

# PROPULSION

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PROPORSION AND  
PREMILINARY  
POWERING

MISSION  
REQUIREMENT

COST  
ESTIMATE

LINES AND  
BODY PLAN

DAMAGE  
STABILITY

HYDROSTATIC  
AND  
BONJEAN  
CURVE

CAPACITY,  
TRIM, AND  
INTACT  
STABILITY

FLOODABLE  
LENGTH AND  
FREEBOARD

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ESTIMATE

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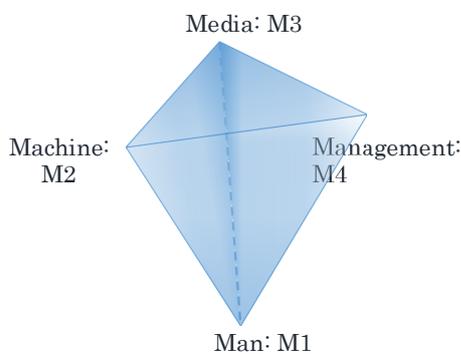
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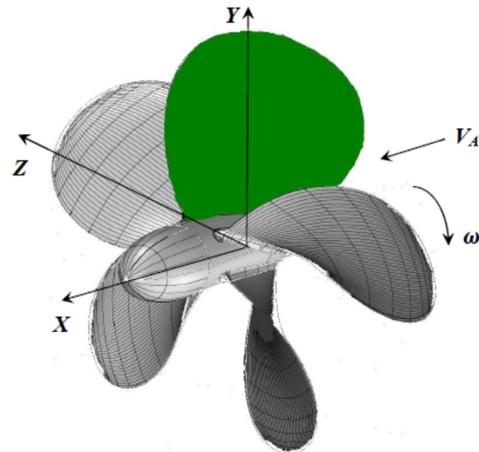
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# STUDI PEMILIHAN METODE *PLATFORM DECOMMISSIONING* DAN ANALISA FREKUENSI TUBRUKAN KAPAL SELAMA PROSES *DECOMMISSIONING*

A. A. B. Dinariyana, Ayudhia Pangestu Gusti, Ketut Buda Artana, AA. Masroeri, I Made Ariana, Yeyes Mulyadi

## Abstract

This study addresses the selection of appropriate methods of platform decommissioning and frequency analysis of ship collisions as a result of the decommissioning process. Object of study in this study is a Wellhead Platform that located 35 km from the Northern island of Madura. In early operation the platform was collapsed because the soil where the platform is in an unstable condition. According to this condition, it is planned to move the platform from the initial position to the new coordinates, 755,337.019 mE; 9,268,400 mN. This study discusses the determination of the appropriate platform removal methods, and collision frequency analysis ships that pass around the platform with the ship used to carry out decommissioning platform. There are four alternative decommissioning methods to be used in the analysis namely HLW (Heavy Lift Vessel), SSCV (Semi Submersible Crane Vessel), SLV (Single Lift Vessel), and BTA (buoyancy Tank Assembly). Selection of decommissioning method is performed using AHP (Analytical Hierarchy process). In this study, only crossing collision between regular vessel with transport are considered. The analysis is done using collision model proposed by IWARP. The selection analysis resulted that using HLW is selected to conduct the decommissioning of platform. The selection results of the study show that the method chosen decommissioning platform is a method of HLW (Heavy Lift Vessel). During the decommissioning process, the frequency of regular vessel collision with the barge transport for crossing collision case is at 0.0138 with a collision angle of 300, 0.015 by 900 and 0.0193 with a collision angle 1500. Due to value of frequency is less than 1, it can be concluded that the number of ship collision frequency which may occur during the process of decommissioning platform in case of crossing collision remained at an acceptable level.

Keywords : Platform Decommissioning, AHP, Ship Collision Frequency, IWARP

## 1. Pendahuluan

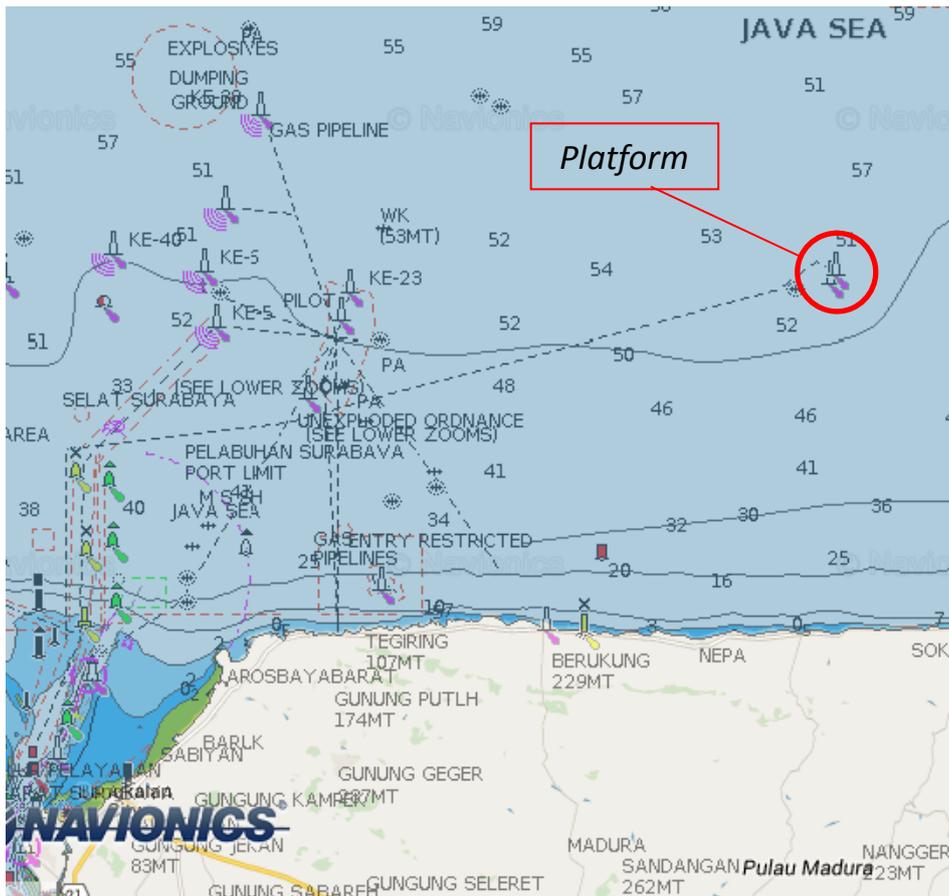
Objek kajian pada studi ini merupakan *Wellhead Platform* yang terletak pada koordinat 755,432mE; 9,268,782mN dengan kedalaman laut 57 m. *Platform* ini dihubungkan dengan kapal FPSO melalui pipa sepanjang 691 m. Dalam kasus ini, *platform* akan dipindahkan dari koordinat awal ke koordinat baru, yaitu 755,337.019 mE; 9,268,400 mN dikarenakan struktur tanah yang menumpu *platform* tersebut tidak stabil sehingga mengakibatkan *platform* berada pada posisi miring. Bangunan atau instalasi lepas pantai yang tidak memenuhi ketentuan atau tidak digunakan wajib dibongkar, sesuai dengan PM. Nomor 68 Tahun 2011 pasal 43 ayat 1.

*Platform decommissioning* adalah menghentikan operasi dari bangunan lepas pantai. Berdasarkan Peraturan Menteri ESDM RI Tahun 2011 tentang Pedoman Teknis Pembongkaran Instalasi Lepas Pantai Minyak dan Gas Bumi pasal 1, pembongkaran adalah peker-

jaan pemotongan sebagian atau keseluruhan instalasi dan pemindahan / pengangkutan hasil pembongkaran ke lokasi yang telah ditentukan. *Platform removal* dan *disposal* bisa dilakukan dengan cara memotong *platform* dan dibawa ke darat, atau memotong *platform* dan dibuang ke laut dalam, kemudian membiarkan *platform* sebagai rumah ikan. Pada studi ini, *platform removal* yang dipilih adalah memotong *platform* dan dibawa ke darat.

*Platform* ini merupakan *platform* jenis *wellhead* dengan jenis struktur *Fixed Platform*. *Fixed platform* terdiri dari dua bagian, yaitu bagian *topside* dan bagian *jacket*. Sehingga proses *decommissioning* dari *platform* dilakukan dengan dua tahap. Tahap pertama adalah proses *decommissioning* bagian *topside*, tahap kedua adalah *decommissioning* bagian *jacket*.

Potongan *platform* yang sudah terpotong akan dibawa menggunakan *transport barge* dari lokasi



Gambar 1 : Posisi platform terhadap Pulau Madura

decommissioning menuju Surabaya. Gambar 1 menunjukkan posisi dari platform terhadap pulau Madura.

Proses platform decommissioning ini memiliki potensi bahaya berupa tubrukan kapal yang melewati alur terdekat dari lokasi dengan kapal pekerja dan transport barge yang bekerja selama proses platform decommissioning. Tujuan dari studi ini adalah untuk memberikan usulan metode teknologi platform decommissioning yang sesuai dan juga untuk mengetahui tingkat frekuensi tubrukan kapal yang melewati alur terdekat lokasi decommissioning dengan kapal pekerja ataupun transport barge selama proses platform decommissioning berlangsung.

## 2. Metode Penelitian

### 2.1. Metode Pengujian

Pemilihan metode platform decommissioning dilakukan dengan menggunakan metode AHP (Analytical Hierarchy Process). Terdapat empat alternatif metode decommissioning yang akan digunakan dalam anali-

sis pemilihan yaitu HLV (Heavy Lift Vessel), SSCV (Semi Submersible Crane Vessel), SLV (Single Lift Vessel), dan BTA (Bouyancy Tank Assembly). Sedangkan untuk analisis frekuensi tubrukan kapal menggunakan model perhitungan frekuensi Quantitative Risk Assessment (QRA) dengan potential hazard berupa Head-on collision.

### 2.2. Analytical Hierarchy Process (AHP)

AHP merupakan suatu model pendukung keputusan yang dikembangkan oleh Thomas L. Saaty. Model pendukung keputusan ini akan menguraikan masalah multi faktor atau multi kriteria yang kompleks menjadi suatu hirarki. Hirarki didefinisikan sebagai suatu representasi dari sebuah permasalahan yang kompleks dalam suatu struktur multi level, dimana level pertama adalah tujuan, yang diikuti level faktor, kriteria, sub kriteria, dan seterusnya ke bawah hingga level terakhir dari alternatif. Dengan hirarki, suatu masalah yang kompleks dapat diuraikan ke dalam kelompok - kelompoknya yang kemudian diatur menjadi suatu bentuk hirarki sehingga permasalahan akan tampak lebih terstruktur dan sistematis. Secara garis besar

prosedur AHP meliputi tahapan sebagai berikut:

- **Dekomposisi Masalah**

Dekomposisi masalah adalah langkah dimana suatu tujuan yang telah ditetapkan selanjutnya diuraikan secara sistematis kedalam struktur yang menyusun rangkaian sistem hingga tujuan dapat dicapai secara rasional.

- **Penilaian atau Perbandingan Elemen**

Apabila proses dekomposisi telah selesai dan hirarki telah tersusun dengan baik. Selanjutnya dilakukan penilaian perbandingan berpasangan (pembobotan) pada setiap hirarki berdasarkan tingkat kepentingan relatifnya. Hasil dari penilaian adalah nilai/bobot yang merupakan karakter dari masing-masing alternatif.

Prosedur penilaian perbandingan berpasangan dalam AHP, mengacu pada skor penilaian yang telah dikembangkan oleh Thomas L. Saaty.

- **Penyusunan Matriks dan Uji Konsistensi**

Selanjutnya adalah penyusunan matriks berpasangan untuk melakukan normalisasi bobot tingkat kepentingan pada tiap-tiap elemen pada

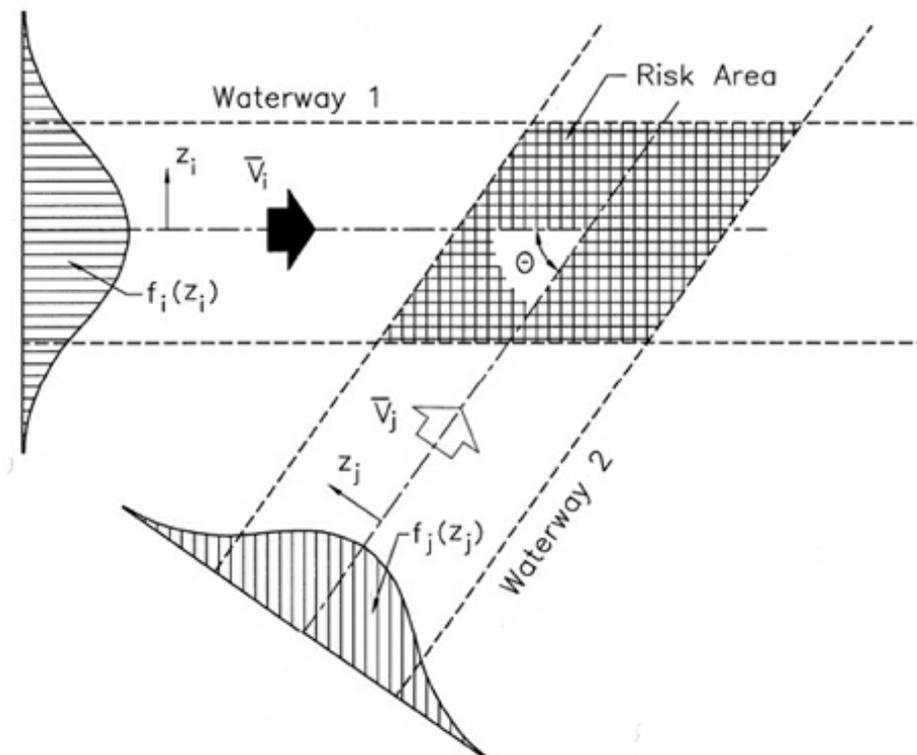
hirarkinya masing-masing. Pada tahapan ini analisis menggunakan *software Expert Choice*. *Expert Choice* merupakan sebuah perangkat lunak yang berfungsi untuk menganalisis hasil dari pembobotan AHP. *Software* ini mempermudah dalam menilai dan menentukan alternatif yang tepat.

