploration phase continues with exposure to fundamentals of transportation system as suggested by Sussman[3]. This includes over view of all modes, supporting infrastructure, vehicles, power, fuels, controls *etc.* and their interrelations. Exposure to the fundamentals would better prepare the students to make a decision on which mode to specialize in *i.e.* trucking, rail, pipelines, marine and aviation. Specialization at an undergraduate level should be by mode so as to create a more marketable profile. This is also an appropriate time to expose them to two overarching principles that the students would need to appreciate throughout; those of transportation having derived demand (emphasizes the need to appreciate the shipper's business environment) and the transportation service variables[4] *i.e.* price, travel time, reliability, frequency, flexibility *etc.* The second stage would be that of the student specializing by selecting a mode for more detailed study. At this stage the student decides which mode he/she has an affinity for. The student now is in a better position to make this academic as well as career choice after being exposed to the mechanics of each mode. Students often enter an undergraduate program with unrealistic vocational expectations. Delaying this decision permits them to make a more mature choice.

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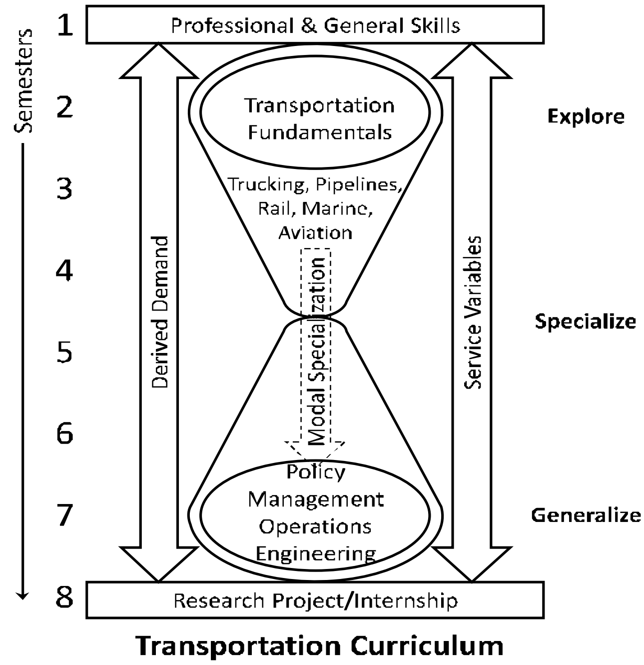
Finally, the hour glass model encourages the student to generalize (broaden) their skill set within the selected mode. It would be fair to assume that they would have to have that flexibility as they progress in their careers. It does tend to be common for a new entrant in transportation to start at an operational level then progress to management with subsequent migration to policy. There are also many instances of transportation professionals making horizontal shifts in to from engineering to commercial operations to management *etc.* This is often actively encouraged by the employers to ensure better exposed senior staff. The student should complete their education with at least one of the following two capstone assignments; a research project and/or internship. Both these options give the student the opportunity to apply their academic knowledge as well as gain transferable soft skills. Research projects tend to increase the student's interest in further education[5], while internships seem to help secure a career-oriented positions after graduation[6].

Figure below graphically represents this hourglass approach. Note; the semester numbers are included only as a guide for the general direction of flow and are not meant as a rigid prescriptive timeline adapted from Indira Nair's[1] generic hourglass model by Amit J. Mokashi using recommendations from the works of Sussman[3, 4], and Wong *et al*[2]

Figure.1.: Hourglass model for undergraduate transportation curriculum



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MILITARY ACTIVITIES IN CHAGOS ARCHIPELAGO: CONCERNS, IMPACTS AND WAY FORWARD

Anjelina Patrick[1]

1. INTRODUCTION:

Diego Garcia is a highly guarded military base of the United States and strategically situated between East Africa, East Asia, and Southeast Asia, making it a vital outpost for basing US naval forces and projecting air and naval power into the region. In 1966, the United Kingdom signed an agreement with the United States, giving it permission to use the island as a naval base for an initial period of 50 years. This agreement is set to expire in 2016. Unless the UK or the US takes steps to terminate the agreement, it will automatically be extended for a further period of twenty years.[i] The expiry of the initial agreement, brought hope for the islanders, who were forced to flee during the period 1967- 1973, and then denied the right to return to their native land.