- **Penarikan Kesimpulan**

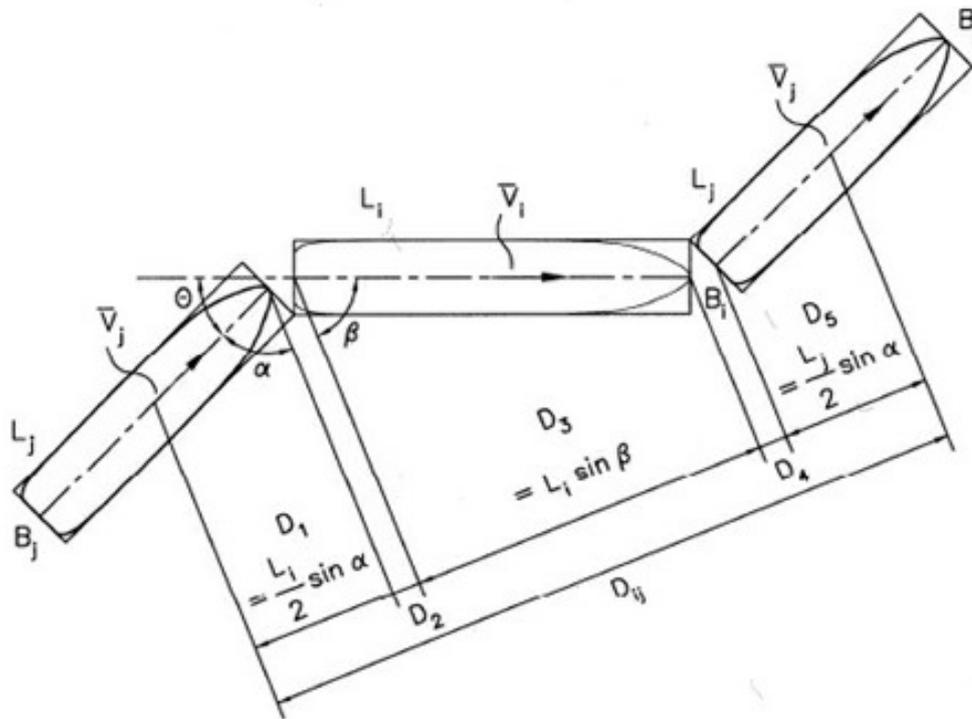
Penarikan kesimpulan dilakukan dengan mengakumulasi nilai yang merupakan nilai sensitivitas masing-masing elemen. Pada tahap ini, sudah terdapat satu alternatif yang terpilih.

### 2.3. Analisa Frekuensi

Analisis frekuensi untuk kasus *crossing collision* ini menggunakan model perhitungan pada IWARP seperti terlihat pada **Gambar 2**. *Crossing collision* merupakan keadaan dimana kapal bertubrukan dengan kapal lain karena berseberangan. Pada kasus ini *Crossing collision* dimungkinkan terjadi antar kapal karena kapal pengangkut *platform* akan melewati jalur pelayaran untuk membawa *platform* ke daratan terdekat.



**Gambar 2** : *Crossing Collision Ship to Ship*



Gambar 3 : Crossing Collision Diameter

$$\lambda_{col} = N_G \cdot P_c \quad (1)$$

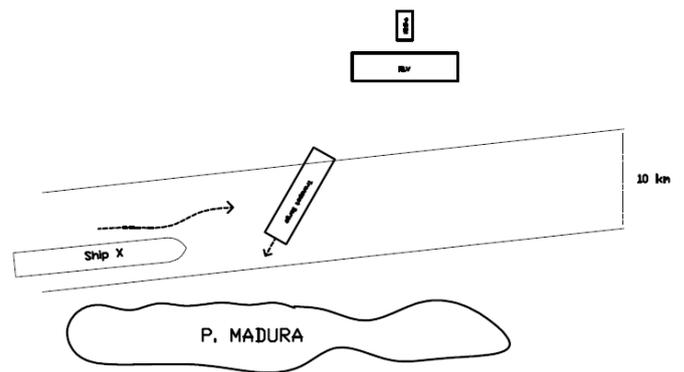
Dilihat pada Persamaan 1 diatas,  $N_G$  merupakan jumlah *crossing collision candidate*, sedangkan  $P_c$  merupakan faktor penyebab terjadinya tubrukan. Dibawah ini merupakan persamaan untuk mencari nilai dari  $N_G$ .

$$N_G^{crossing} = \sum_{i,j} \frac{Q_i Q_j}{(v_i)(v_j)} D_{ij} V_{ij} \frac{1}{\sin \theta} \quad (2)$$

$Q_i$  merupakan frekuensi kapal di jalur  $i$  selama proses *decommissioning*,  $Q_j$  merupakan frekuensi kapal di jalur  $j$  selama proses *decommissioning*,  $V_i$  merupakan kecepatan kapal di jalur  $i$ ,  $V_j$  merupakan kecepatan kapal jalur  $j$ ,  $D_{ij}$  merupakan *crossing collision diameter*,  $V_{ij}$  merupakan kecepatan relatif kedua kapal, sedangkan  $\theta$  merupakan sudut terjadinya tubrukan.

Gambar 3 menunjukkan cara untuk mengetahui nilai dari *crossing collision diameter* yang menggunakan Persamaan 3 dimana  $L_i$  merupakan fungsi dari panjang

kapal  $i$ ,  $B_i$  merupakan lebar kapal  $i$ ,  $V_i$  merupakan kecepatan kapal  $i$ ,  $L_j$  merupakan panjang kapal  $j$ ,  $B_j$  merupakan lebar kapal  $j$ ,  $V_j$  merupakan kecepatan kapal  $j$ ,  $V_{ij}$  merupakan kecepatan relatif kedua kapal  $\theta$  merupakan sudut terjadinya tubrukan. Gambar 4 menunjukkan skenario terjadinya tubrukan antara *transport barge* dengan kapal yang lewat disekitar lokasi *decommissioning*.



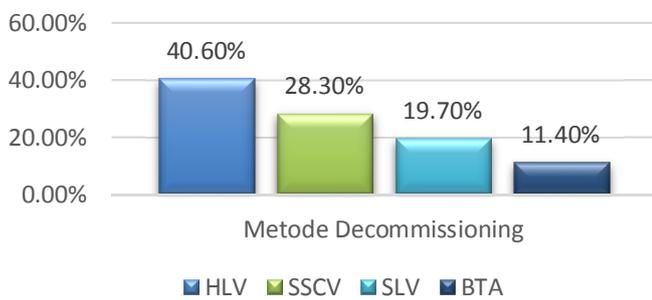
Gambar 4 : Posisi Transport Barge terhadap Kapal pada kasus Crossing Collision

$$D_{ij} = \frac{L_i V_j + L_j V_i}{V_{ij}} \sin \theta + B_j \left\{ 1 - \left( \sin \theta \frac{V_i}{V_{ij}} \right)^2 \right\}^{1/2} + B_i \left\{ 1 - \left( \sin \theta \frac{V_j}{V_{ij}} \right)^2 \right\}^{1/2} \quad (3)$$

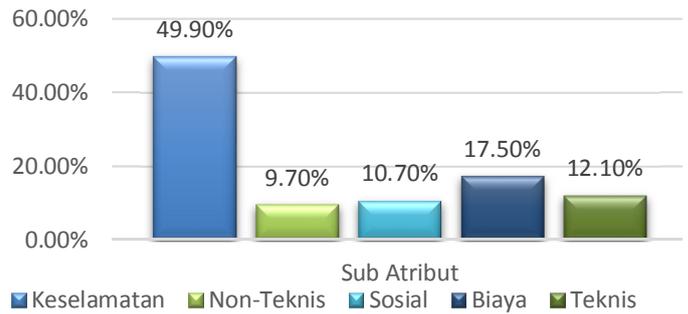
### 3. Hasil dan Pembahasan

#### 3.1. Hasil Pemilihan Metode Platform Decommissioning dengan AHP

Susunan hierarki untuk pemilihan metode platform decommissioning ini mempunyai lima atribut, yaitu keselamatan, non teknis, sosial, biaya, dan kelayakan teknis. Setiap atribut mempunyai minimal dua sub atribut. Dengan menggunakan software expert choice didapatkan hasil seperti terlihat pada Gambar 5 dan Gambar 6.

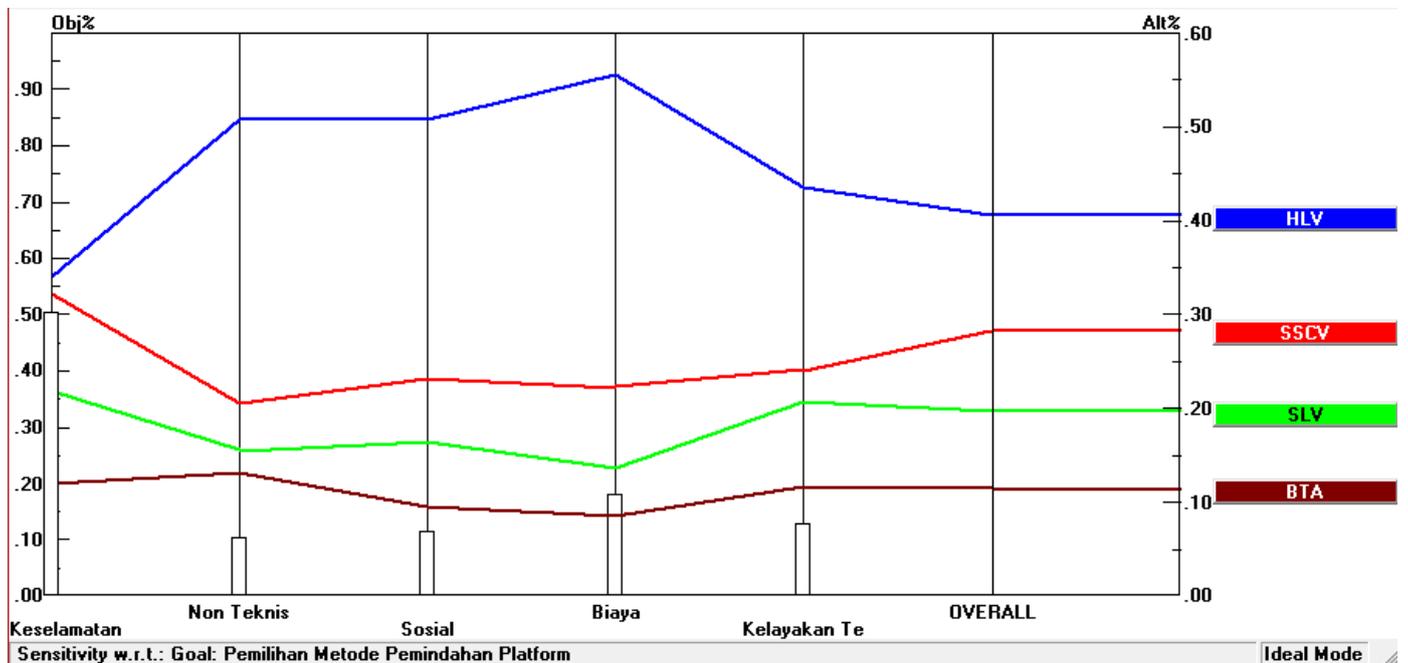


Gambar 5 : Rangkaian setiap alternatif metode decommissioning



Gambar 6 : Rangkaian setiap atribut metode decommissioning

Sedangkan Gambar 7 menunjukkan grafik sensitivitas dari keempat alternatif. Analisis sensitivitas bertujuan memprediksi keadaan apabila terjadi perubahan yang cukup besar sehingga berpengaruh terhadap urutan prioritas dari alternatif. Dengan menggunakan dynamic sensitivity yang terdapat pada software expert choice, nilai sensitivitas pada setiap atribut dapat diketahui. Dari hasil analisis sensitivitas setiap atribut disimpulkan bahwa seberapa besarpun nilai sensitivitas dirubah, tidak akan berpengaruh terhadap alternatif yang terpilih, yaitu HLV tetap di ranking pertama, kemudian SSCV ranking kedua, disusul SLV dan terakhir BTA.



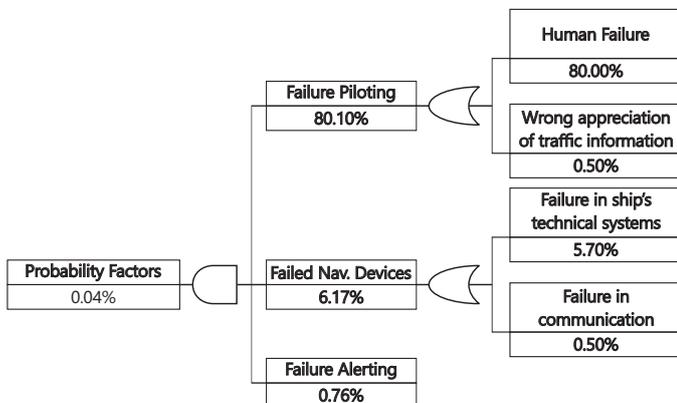
Gambar 7 : Performance Sensitivity

3.2. Hasil Perhitungan Frekuensi Tubrukan Kapal *Crossing Collision*

Kasus tubrukan kapal *crossing collision* ini melibatkan seluruh kapal yang berada di alur pelayaran Surabaya menuju Indonesia bagian Timur (Makasar dan Jayapura) maupun sebaliknya dengan *transport barge* yang menuju Pelabuhan Telaga Biru, Madura.

Tahap pertama yang dilakukan dalam menghitung frekuensi tubrukan *ship to ship crossing collision* adalah menentukan faktor-faktor yang berpengaruh pada perhitungan jumlah kandidat tubrukan seperti dimensi kapal, kecepatan kapal, dan jumlah kapal yang berlayar selama proses *platform decommissioning*. Pada kasus ini, diasumsikan kecepatan dari *transport barge* 10 knots, sedangkan kecepatan kapal ukuran terbesar adalah 12 knots (Loa = 177,3 meter dan B = 28 meter). Tahap selanjutnya adalah menentukan faktor-faktor penyebab terjadinya tubrukan, seperti *failed piloting*, *failed navigation devices* dan *failure alerting* seperti diperlihatkan pada Gambar 8 dibawah.

Pada kasus *crossing collision*, pemodelan tubrukan dibagi menjadi tiga model. Model pertama untuk kasus *crossing collision* dengan sudut tubrukan  $30^\circ$ , model kedua untuk kasus *crossing collision* dengan sudut tubrukan  $90^\circ$  dan model ketiga untuk kasus *crossing collision* dengan sudut tubrukan  $150^\circ$ . Perbedaan sudut dalam pemodelan dimaksudkan untuk mengetahui pengaruh besarnya sudut tubrukan terhadap frekuensi terjadinya *crossing collision*. Dibawah ini merupakan tabel hasil perhitungan frekuensi *crossing collision* untuk setiap pemodelan.



Gambar 8 :

*Fault Tree Analysis* untuk kasus *crossing collision*

Tabel 1 : Hasil Perhitungan *Crossing Collision* dengan  $\theta=30^\circ$

	Lama Pengerjaan	31 Hari
A	Human Eror	80%
B	Wrong appreciation of traffic information	0.50%
C	Failed Piloting $= (A + B) - (A \times B)$	80.100%
D	Failed Technical System	5.70%
E	Failed Communication	0.50%
F	Failed Navigation Devices $= (D + E) - (D \times E)$	6.17%
G	Failure Alerting	0.76%
H	Prob. Collision/Passing $= C \times D \times E$	0.04%
I	Speed Vessel (A) in m/s	5.14
J	Speed Vessel (B) in m/s	6.17
K	Relative speed between the vessel ( $V_{ij}$ ) in m/s	3.09
L	Collision Diameter ( $D_{ij}$ ) in m	262.41
M	Number of passage per year in line 1 (Q1) in unit per year	4
N	Number of passage per year in line 1 (Q2) in unit per year	179
O	Number of Collision candidate ( $N_G$ ), in ship per year	37
P	Crossing Collision fequency in collisions / year	0.0138

**Tabel 2** : Hasil Perhitungan *Crossing Collision* dengan  $\theta=90^\circ$  dan  $\theta=150^\circ$ 

Lama Pengerjaan		31 Hari	Lama Pengerjaan		31 Hari
A	Human Eror	80%	A	Human Eror	80%
B	Wrong appreciation of traffic information	0.50%	B	Wrong appreciation of traffic information	0.50%
C	Failed Piloting $= (A + B) - (A \times B)$	80.10%	C	Failed Piloting $= (A + B) - (A \times B)$	80.10%
D	Failed Technical System	5.70%	D	Failed Technical System	5.70%
E	Failed Communication	0.50%	E	Failed Communication	0.50%
F	Failed Navigation Devices $= (D + E) - (D \times E)$	6.17%	F	Failed Navigation Devices $= (D + E) - (D \times E)$	6.17%
G	Failure Alerting	0.76%	G	Failure Alerting	0.76%
H	Prob. Collision/Passing $= C \times D \times E$	0.04%	H	Prob. Collision/Passing $= C \times D \times E$	0.04%
I	Speed Vessel (A) in m/s	5.14	I	Speed Vessel (A) in m/s	5.14
J	Speed Vessel (B) in m/s	6.17	J	Speed Vessel (B) in m/s	6.17
K	Relative speed between the vessel ( $V_{ij}$ ) in m/s	8.04	K	Relative speed between the vessel ( $V_{ij}$ ) in m/s	10.94
L	Collision Diameter ( $D_{ij}$ ) in m	219.76	L	Collision Diameter ( $D_{ij}$ ) in m	104.37
M	Number of passage per year in line 1 (Q1) in unit per year	4	M	Number of passage per year in line 1 (Q1) in unit per year	4
N	Number of passage per year in line 1 (Q2) in unit per year	179	N	Number of passage per year in line 1 (Q2) in unit per year	179
O	Number of Collision candidate ( $N_G$ ), in ship per year	40	O	Number of Collision candidate ( $N_G$ ), in ship per year	51
P	Crossing Collision fequency in collisions / year	0.0150	P	Crossing Collision fequency in collisions / year	0.0193

Seperti diperlihatkan pada **Tabel 1** dan **Tabel 2** tentang hasil perhitungan frekuensi untuk kasus *crossing collision* dengan sudut tubrukan  $30^\circ$ ,  $90^\circ$ , dan  $150^\circ$ , dapat diketahui nilai frekuensi adalah kurang dari 1, yang berarti bahwa proses pemindahan *platform* selama proses *decommissioning platform* untuk semua pemodelan masih dapat diterima.

#### 4. Kesimpulan

Berdasarkan analisis yang telah dilakukan, metode *platform decommissioning* yang terpilih adalah HLV (*Heavy Lift Vessel*). Sedangkan hasil perhitungan frekuensi menunjukkan untuk kasus *crossing collision* tingkat frekuensi tubrukan bernilai 0,0138 untuk sudut tubrukan  $\theta=30^\circ$ , 0,015 untuk sudut tubrukan  $\theta=90^\circ$ , dan 0,0193 untuk sudut tubrukan sebesar  $\theta=150^\circ$ , dimana nilai-nilai tersebut berada dibawah 1, yang berarti bahwa proses pemindahan *platform* selama proses *decommissioning platform* untuk semua pemodelan masih dapat diterima.

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# ESTIMASI FREKUENSI TUBRUKAN KAPAL DENGAN MENGGUNAKAN METODE SAMSON SELAMA PROSES PIPELINE DECOMMISSIONING PADA ALUR PELAYARAN BARAT SURABAYA

Ketut Buda Artana, Emmy Pratiwi, A.A.B. Dinariyana, AA. Masroeri, I Made Ariana, Yeyes Mulyadi

## Abstract

Surabaya West Access Channel (SWAC) is one of the busiest shipping channels in Indonesia. Currently, with the depth of shipping channel - 9m LWS and width 100 m, large vessels with deeper draft can not pass the channel. In order to increase the amount of cargo carried by larger vessels and to decrease logistic costs, PT. Pelindo III plans to revitalise the channel. The shipping channel will be deepened to - 16 m LWS and also be widened to 200 m. The revitalization project can not be conducted until subsea gas pipelines relocation process in the shipping channel is completed. One hazard that may occur during pipeline decommissioning process is regular ships collision to Diving Support Vessel (DSV) and pipelay barge that operated during the process. Hence, this study aims to proposed method of pipeline removal and also to determine the frequency of ships collision that pass DSV and pipelay barge during pipeline decommissioning process. There are two alternative methods of pipeline removal considered in this study namely, Reverse S-Lay and Cut & Lift. The selection is carried out using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), while the collision frequency is calculated using SAMSON Model that originally proposed by MARIN, Netherlands. TOPSIS selected Reverse S-Lay as a method for decommissioning the subsea gas pipelines. During the process of decommissioning pipeline with a Reverse S-Lay, the annual frequency of powered and drifting collisions are 0.0153 and 0.00511 respectively. Due to the value of annual frequencies are less than unity (1) for both collision scenarios, it can be concluded that the risks due to collisions during decommissioning pipeline are acceptable.

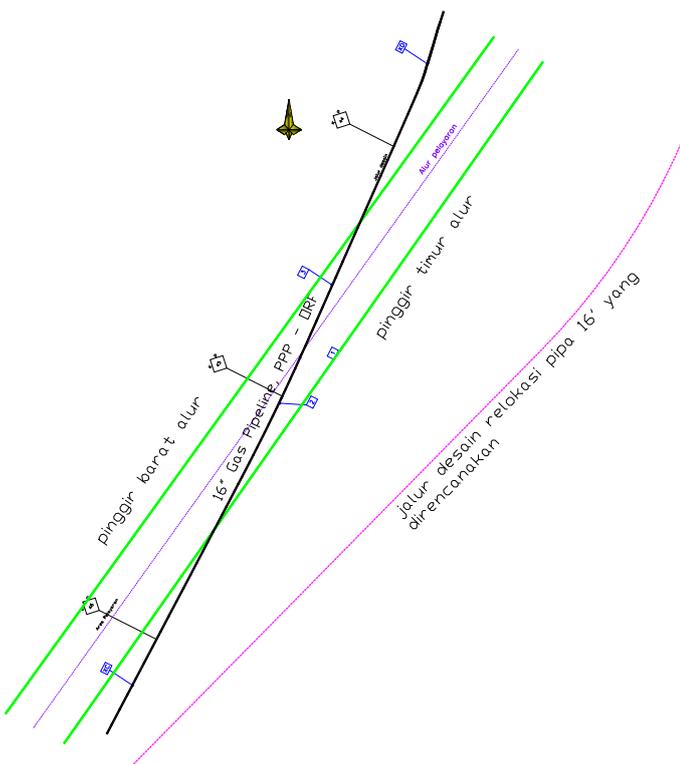
Keywords : Pipeline Decommissioning, Ship Collision, TOPSIS, SAMSON Model

## 1. Pendahuluan

Alur Pelayaran Barat Surabaya (APBS) merupakan salah satu akses laut menuju wilayah Timur Indonesia khususnya di Pelabuhan Tanjung Perak, Surabaya. APBS yang saat ini memiliki kedalaman sekitar -9 Low Water Spring (LWS) dengan lebar 100 meter masih belum bisa menampung kapal-kapal dengan *draft* yang tinggi sehingga arus barang dapat terkendala. Karena kondisi APBS yang seperti ini, PT. Pelindo III akan melakukan revitalisasi dengan mendalamkan alur hingga nantinya APBS memiliki lebar 200 meter dan kedalaman -16 mLWS. Dengan adanya revitalisasi ini maka APBS dapat digunakan untuk *two way traffic* atau lalu lintas dua arah dan kapal dengan generasi baru dengan *draft* yang lebih tinggi dapat melewati APBS. Hal ini akan berdampak pada penurunan biaya logistik dan kelancaran arus barang di Pelabuhan Tanjung Perak. Selain itu dengan revitalisasi ini diperkirakan jumlah

kapal dan arus bongkar muat di Pelabuhan Tanjung Perak dapat meningkat hingga 4 sampai 5%.

Proses revitalisasi APBS terus dilakukan namun masih belum bisa berjalan dengan baik akibat adanya pipa yang melintang di *crossing II* di KP (*Kilometer Point*) 44-46 APBS. Pipa ini terpendam dan berada di kedalaman minus 2 – 2,3 meter dibawah *seabed*. Pada analisis yang telah ada sebelumnya, apabila pengerukan alur ini dilakukan, maka pipa pada *crossing II* ini bisa muncul ke dasar laut. Oleh karena itu, untuk menyelesaikan pengerukan APBS secara cepat, maka pemindahan pipa perlu dilakukan. Direncanakan pipa akan dipotong dari masing-masing ujung *crossing* sepanjang 200 meter, sehingga seluruh pipa sepanjang 2900 meter ini dapat dipindahkan seluruhnya. Posisi pipa pada *crossing II* di alur ini dapat dilihat pada Gambar 1.