This issue brief studies the social and environmental impact of military activities on the Chagos Archipelago. It provides a brief history of Diego Garcia and its strategic importance for both the United States and United Kingdom. It examines Mauritius claims over the archipelago and provides an insight to the Chagos Marine Protected Area. The paper also makes recommendations or the way ahead to resolve the highlighted issues.

2. BRIEF HISTORY AND IMPORTANCE OF DIEGO GARCIA:

The Chagos Archipelago comprises of seven atolls and more than 60 islands, and Diego Garcia is the largest. It was claimed by the French during the 18th century and used for plantation of coconuts and fishing. Mauritius and its dependencies - Chagos Archipelago and Seychelles, were ceded to the United Kingdom by France in 1814 through the Treaty of Paris, and thereafter administered by Mauritius. Later, the Archipelago was retained by the United Kingdom, as one of the conditions for Mauritius to attain independence in 1968. On 30th December 1966, Britain agreed to lease Diego Garcia to the United States for the construction of a naval base.[ii] Due to its

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small population, the UK successfully uprooted the island's people, as well as managed to avoid large-scale controversy.[iii] The depopulation from 1968 to 1973 was undertaken by intimidation and restricting inward migration. The displaced Chagossians settled mostly in Mauritius and Diego Garcia is often regarded to be at the core of United States' strategy in the Indian Ocean. The United States did not entail any monetary liability on account of the lease, but a US $ 14 million 'discount' to UK was offered for acquiring the Polaris nuclear missiles. The island is strategically significant for the United States as it is remote, secure and centrally placed. It is relatively immune from land based attack and, due to the absence of a local population; the base has been insulated from local political conflicts over the last five decades.[iv]

The island is home to about 1,700 military personnel and 1,500 civilian contractors with only about 50 British troops. The island is used jointly by the US Navy and the Air Force.[v] A number of air operations during the 1991 Persian Gulf War, 1998 Iraq War, and 2001 strikes in Afghanistan were launched from Diego Garcia. During the Cold War, Diego Garcia was highly valuable for the United States to monitor the activities of the erstwhile USSR. In Post-Cold War, the base is vital for US security and foreign policy interest such as the war on terror and monitoring of other naval activities in the Indian Ocean Region.

3. MAURITIUS CLAIMS OVER THE ARCHIPELAGOS:

Mauritius government has maintained its claim to sovereignty over the Chagos Archipelago, arguing that it was illegally separated from Mauritius, before it gained independence in 1968. Mauritius views the issue as a breach of United Nations resolutions on decolonization, most notably the United Nations General Assembly Resolution 1514/XV of 14 December 1960, stating:

> "Immediate steps shall be taken... all other territories which have not yet attained independence, to transfer all powers to the people of those territories, without any condition or reservations...enable them to enjoy complete independence and freedom."[vi]

The Chagossians have unsuccessfully waged a number of legal battles to resettle on the island since 2000. However, they have achieved a few successes like financial compensations and the right to own a British passport. The UK also came under criticism after it declared the BIOT as marine reserve, with the exception of Diego Garcia, leading to Mauritius filing a case under the United Nations Convention on the Law of the Sea (UNCLOS).

4. THE ISSUE OF CHAGOS MARINE PROTECTED AREA - SOCIAL AND ENVIRONMENTAL IMPACT:

In February 2009, the British government announced plans to establish a marine reserve in the BIOT. After numerous protests by Mauritius, the UK initiated a four-month public consultation on its decision to establish a Marine Protected Area (MPA) in Chagos. Chagos MPA was declared on 1st April 2010 by the BIOT Commissioner. It is one of the largest 'No-take' MPA *i.e.* prohibition on fishing, dredging, extraction of minerals, construction and dumping. The MPA covers the entire 200-mile Exclusive Economic Zone (EEZ) around the territorial waters of the Chagos Archipelago, except for Diego Garcia, with the MPA ending 3 nautical miles around the island.[vii] This raised several questions including whether it was an excuse to prevent the inhabitants from returning back to their homes or if it was genuinely meant to conserve the local ecology.

The Chagos MPA came under controversy after a diplomatic cable was leaked on 1st December 2010, which stated that the reserve was an outcome of a deliberate plan by the United Kingdom and United States, with an agenda of preventing the indigenous population from returning to their land.