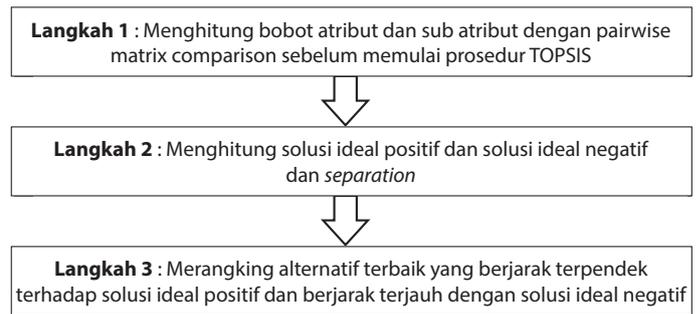
**Gambar 1 :** Posisi Pipa pada *Crossing II* di Alur Pelayaran Barat Surabaya

Proses pemindahan pipa atau *pipeline decommissioning* memiliki potensi bahaya berupa tubrukan kapal-kapal yang melewati APBS dengan *Diving Support Vessel (DSV)* dan *pipelay barge* yang bekerja selama proses tersebut. Tujuan dari studi ini adalah untuk memberikan usulan metode teknologi pemindahan pipa yang sesuai dan juga untuk mengetahui frekuensi tubrukan kapal-kapal yang melewati APBS dengan DSV ataupun *pipelay barge* selama proses *pipeline decommissioning*.

## 2. Tinjauan Pustaka

### 2.1. *Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)*

TOPSIS adalah salah satu metode yang digunakan untuk pengambilan keputusan multikriteria dimana alternatif yang terpilih harus mempunyai jarak terdekat dari solusi ideal positif, dan terjauh dari solusi ideal negatif. Secara garis besar, langkah-langkah dalam perhitungan TOPSIS seperti pada Gambar 2 berikut :



**Gambar 2 :** Langkah-langkah Perhitungan *TOPSIS*

## 2.2. Analisis Frekuensi

Perhitungan frekuensi tubrukan kapal dengan kapal yang beroperasi selama *pipeline decommissioning* pada proses pemindahan pipa ini menggunakan model SAMSON (*Safety Assessment Models for Shipping and Off-shore in the North Sea*) yang dipublikasikan oleh MARIN (*Maritime Research Institute Netherlands*).

### 2.2.1. *Drifting Collision*

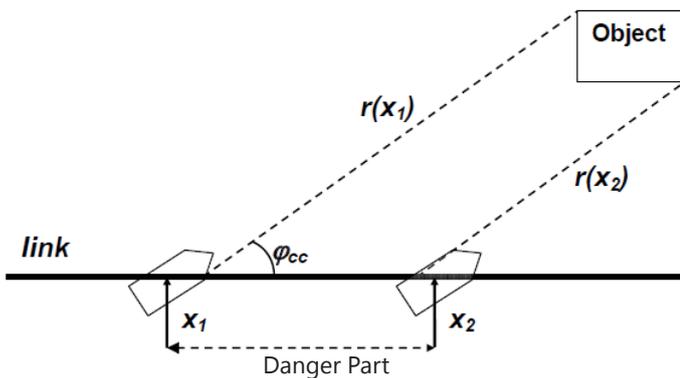
*Drifting Collision* adalah suatu kejadian yang tidak bisa dihentikan oleh *crew* kapal yang disebabkan karena kapal mengalami kerusakan mesin sehingga menyebabkan kapal menyimpang dari alur. Setelah kegagalan pada mesin, kapal mulai bergerak menyimpang dengan kecepatan tertentu (*drift velocity*) tergantung dari kondisi lingkungan seperti kecepatan udara dan arus. Kapal ini dapat menabrak objek lain apabila kapal mengarah ke objek dan kapal tidak bisa memperbaiki kerusakan mesin pada waktu tertentu. Berikut ini prosedur untuk menentukan jumlah kapal yang mengalami *drifting* dan menabrak objek :

#### a. Menentukan *danger part* dari *link*

Langkah yang pertama adalah menentukan pada bagian *link* yang mana kapal akan menabrak objek ketika mesin kapal gagal sesuai dengan arah angin (*drift direction*). Bagian *link* inilah yang disebut dengan *danger part* dari *link*, lihat pada Gambar 3. Jarak titik kapal ke objek ( $r(x)$ ) mempengaruhi waktu *drifting* setelah kecepatan *drifting* diketahui.

#### b. *Drifting velocity*

Pada model ini, *drift velocity* pada kapal  $i$  dengan arah angin mengikuti *Beaufort class b* dihitung dengan persamaan 1.



**Gambar 3 : Danger Part**  
( Sumber : MARIN, Contact Drift Model )

Kecepatan *drifting* dihitung berdasarkan  $v_b$  adalah *wind velocity* untuk *Beaufort class*  $b$ ,  $\rho_{air}$  density udara,  $\rho_w$  density air,  $A_{Lin}$  adalah permukaan lateral udara pada kapal  $i$  saat kondisi berbeban  $n$ ,  $L_i$  merupakan panjang kapal  $i$ ,  $T_{in}$  ialah sarat kapal  $i$  pada kondisi berbeban  $n$ ,  $c_b$  atau *significant wave amplitude* diasumsikan dihasilkan untuk *Beaufort class*  $b$ ,  $c_{dwind}$  dengan nilai asumsi 0,9 adalah koefisien permukaan lateral angin kapal,  $c_d$  sebesar 0,8 untuk semua tipe kapal adalah koefisien gesekan lateral pada *body* yang tercelup air, *wave drift coefficient* atau  $R$  dan  $g$  merupakan *gravity constant*.

$$v_{drift} = \sqrt{\frac{\rho_{air} A_{Lin} c_{dwind}}{\rho_w L_i T_{in} c_d} v_b^2 + \frac{1}{8} \frac{\zeta_b^2 g R^2}{T_{in} c_d}} \quad (1)$$

Setelah diketahui kecepatan *drifting* kapal dan jarak *drifting* dari titik kapal ke objek yang akan ditubruk, maka waktu yang diperlukan untuk mencapai objek tersebut hingga kapal menubruk dapat dihitung dengan persamaan umum yakni jarak dibagi kecepatan. Jika waktu untuk perbaikan mesin lebih lama dari  $t_s$ , maka kapal tidak akan mampu menghindari DSV atau *laybarge* sehingga kapal dapat tertabrak. Peluang kapal menubruk objek ini dihitung dengan persamaan 2 dan 3.

$$P_{EF}(t > t_s) = 1 \quad \text{untuk } t < 0.25 \quad (2)$$

$$P_{EF}(t > t_s) = \frac{1}{1.5(t_s - 0.25) + 1} \quad \text{untuk } t > 0.25 \quad (3)$$

Kapal hanya akan menabrak objek ketika berada di daerah bahaya dari link, jadi hanya diantara  $x_1$  dan  $x_2$  saja. Sehingga dengan mengintegrasikan persamaan 2 atau 3 diatas pada titik  $x_1$  dan  $x_2$  akan memberikan total kemungkinan terjadinya *drifting* :

$$P_{DRIFT} = \int_{x_1}^{x_2} P_{drift}(x) dx \quad (4)$$

dengan  $x_1$  dan  $x_2$  adalah titik batas dari *danger part*.

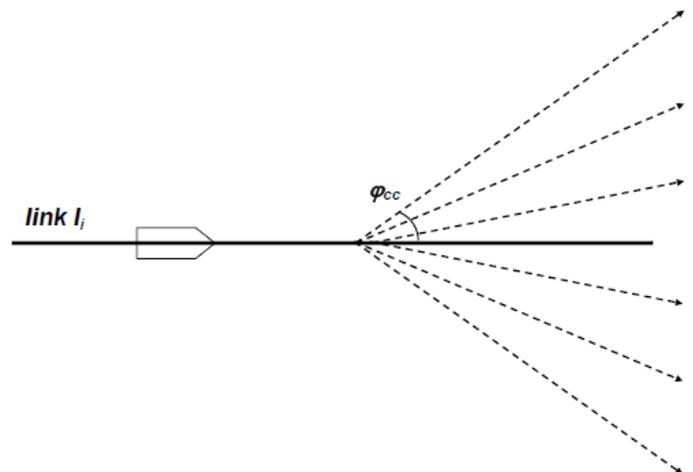
Langkah terakhir untuk menentukan jumlah kapal yang akan menabrak objek adalah dengan mengalikan peluang *engine failure* ini dengan kegagalan *emergency anchor* ( $P_{AF}$ ), jumlah kapal yang lewat ( $N$ ) dan *breakdown frequency*, maka frekuensi tubrukan kapal akibat *drifting* dapat diketahui.

### 2.2.2. Powered Vessel atau Ramming Collision

*Ramming collision* dengan objek tertentu disebabkan adanya *navigational error* atau *human error*. Berikut ini langkah-langkah dalam menentukan *ramming collision* :

#### a. Danger Part

Perhitungan *danger part* pada *ramming model* sama dengan *drifting model*. Yang membedakan hanya pada arah kemana kapal akan melaju. Pada *ramming model*, tubrukan kapal karena gagal navigasi dapat menyebabkan kapal berubah arah ke 7 sudut mulai dari  $-30^\circ$  hingga  $30^\circ$  dengan interval  $10^\circ$  seperti pada Gambar 4. Masing-masing perubahan sudut memiliki nilai probabilitas yang berbeda yakni 0,05 ; 0,1 ; 0,2 ; 0,3 ; 0,2 ; 0,1 ; 0,05.



**Gambar 4 : Ram-Direction yang Berbeda**  
( Sumber : MARIN, Contact Ram Model )

#### b. Avoidance function

*Avoidance function* atau sama dengan *repair function* pada *contact drift model* digunakan untuk mengetahui apakah kapal dapat menghindari tubrukan atau tidak yang tergantung dari panjang (ukuran) kapal dan *ramming distance*. Kapal yang besar akan membutuhkan waktu yang lebih lama untuk mengubah arahnya jika dibandingkan dengan kapal kecil, sehingga kemungkinan untuk menghindari tubrukan adalah kombinasi dari *ramming distance* ( $r$ ) dan ukuran kapal

(L) dengan  $\alpha$  yakni (*dimensionless*) *danger measure* (nilainya 0,1) :

$$P_{HIT}(r, L) = e^{-\alpha r} \quad (6)$$

Dengan mengalikan integral dari  $P_{HIT}$  dengan jumlah kapal ( $N$ ) yang lewat di alur serta Probabilitas kapal menabrak objek dari titik tertentu sepanjang *danger part* akibat adanya *navigational error* pada arah  $\Psi$  ( $P_{RAM}$ ) maka *Ramming Opportunities* (RO) karena *navigational error* adalah :

$$RO = P_{RAM} N \int_{x_1}^{x_2} e^{-\alpha \frac{r(x)}{L}} dx \quad (7)$$

Langkah terakhir adalah mengalikan *Ramming Opportunities* (RO) dengan kemungkinan terjadinya *navigational error* untuk tipe dan ukuran kapal tertentu.

$$N_{ramming} = NER \times RO \quad (8)$$

- $N_{ram}$  = Jumlah tubrukan kapal
- NER = Navigational Error Rate ( $0,65 \times 10^{-4}$  untuk setiap kapal)

### 3. Metodologi

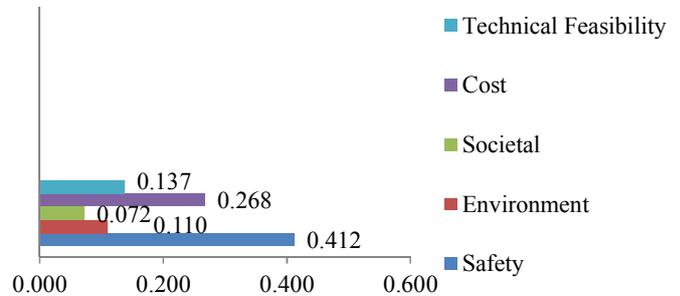
Pada studi ini, analisis frekuensi tubrukan kapal selama proses *pipeline decommissioning* dipengaruhi oleh metode *pipeline removal* yang dipakai seperti durasi proses pengerjaan, teknis pekerjaan, skenario posisi kapal yang beroperasi dan lain-lain. Alternatif metode pemindahan pipa yang ditawarkan ada dua macam, yakni *Reverse S-Lay* dan *Cut and Lift*. Alternatif ini akan dipilih salah satu yang paling sesuai dengan metode *Technique for Order of Preference by Similarity to Ideal Solution* (TOPSIS). Setelah metode *pipeline removal* terpilih, maka selanjutnya skenario pemindahan pipa dikembangkan sebagai dasar dari skenario tubrukan kapal yang berpotensi terjadi. Perhitungan frekuensi tubrukan kapal berupa *powered collision* atau *ramming collision* dan *drifting collision* menggunakan model SAMSON dari MARIN.

### 4. Hasil dan Pembahasan

#### 4.1 Hasil Pemilihan Metode Pemindahan Pipa dengan TOPSIS

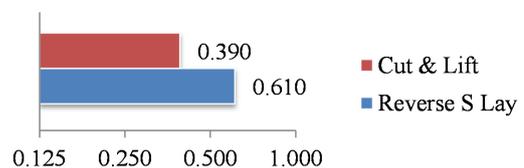
Pada TOPSIS ini terdapat atribut yang masing-masing atributnya memiliki beberapa sub atribut. Penilaian

kecocokan dan nilai preferensi antar atribut maupun atribut didapatkan dari kuisioner yang diisi oleh responden yang sekiranya paham terhadap bidang ini. Penilaian kepentingan ini menggunakan *pairwise comparison*. **Gambar 5** menampilkan salah satu hasil perhitungan yakni bobot untuk semua atribut.



**Gambar 5 : Bobot Atribut**

Bobot masing-masing sub atribut maupun atribut dan nilai preferensi dari hasil kuisioner akan menjadi data *input* dalam perhitungan TOPSIS untuk memilih metode pemindahan pipa yang paling sesuai. Dengan melakukan langkah-langkah perhitungan seperti pada persamaan 1 sampai 5, maka metode yang terpilih adalah *reverse S-Lay* dengan nilai sebesar 0,61 sedangkan *cut and lift* hanya mendapatkan nilai 0,39. Hasil perhitungan ini dapat dilihat pada **Gambar 6** berikut.



**Gambar 6 : Hasil Pemilihan Metode Pemindahan Pipa dengan TOPSIS**

Untuk menverifikasi hasil yang didapatkan dari perhitungan TOPSIS, pemilihan metode pemindahan pipa juga dilakukan dengan AHP (*Analytical Hierarchy Process*) menggunakan *software Expert Choice*.

**Gambar 7** menunjukkan bahwa berdasarkan perhitungan AHP dengan *Expert Choice*, metode pemindahan pipa yang dipilih adalah *Reverse S-Lay* dengan nilai 0,5452 (54,5 %) sedangkan *cut and lift* berada tipis dibawahnya dengan nilai 0,455 (45,5%). Meskipun hasil dari TOPSIS dan AHP dengan *Expert Choice* memberikan hasil yang sama yakni *reverse S-Lay* sebagai metode yang terpilih namun nilai yang diberikan berbeda.

Overall Inconsistency = .06



Gambar 7 : Hasil Pemilihan Metode Pemindahan Pipa dengan Expert Choice

Tabel 1 : Spesifikasi Pipelay Vessel dan Diving Support Vessel

Pipelay Vessel		Diving Support Vessel	
Length	= 85.34 m	Length	= 77 m
Breadth	= 24.38 m	Breadth	= 20,4 m
Draught	= 5.5 m	Draught	= 8 m
Tension Capacity	= 30 ton	DP 2 dynamic positioning system	
Class / Flag	= GL / Indonesia		

4.2. Pengembangan Skenario Pipeline Decommissioning

Metode pemindahan pipa yang terpilih berdasarkan TOPSIS dan AHP adalah *reverse S-lay*. Pada metode *reverse S-lay* ini akan digunakan *pipelay barge* dan *Diving Support Vessel (DSV)*. Dari beberapa opsi kapal *pipelay*, *pipelay barge* yang dipilih untuk proses *reverse S-lay* serta DSV yang digunakan memiliki spesifikasi seperti pada **Tabel 1** :

Skenario untuk *pipeline decommissioning* ini bisa dilihat **Gambar 8** dimana DSV akan memotong pipa setiap 200 meter. Aktivitas DSV selama proses pemotongan bisa menimbulkan potensi tubrukan kapal dengan DSV. Sedangkan *pipelay barge* tetap berada di dekat alur selama proses pemotongan pipa, persiapan dan *expose pipe*.

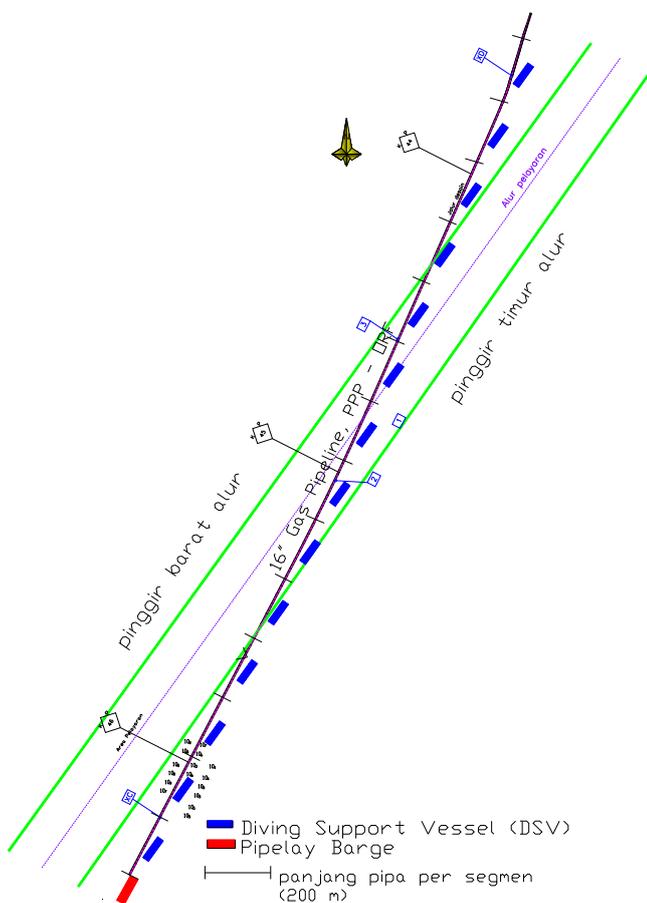
Dengan menggunakan metode *Reverse S - Lay*, waktu yang dibutuhkan untuk pemindahan pipa tiap segmen adalah 14 jam maka total waktu *pipeline decommissioning* sepanjang 2900 m adalah 215 jam. Jika pekerjaan berhenti beroperasi pada malam hari atau hanya 10 jam per hari maka dibutuhkan waktu 22 hari hingga seluruh pipa selesai dipindah.

4.3. Hasil Perhitungan Frekuensi

Pada perhitungan frekuensi ini, kapal yang akan dianalisis adalah semua kapal yang menuju ataupun keluar Gresik dan Pelabuhan Tanjung Perak Surabaya yang melewati *crossing II* APBS. Sesuai data dari PT. Pelindo III, jumlah kapal yang melewati APBS pada tahun 2013 adalah 24.093 unit kapal. Dengan estimasi kenaikan jumlah kapal tiap tahun sebesar 3% maka jumlah kapal yang melewati APBS pada tahun 2015 setiap jam adalah 3 unit kapal sehingga jumlah kapal (N) yang berpotensi menubruk DSV adalah 6 kapal dan untuk *laybarge* sebanyak 420 kapal.

4.3.1. Hasil Perhitungan Frekuensi Drifting Collision

Kecepatan *drifting* dari hasil perhitungan dengan persamaan 1 adalah sebesar 0,59 m/s atau 3,46 knot. Setelah diketahui kecepatan *drifting* kapal dan jarak *drifting* dari titik kapal ke objek yang akan ditubruk, maka waktu yang diperlukan untuk mencapai objek tersebut hingga kapal



Gambar 8 : Skenario Pemotongan Pipa

**Tabel 2 :** Frekuensi *Drifting Collision* Berdasarkan Model SAMSON (*outgoing*)

Objek	$r_{\psi}$	$t_s$	$P_{EF}$	$P_{AF}$	$N$	Break Freq	$N_{drifting}$
Segmen 1	716.19	0.28	0.951	0.35	6	0.000029	5.791E-05
Segmen 2	648.51	0.26	0.989	0.35	6	0.000029	6.022E-05
Segmen 3	602.45	0.24	1	0.35	6	0.000029	6.090E-05
Segmen 4	541.86	0.22	1	0.35	6	0.000029	6.090E-05
Segmen 5	483.17	0.19	1	0.35	6	0.000029	6.090E-05
Segmen 6	423.78	0.17	1	0.35	6	0.000029	6.090E-05
Segmen 7	361.73	0.14	1	0.35	6	0.000029	6.090E-05
Segmen 8	280.48	0.11	1	0.35	6	0.000029	6.090E-05
Segmen 9	200.37	0.08	1	0.35	6	0.000029	6.090E-05
Segmen 10	106.48	0.04	1	0.35	6	0.000029	6.090E-05
Segmen 11	142.87	0.06	1	0.35	6	0.000029	6.090E-05
<i>Pipelay barge</i>	718.29	0.29	0.95	0.35	30	0.000029	2.892E-04

**Tabel 3 :** Frekuensi *Drifting Collision* Berdasarkan Model SAMSON (*incoming*)

Objek	$r_{\psi}$	$t_s$	$P_{EF}$	$P_{AF}$	$N$	Break Freq	$N_{drifting}$
Segmen 8	262.39	0.10	1	0.35	6	0.000029	6.090E-05
Segmen 9	465.86	0.19	1	0.35	6	0.000029	6.090E-05
Segmen 10	706.67	0.28	0.96	0.35	6	0.000029	5.822E-05
Segmen 11	923.95	0.37	0.85	0.35	6	0.000029	5.181E-05
Segmen 12	1135.70	0.45	0.77	0.35	6	0.000029	4.679E-05
Segmen 13	1340.59	0.53	0.70	0.35	6	0.000029	4.278E-05
Segmen 14	1548.00	0.61	0.65	0.35	6	0.000029	3.936E-05
Segmen 15	1856.09	0.74	0.58	0.35	6	0.000029	3.519E-05
Frekuensi Kumulatif <i>Drifting</i> Kapal dengan DSV							3.959E-04
Frekuensi Kumulatif <i>Drifting</i> Kapal dengan <i>Pipelay barge</i>							4.049E-03
Frekuensi Kumulatif <i>Drifting</i> Kapal							4.445E-03

menubruk. Jika waktu untuk perbaikan mesin lebih lama dari  $t_s$ , maka kapal tidak akan mampu menghindari DSV atau *laybarge* sehingga kapal dapat tertabrak. Dengan mengalikan peluang *engine failure* ini dengan kegagalan *emergency anchor*, jumlah kapal yang lewat dan *breakdown frequency*, maka frekuensi tubrukan kapal akibat *drifting* dapat diketahui.

Dengan menjumlahkan seluruh frekuensi tubrukan kapal dengan DSV pada seluruh segmen, maka frekuensi kumulatifnya adalah 0,001062. Frekuensi *pipelay barge* lebih besar karena durasi *pipelay barge* didekat alur lebih lama yakni 10 jam per hari, sehingga jumlah kapal ( $N$ ) adalah 30 kapal untuk 10 jam per hari. Karena dari hasil estimasi durasi *pipelay barge* bekerja untuk pemindahan pipa

ini adalah 140 jam, maka frekuensi kumulatif *drifting* kapal dengan *pipelay* adalah 0,004049. Berdasarkan perhitungan dengan model SAMSON, Selama proses *pipeline decommissioning*, frekuensi tubrukan kapal dengan DSV dan *pipelay barge* adalah sebesar 0,00511.

#### 4.3.2. Hasil Perhitungan Frekuensi *Powered Vessel* atau *Ramming Collision*

Dari hasil perhitungan untuk frekuensi tubrukan kapal berupa *powered* atau *ramming collision* pada sudut  $10^\circ$ ,  $20^\circ$  dan  $30^\circ$  serta frekuensi kumulatifnya terangkum pada Tabel 4 dibawah ini.

Berdasarkan hasil perhitungan frekuensi *ramming collision* pada Tabel 4.76 diatas, frekuensi tubrukan terbesar terjadi

**Tabel 4 : Frekuensi Kumulatif Ramming Collision untuk Semua Sudut**

Objek	$\Psi = 10^\circ$		$\Psi = 20^\circ$		$\Psi = 30^\circ$	
	N ramming (outgoing)	N ramming (incoming)	N ramming (outgoing)	N ramming (incoming)	N ramming (outgoing)	N ramming (incoming)
Segmen 1	3.35E-05	5.47E-05	2.54E-05	3.32E-05	1.45E-05	1.75E-05
Segmen 2	3.62E-05	6.21E-05	2.64E-05	3.44E-05	1.49E-05	1.79E-05
Segmen 3	3.82E-05	6.28E-05	2.71E-05	3.53E-05	1.52E-05	1.82E-05
Segmen 4	4.10E-05	6.77E-05	2.82E-05	3.66E-05	1.56E-05	1.87E-05
Segmen 5	4.40E-05	7.00E-05	2.92E-05	3.69E-05	1.60E-05	1.87E-05
Segmen 6	4.73E-05	7.00E-05	3.02E-05	3.69E-05	1.64E-05	1.87E-05
Segmen 7	5.08E-05	7.00E-05	3.14E-05	3.69E-05	1.68E-05	1.87E-05
Segmen 8	5.60E-05	7.00E-05	3.29E-05	3.69E-05	1.74E-05	1.87E-05
Segmen 9	6.15E-05	6.44E-05	3.46E-05	3.53E-05	1.80E-05	1.82E-05
Segmen 10	6.88E-05	5.83E-05	3.66E-05	3.35E-05	1.87E-05	1.75E-05
Segmen 11	7.61E-05	5.33E-05	3.50E-05	3.19E-05	1.84E-05	1.70E-05
Segmen 12	7.61E-05	4.89E-05	3.23E-05	3.05E-05	1.83E-05	1.65E-05
Segmen 13	6.86E-05	4.49E-05	3.67E-05	2.92E-05	1.87E-05	1.60E-05
Segmen 14	6.10E-05	4.13E-05	3.47E-05	2.77E-05	1.80E-05	1.54E-05
Segmen 15	5.34E-05	3.63E-05	3.25E-05	2.61E-05	1.72E-05	1.48E-05
Pipelay barge	2.15E-03	3.72E-03	1.77E-03	2.29E-03	1.02E-03	1.21E-03
Frekuensi Kumulatif (DSV)	1.69E-03		9.74E-04		5.17E-04	
Frekuensi Kumulatif (Pipelay)	5.87E-03		4.06E-03		2.23E-03	
Frek Kumulatif	7.55E-03		5.04E-03		2.74E-03	

pada kapal yang mengalami perubahan arah  $10^\circ$  dengan nilai frekuensi 0,00169 untuk kapal dengan DSV dan 0,0058 untuk kapal dengan *pipelay barge*. Hal ini diakibatkan nilai probabilitas perubahan arah ke sudut  $10^\circ$  paling besar yakni 0,2. Frekuensi kumulatif tubrukan kapal dengan DSV dan *pipelay barge* selama proses *pipeline decommissioning* adalah sebesar 0,00755 untuk  $10^\circ$ , 0,00504 untuk  $20^\circ$  dan 0,00274 untuk  $30^\circ$  serta untuk semua sudut frekuensinya menjadi 0,0153.