On 20th December 2010, the Mauritian Government commenced litigation proceedings against the UK Government under UNCLOS to challenge the legality of the Chagos MPA. During the proceedings, it was observed that the United Kingdom, had violated 1982 UNCLOS provision, which required it to consult the Mauritius prior to establishing the MPA.

The Tribunal found that the UK was bound under international law to:

(a) Return Chagos back to Mauritius, when it was no longer needed for defense purposes.

(b) Preserve the benefits of any minerals or oil discovered in or near the Chagos Archipelago for Mauritius.

(c) Ensure that fishing rights in the Chagos Archipelago would remain available to Mauritius as far as practicable.[viii]

From the United Kingdom's perspective, the MPA was an effort to protect the flora and fauna of the Chagos archipelago. The US has also been trying to highlight its seriousness in undertaking international environmental responsibilities through the MPA. Their actions may be considered to resemble the concept of "greenwash" that tends to distract attention from the negative aspects of militarism, including instances of environmental degradation, the mistreatment of human subjects, and the perpetuation of colonial forms of government. According to Peter Harris, professor in the University of Texas, "UK clearly believes that it is possible to marry military and environmental objectives in BIOT, but only at the exclusion of the Chagossians' right of return".[ix]

Military construction and normal operations of the base, have generated numerous environmental concerns apart from creating a number of social issues. There has not been any extensive study on the environmental issues, due to denial of public access to the island. Diego Garcia's lagoon has been subject to blasting and dredging. For instance, a paved airport runway was built on a 3.6 km trail of land on crushed coral. A number of trees were cut down to make way for the base, leading to wildlife retreat and soil erosion. Since its construction, the island has seen more than one million gallons of jet fuel leaks, water fouled with diesel fuel sludge, the warehousing of depleted uranium-tipped bunker buster bombs, and the likely storage of nuclear weapons.[x] Anchor chains are also causing substantial damage to the corals especially in the northern basin of Diego Garcia. US ships have been pouring waste including treated human sewage for three decades into the lagoon where a Foreign Commonwealth Officer has admitted that the British "no-discharge policy" were not being followed by US vessels. Various tests have found high levels (four times) of nutrients - nitrogen and phosphates causing damage to corals on Diego Garcia.[xi] This questions the efficacy of the Marine reserve with the exclusion of Diego Garcia, where military continues with its environment damaging practices. Large amount of floating plastic debris has been found on the beaches of Chagos.

5. POTENTIAL WAY FORWARD:

With the Indian Ocean becoming the center stage of global geopolitics, it may be necessary to recognize the significance and utility of the archipelago to the US. However, the Outer Chagos Islands, which lie 100 miles from Diego Garcia and have never been used for defense purposes, could be ceded to Mauritius without jeopardizing the functionality of the base.[xii] In addition, adequate compensation may be provided to the indigenous population, for the damages suffered as a result of their displacement.

Co-management of the archipelagos could initiate bilateral talks between the UK and Mauritius. Ultimately, proper attention should be directed towards the military's environmentally destructive activities rather than just creating an MPA. Appropriate steps must be taken to ensure that the 'no-discharge' policy is followed strictly. Proper environmental assessments should be undertaken before any significant activities such as dredging, which may affect the island's ecology. This would help in reducing the possibility of ecological damage and costs. After proper assessment, the particular operation may be tailored to reduce environmental damage.[xiii] Stricter environmental monitoring system must be in place, especially to oversee the proper disposal of toxic waste, *etc*. The role of multilateral co-operative mechanisms in resolution of such problems cannot be overstated; for instance, the IORA which has 'marine security and environment' as one of its agenda, can play a critical role in preserving the fragile environment as well as bringing about redressal for the social issues. Mauritius is a member country of the IORA and UK and US are dialogue partners.

6. CONCLUSION:

Amidst the growing demands of the Chagossians to return back, and Mauritius's claims of sovereignty, the UK has continued to lease the island to US until 2036. The MPA for now serves to bypass the sovereignty of Mauritius over the islands and the strategic importance of Diego Garcia, rather than ecological or social concerns. A number of measures can be taken to reduce the adverse impacts of the military installation at Diego Garcia, which includes renewed thrust, especially on the part of IORA.

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