## 5. Kesimpulan

Hasil perhitungan frekuensi tubrukan kapal untuk *powered vessel* atau *ramming collision* sebesar 0,0153 dan drifting collision sebesar 0,00511 menunjukkan bahwa selama proses *pipeline decommissioning* dengan metode *reverse S-lay* tersebut, frekuensi tubrukan kapal masih dapat diterima karena nilainya kurang dari 1. Hal ini telah sesuai dengan tujuan dari Pelindo III bahwa di APBS nantinya tidak terjadi kecelakaan pelayaran setelah dilakukan revitalisasi. Selain itu, jika frekuensi dari hasil perhitungan ini kurang dari satu maka proses *pipeline decommissioning* tidak mengganggu keselamatan pelayaran.

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# PENILAIAN RISIKO KEBAKARAN PROSES GAS LIQUEFACTION PADA UNIT FLNG

Munir Muradi, Ketut Buda Artana, A.A.B Dinariyana D.P

## Abstract

Process of gas liquefaction units on Floating Liquefied Natural Gas (FLNG) is still very vulnerable to fire risks and other types of damage caused by gases released during operation. It is necessary for the proper analysis of fire risk analysis on the system. Methods of risk assessment Carried out According to the rules of the Application of Risk Assessment for the Marine and Offshore Oil and Gas Industries. Hazard identification is done by using Hazard Operability (HAZOP), frequency analysis with Fault Tree Analysis (FTA) and the value of the frequency of occurrence of the possible repercussions of the release of gases Reviews such as Jet Fire, Flash Fire, explosion of gas and gas dispersion using Tree analysis (ETA). Consequence Analysis with fire simulation software. Based on the analysis of the frequency and consequence, the level of risk represented by the F-N curve Refers to the standard UK offshore 1991. The results obtained from this study that the potential impact of the type of jet fire Consequences are in acceptable condition, the risk of a gas pipeline on the acceptable level. The Consequences of a very small possibility of a gas explosion at a frequency value  $< 10^{-6}$  and the Consequences of the gas dispersion can not cause toxic effects in Humans due to the release of the gas is still under 50,000 ppm.

Keywords : Risk Assessment, Jet Fire, Flash Fire, Gas Explosion, Gas Dispersion

## 1. Pendahuluan

Potensi gas bumi yang dimiliki Indonesia berdasarkan status tahun 2008 mencapai 170 TSCF dan produksi per tahun mencapai 2,87 TSCF, dengan komposisi tersebut Indonesia memiliki *reserve to production* (R/P) mencapai 59 tahun [ESDM, MIGAS, 2007]. Namun lokasi jauh daratan dan dengan sistem pipanisasi tidak memungkinkan gas untuk dibawa ke darat dan aplikasi tersebut tidak kompetitif. Pemerintah Indonesia saat ini tengah melakukan perencanaan untuk eksploitasi gas tersebut dengan membangun sebuah *Floating Liquefied Natural Gas* (FLNG). Dalam perencanaan fasilitas instalasi tersebut harus memperhatikan banyak hal penting, salah satunya adalah Instalasi *gas liquefaction process*. Untuk itu pengadaan sebuah instalasi yang dibangun dengan tujuan pengolahan gas bumi harus memenuhi syarat-syarat teknis dan keselamatan kerja yang sesuai dengan sifat-sifat khusus dari proses dan lokasi operasi dari fasilitas tersebut [PP No. 11 Tahun 1979]. Dari pengamatan terhadap adanya upaya pemenuhan syarat-syarat keselamatan tersebut, maka harus dilakukan analisa risiko yang tepat untuk keberlangsungan pengoperasian instalasi tersebut.

## 2. Metode

Metode yang digunakan adalah seperti yang terdapat di dalam Tabel 1.

## 3. Hasil dan Diskusi

### 3.1. Identifikasi *Hazard* dengan HAZOP

Dalam pelaksanaan identifikasi dilakukan pembagian sub-sistem atau biasa dikenal dengan pembagian *node* agar mempermudah untuk melakukan analisa terhadap sistem yang diidentifikasi.

Dalam melakukan identifikasi umumnya sistem yang dianalisa akan dipecah menjadi beberapa bagian sub-sistem dan selanjutnya sebuah tim akan melakukan evaluasi dengan metode *brain storming* atau dibantu seperangkat *checklist* [Artana, et al. 2013].

Untuk hal yang sama seperti pada Tabel 3. Dilakukan terhadap semua *node* atau *subsystem* sehingga akan dihasilkan identifikasi terhadap bagian-bagian atau kompoen-kom-

Tabel 1 : Risk Assessment Method

Risk Assessment Method			
Hazard Identification	Frequency Analysis	Consequence Analysis	Risk Evaluation
HAZOP, dalam proses ini kata kunci (how, low, no,dll) mengetahui deviasi proses berdasarkan parameter yang telah ditetapkan	Frekuensi dari gagalnya system dengan FTA dan Frekuensi terjadinya <i>incident</i> dalam hal ini <i>fire risk</i> dengan <i>Event Tree Analysis</i> (ETA).	Perkiraan konsekuensi dengan simulasi pemodelan sesuai dengan bentuk skenario menggunakan <i>software ALOHA</i>	Risiko tersebut direpresentasikan kedalam <i>f-N Curve</i> berdasarkan <i>Acceptance Criteria</i> UK Offshore HSE, 1991

Tabel 2 : Pembagian Node

No.	Node.	Deskripsi
1.	<i>Warm MCHE</i>	Merupakan proses pendinginan <i>dry natural gas</i> (FEED GAS) untuk memudahkan dalam proses pencairan.
2.	<i>WMR Accumulator</i>	WMR Accumulator merupakan system rangkaian multi komponen refrigerant dalam hal ini pengkondisian gas butane menjadi dua fasa yaitu <i>liquid dan vapour</i> .
3.	<i>CMR Separator</i>	CMR Separator merupakan rangkaian sistem pencairan gas, dimana pendingin ( <i>nitrogen dan ethane</i> ) yang telah digunakan kedalam <i>Warm MCHE</i> .
4.	<i>Cold MCHE</i>	Merupakan tahap proses pencairan dan <i>subcooling</i> pada <i>dry natural gas</i> sehingga mencair pada suhu $-162^{\circ}\text{C}$ dengan menggunakan multi komponen refrigerant.

ponen yang dapat mengalami kegagalan fungsi pada setiap *node* atau *subsystem*.

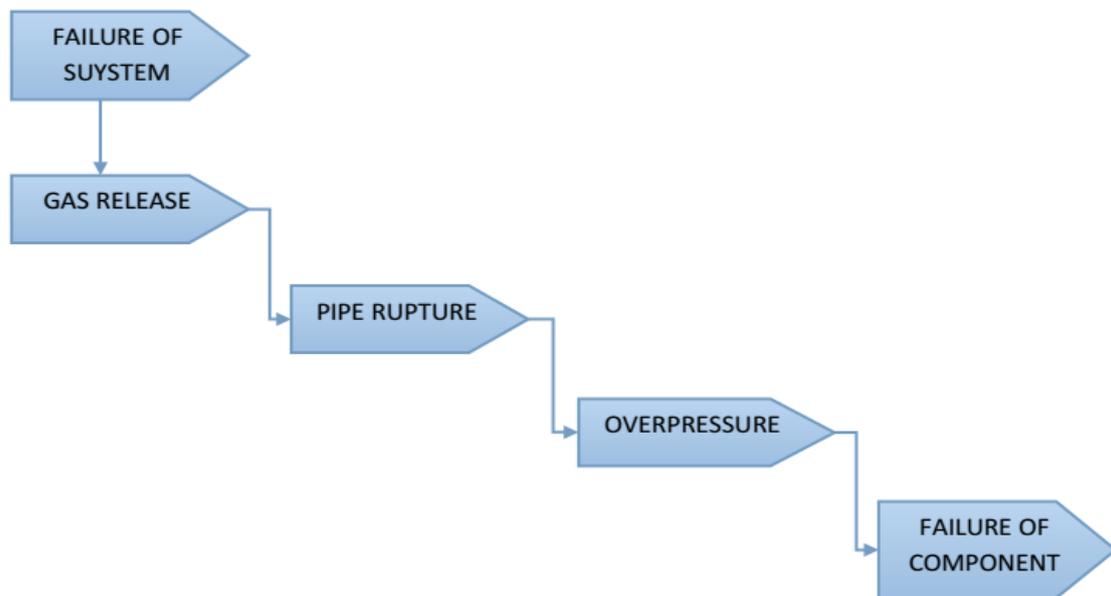
### 3.2. Analisa Frekuensi

Dengan *input database* nilai estimasi besarnya *hole* (*hole size*) berdasarkan *A Guide To Quantitative Risk Assessment for Offshore Installation* (DNV Technica) dan kondisi gas *release rate* dan *ignition probability* akibat kebocoran pipa mengacu pada *International Association of Oil and Gas Producers Ignition Probability* [Risk Assessment

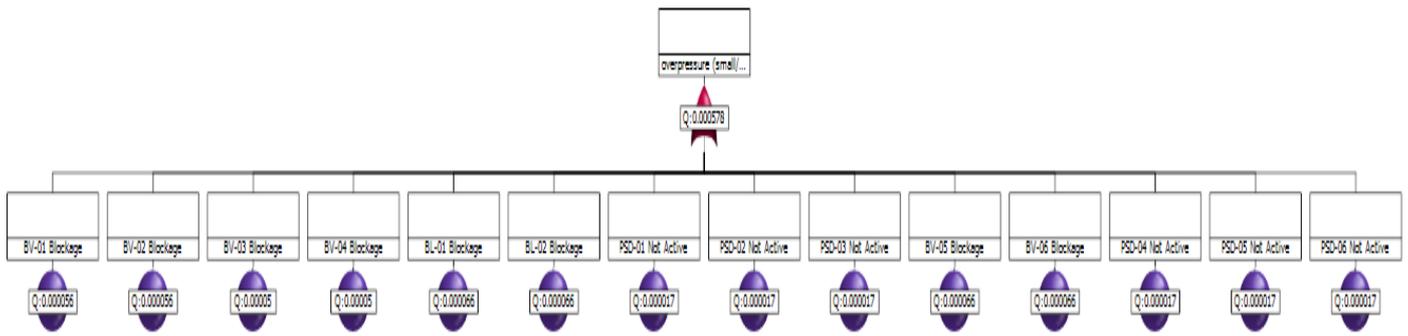
Data Directory, 2010] dan *process release frequency* [Risk Assessment Data Directory, 2010]. Sedangkan untuk Probabilitas terjadinya *Flash Fire, Gas Explosion* berdasarkan data dari *Chemical Engineering Transaction* Vol. 36, 2014, pada publikasi *Risk Analysis of LNG Terminal* [Vianello, et al., 2014]. Setelah data frekuensi kegagalan diperoleh, maka selanjutnya adalah melakukan perhitungan frekuensi kegagalan untuk tiap *node*, dalam simulasi ini diskenariokan gagalnya sistem dapat dilihat pada gambar berikut ini (Gambar 1).

**Tabel 3 : HAZOP Node 1. Warm MCHE**

STUDY TITLE = FLNG		SHEET = 1 of 4	
DRAWING NO = DWG. NO.204.006.001		NODE : 1 P&ID	
PART CONSIDERED = WARM MAIN CRYOGENIC HEAT EXCHANGER			
DESIGN INTENT = SOURCE		1. BUTTERFLY VALVE 2. GLOBE VALVE 3. REDUCER 4. FLOW TRANSMITTER 5. FLOW INDICATOR 6. GATE VALVE	7. TEMP.TRANSMITTER 8.TEMP.INDICATOR 9.PRESSURE SAFETY VALVE 10.PRESSURE TRANSMITTER 1. PRESSURE INDICATING
DEVIATION		ACTIVITY :  PRE-COOLING	
NO	SOURCE	POSSIBLE CAUSES	RECOMMENDATIONS
1.	BV-01 (20")  BV-02 (20")	if valve BV-01 and BV-02 blockage, gas line overpressure which could lead to gas release on flanged	1. Seal on the flange must be rigid 2. Seal on the flange must be insulated 3. Provide automatic cutoff valves for line leaks 4. Insulate drainage through under transfer lines
	No flow	overpressure on pipe, if pipe rupture gas release leads to Gas Dispersion and jet fire, flash fire if any source of fire	1.Flow transmitter/indicator



**Gambar 1 : Skenario kegagalan system / gas release**



Gambar 2 : FTA analysis for Frekuensi overpressure with hole diameter leak is 50mm, Node 1

Tabel 4 : Hasil perhitungan frekuensi terjadinya gas release untuk masing-masing rentang diameter kebocoran pada masing-masing node

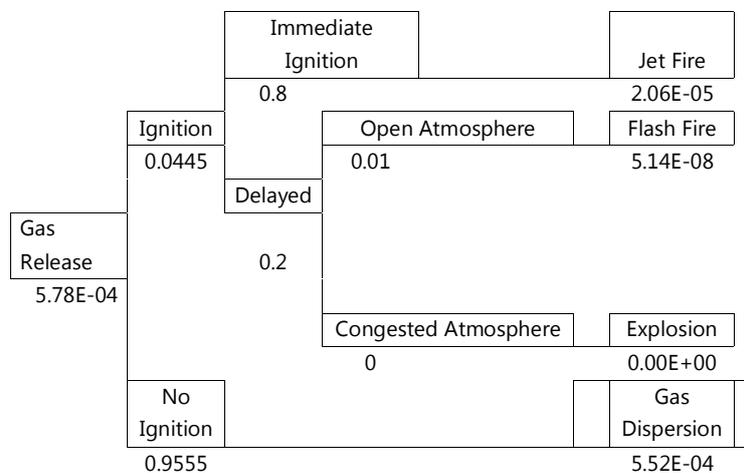
No.	Node.	Scenario	Gas release frequency		
			50 mm	100 mm	200 mm
1.	Warm MCHE	Gas release	5.78E-04	1.912E-04	1.054E-04
2.	WMR Accumulator	Gas release	3.97E-04	1.782E-04	2.29E-05
3.	CMR Separator	Gas release	3.70E-04	5.38E-05	4.16E-05
4.	Cold MCHE	Gas release	5.22E-04	1.63E-04	1.198E-04

Gambar 2 menunjukkan perhitungan frekuensi terjadinya *overpressure* untuk diameter lubang kebocoran 50 mm pada *Node 1*. Untuk hal yang sama dilakukan analisa serupa terhadap beberapa asumsi lubang kebocoran pada setiap *node*. Dan hasilnya dapat dilihat pada Tabel 4.

Dan selanjutnya dari nilai tersebut digunakan untuk menentukan frekuensi terjadinya *incident* berupa *Jet Fire*, *Flash Fire*, *gas explosion* dan *gas dispersion*. Dengan meng-

gunakan analisa *Event Tree Analysis (ETA)* dilakukan terhadap semua *node* untuk beberapa asumsi ukuran diameter kebocoran pipa. Sehingga proses analisa perhitungannya dapat dilihat pada gambar 3.

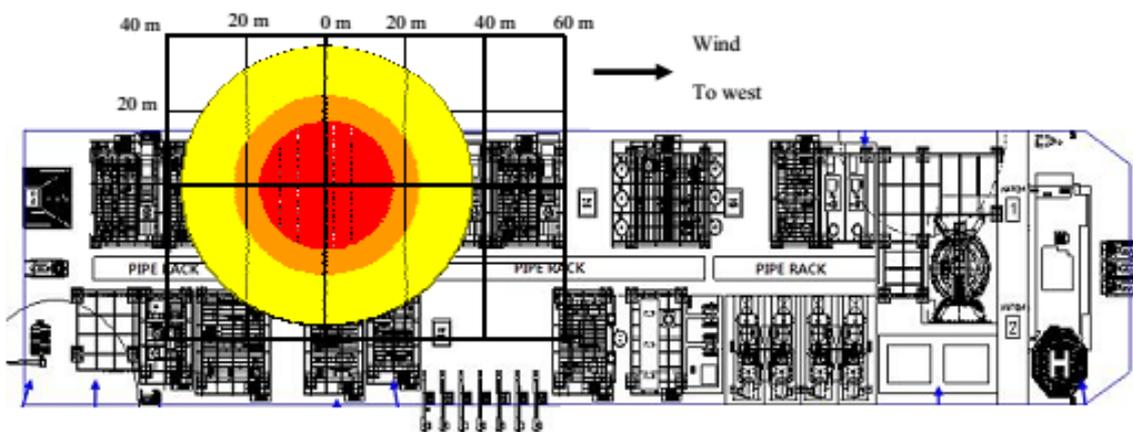
Dengan analisa perhitungan yang sama juga dilakukan terhadap semua *node* untuk tiap ukuran diameter kebocoran, sehingga hasilnya dapat dilihat pada Tabel 5.



Gambar 3 : Proses perhitungan frekuensi terjadinya incident untuk kebocoran 50 mm pada node 1

**Tabel 5** : Hasil perhitungan frekuensi terjadinya *insident* akibat *gas release*

Hole	Node	Gas Release	Jet Fire	Flash Fire	Gas Explosion	Gas Dispersion
50 mm	WMCHE	5.78E-04	2.06E-05	5.14E-08	0.00E+00	5.52E-04
	WMR	3.97E-04	1.41E-05	3.53E-08	0.00E+00	3.79E-04
	CMR	3.70E-04	1.32E-05	3.29E-08	0.00E+00	3.54E-04
	CMCHE	5.22E-04	1.86E-05	4.65E-08	0.00E+00	4.99E-04
100 mm	WMCHE	1.91E-04	7.65E-06	1.91E-08	0.00E+00	1.82E-04
	WMR	1.78E-04	7.13E-06	1.78E-08	0.00E+00	1.69E-04
	CMR	5.83E-05	2.15E-06	5.38E-09	0.00E+00	5.11E-05
	CMCHE	1.63E-04	6.52E-06	1.63E-08	0.00E+00	1.55E-04
200 mm	WMCHE	1.05E-04	4.22E-06	1.05E-09	1.05E-09	1.00E-04
	WMR	2.29E-05	9.16E-07	2.29E-09	2.29E-10	2.18E-05
	CMR	4.16E-05	1.66E-06	4.16E-09	4.16E-10	3.95E-05
	CMCHE	1.20E-04	4.79E-06	1.20E-09	1.20E-09	1.14E-04


**Gambar 4** : Hasil plot simulasi *jet fire* pada *Liquefaction process* dengan kebocoran 50 mm

### 3.3. Analisa Kosekuensi

Analisa kebakaran yang timbul karena gagalnya sistem adalah disimulasikan dengan menggunakan *software* ALOHA (Areal Locations Of Hazardous Area) yang memberikan output nilai besarnya kebocoran dan radius sebaran api atau gas yang terdispersi. Adapun skenario yang disimulasikan adalah *Gas Dispersion*, *Flash Fire*, *Gas Explosion* dan *Jet Fire* dengan sumber kebocoran adalah pipa. Setelah dilakukan simulasi dan diplotkan pada gambar FLNG unit maka hasilnya dapat dilihat pada Gambar 4.

Dari hasil plot simulasi pada sistem di kapal, dapat diketahui jumlah orang yang terdampak berdasarkan jumlah orang yang bekerja pada module proses/ instalasi lain di atas FLNG.

Dari Tabel 5 dapat disimpulkan bahwa untuk kemungkinan terjadinya *jet fire* untuk ukuran kebocoran 50 mm dengan jumlah orang yang terdampak sebanyak 5 orang dengan jarak 17-37 m, untuk kebocoran 100 mm dengan jumlah orang terdampak sebanyak 6 orang pada radius 21-45 m, serta untuk kebocoran 200 mm dengan jumlah terdampaknya total 8 orang pada jarak 23-50 m.

### 3.4. Representasi Risiko

Dari hasil analisa frekuensi dan konsekuensi untuk semua ukuran kebocoran pada setiap *node* maka dihasilkan seperti pada tabel berikut :

Setelah mendapatkan nilai frekuensi kejadian dan konsekuensi yang ditimbulkan karena terjadinya *insident*, maka kedua nilai tersebut dianalisa direpresentasikan dengan menggunakan *F-N curve*.

Tabel 6 : Hasil simulasi *Jet Fire*

No	Ukuran kebocoran (mm)	Jumlah orang terdampak (N)			Radius (m)
		Mati	Luka bakar	Terpapar panas	
1	50	1			17
			1		24
				3	37
2	100	1			21
			2		29
				3	45
3	200	1			23
			3		32
				4	50

Tabel 7 : Incident frequency vs Number of Fatalities (N)

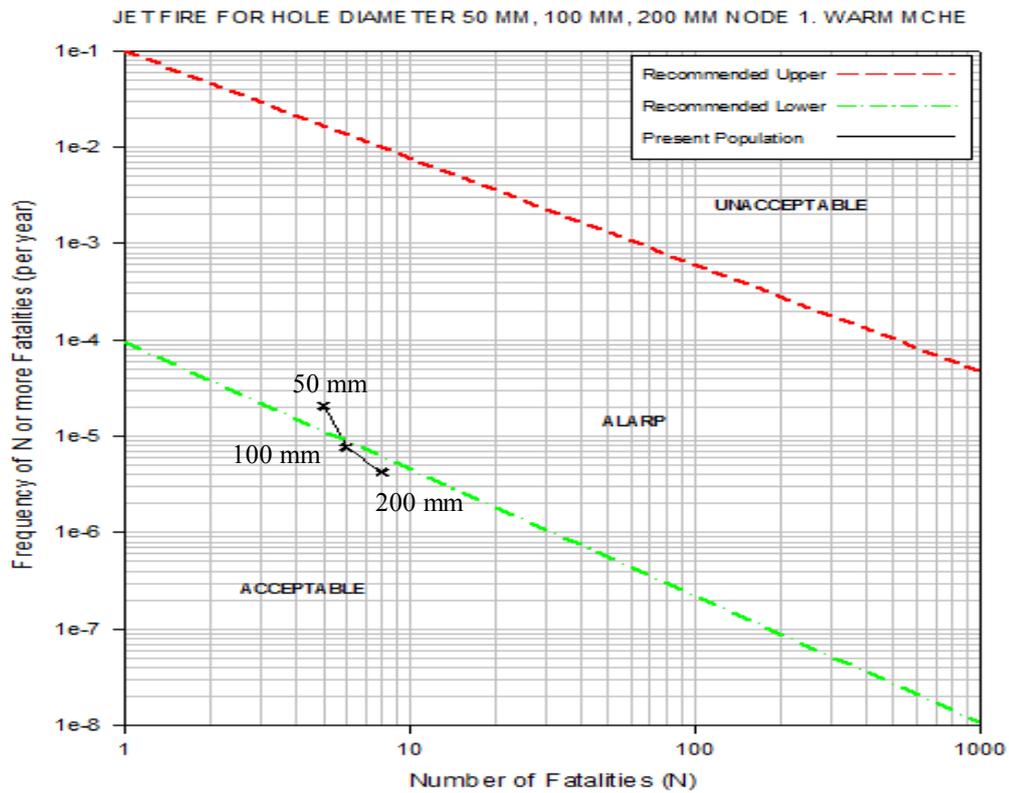
Hole	Node	Jet Fire	N	Flash Fire	N	Gas Explosion	N	Gas Dispersion	N
50 mm	WMCHE	2.06E-05	5	5.14E-08	-	0.00E+00	-	5.52E-04	-
	WMR	1.41E-05	5	3.53E-08	-	0.00E+00	-	3.79E-04	-
	CMR	1.32E-05	5	3.29E-08	-	0.00E+00	-	3.54E-04	-
	CMCHE	1.86E-05	5	4.65E-08	-	0.00E+00	-	4.99E-04	-
100 mm	WMCHE	7.65E-06	6	1.91E-08	-	0.00E+00	-	1.82E-04	-
	WMR	7.13E-06	6	1.78E-08	-	0.00E+00	-	1.69E-04	-
	CMR	2.15E-06	6	5.38E-09	-	0.00E+00	-	5.11E-05	-
	CMCHE	6.52E-06	6	1.63E-08	-	0.00E+00	-	1.55E-04	-
200 mm	WMCHE	4.22E-06	8	1.05E-09	-	1.05E-09	all	1.00E-04	-
	WMR	9.16E-07	8	2.29E-09	-	2.29E-10	all	2.18E-05	-
	CMR	1.66E-06	8	4.16E-09	-	4.16E-10	all	3.95E-05	-
	CMCHE	4.79E-06	8	1.20E-09	-	1.20E-09	all	1.14E-04	-

Pada grafik-grafik tersebut diatas menunjukkan bahwa representasi risiko untuk kebocoran 50 mm berada pada kondisi risiko ALARP untuk semua *node*, sedangkan untuk kebocoran 100 mm dan 200 mm berada kondisi risiko yang dapat diterima (*acceptable*) untuk semua *node*.

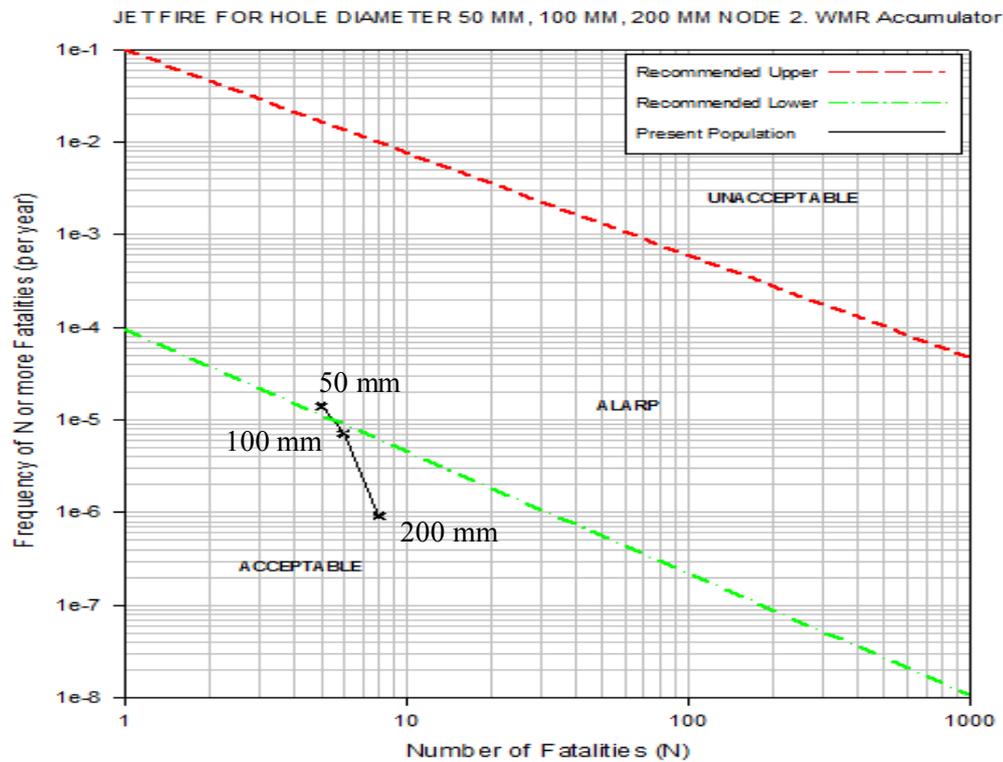
#### 4. Kesimpulan

- 1). Dari identifikasi *Hazard* yang telah dilakukan maka risiko *fire hazard* yang mungkin terjadi pada FLNG yaitu *Jet Fire*, *Gas Explosion* dan *Gas Dispersion*.
- 2). Dari hasil simulasi *fire Hazard* yang mungkin terjadi dengan *software* ALOHA diperoleh hasil sebagai berikut:

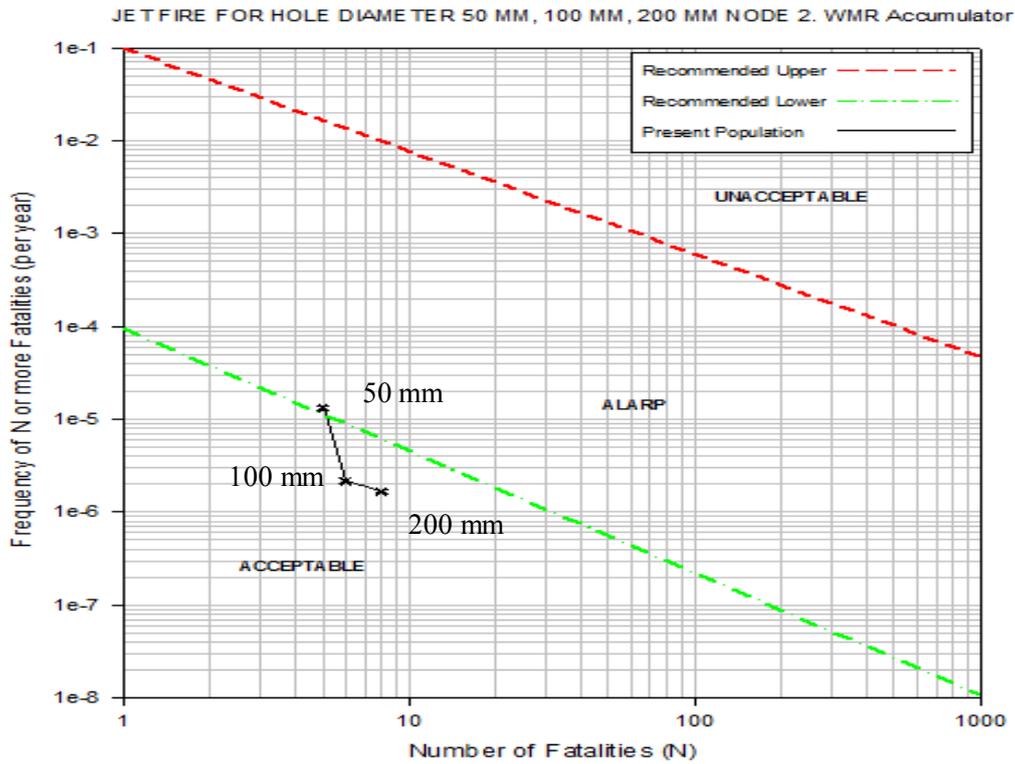
- a). Hasil analisa untuk *jet fire* diperoleh jarak sebaran api dengan skenario kebocoran 50 mm, 100 mm dan 200 mm dengan jarak 17 m - 50 m dengan total *fatalities* 8 orang.
- b). Untuk risiko *Gas Explosion* kemungkinan terjadinya sangat kecil yang terjadi pada *hole* 200 mm pada semua *node*, namun apabila terjadi dapat menghancurkan unit FLNG dengan jarak ledakan 644 m.
- c). Sedangkan untuk *Gas Dispersion* dengan kebocoran maksimum 50mm, 100mm, 200mm hanya dapat merelease gas sebesar 17,000 ppm dan tidak membahayakan, karena yang termasuk kategori berbahaya ialah bila gas yang terilis dengan kadar gas >50,000 ppm.



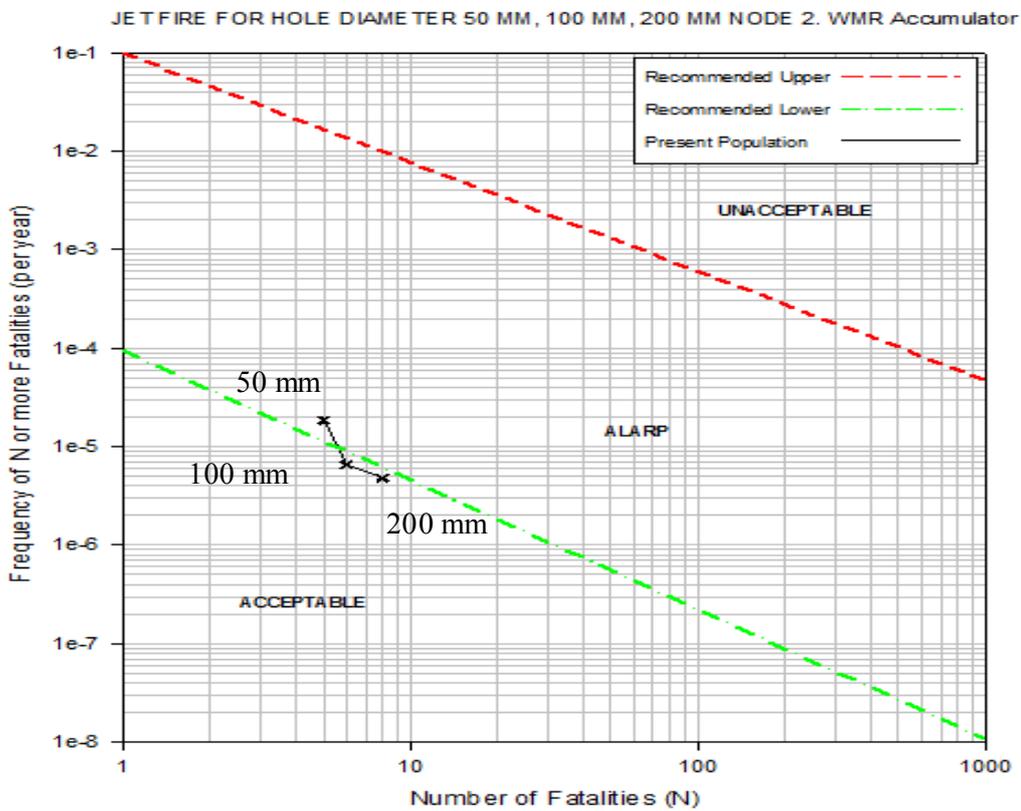
Gambar 5 : Representasi F-N curve jet fire event pada Node 1



Gambar 6 : Representasi F-N curve jet fire event pada Node 2



Gambar 7 : Representasi F-N curve jet fire event pada Node 3



Gambar 8 : Representasi F-N curve jet fire event pada Node 4

- 3). Berdasarkan dari plot hasil analisa frekuensi dan konsekuensi kedalam F-N curve, bentuk risiko yang mungkin terjadi yaitu *jet fire* untuk ukuran hole 50 mm berada pada kondisi ALARP. Dimana kondisi ini masih pada kondisi aman, namun bisa juga dilakukan mitigasi, salah satu langkah mitigasi yang dilakukan yaitu memperkecil peluang gagalnya *system* dengan menambah komponen pengaman pada sistem perpipaan. Sedangkan untuk diameter kebocoran 100 mm dan 200 mm berada pada kondisi *Acceptable* artinya risiko yang ditimbulkan dapat diterima.

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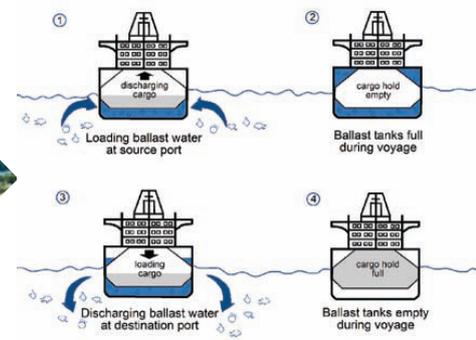
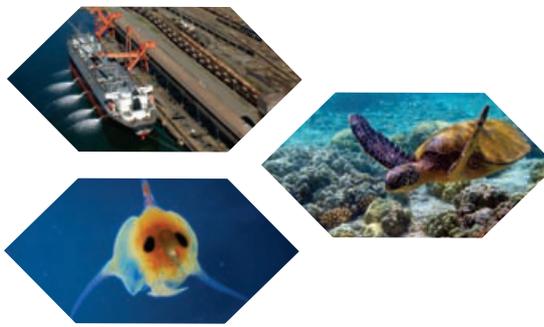


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# BKI 1<sup>st</sup> Guide in BWM Convention



## Ratifikasi BWM Convention oleh Indonesia:

November 2015



to be mandatory...

## Kapal yang terkena aturan BWM Convention

Pada dasarnya pemberlakuan peraturan BWM adalah untuk semua kapal yang didesain dengan sistem air ballast kecuali kapal yg menggunakan ballast tetap. Sedangkan persyaratan sertifikasi BWM adalah untuk kapal 400 GT atau lebih kecuali floating platform, FSU dan FPSO.

## Pemenuhan aturan BWM Convention

Untuk memenuhi aturan BWM Convention, kapal harus memiliki BWMP (*Ballast Water Management Plan*) yang harus disetujui. Gambaran umum BWMP adalah sebagai berikut:

- Prosedur keselamatan kapal terkait dengan BWM.
- Deskripsi langkah - langkah dalam menerapkan persyaratan BWM.
- Rincian prosedur dalam membuang sedimen di laut maupun di darat.
- adanya designate officer yang bertanggungjawab terhadap BWMP.

## Time frame implementasi BWM sebelum enter into force :

Tanggal Pembangunan	Kapasitas Air Ballast	2009	2012	2014	2016
< 2009	1.500 m <sup>3</sup> ≤ Kapasitas < 5.000 <sup>3</sup> m	D1 atau D2	D1 atau D2	D2	D2
< 2009	< 1.500 m <sup>3</sup> atau < 5.000 m <sup>3</sup>	D1 atau D2	D1 atau D2	D1 atau D2	D2
> 2009	< 5.000 m <sup>3</sup>	D2	D2	D2	D2
2009 ≤ tahun < 2012	≥ 5.000 m <sup>3</sup>	D1 atau D2	D1 atau D2	D1 atau D2	D2
≥ 2012	Semua kapasitas		D2	D2	D2

## Substantial Guidelines dalam BWM Convention:

- Guidelines for ballast water management and development of ballast water management plans (G4) diadopsi melalui resolusi MEPC.127(53)
- Guidelines for ballast water exchange (G6) diadopsi melalui resolusi MEPC.124(53)
- Guidelines for approval of ballast water management systems (G8) diadopsi melalui resolusi MEPC.174(58)
- Guidelines for ballast water exchange design and construction standards (G11) diadopsi melalui resolusi MEPC.149(55)

## Link informasi terkait BWM Convention:

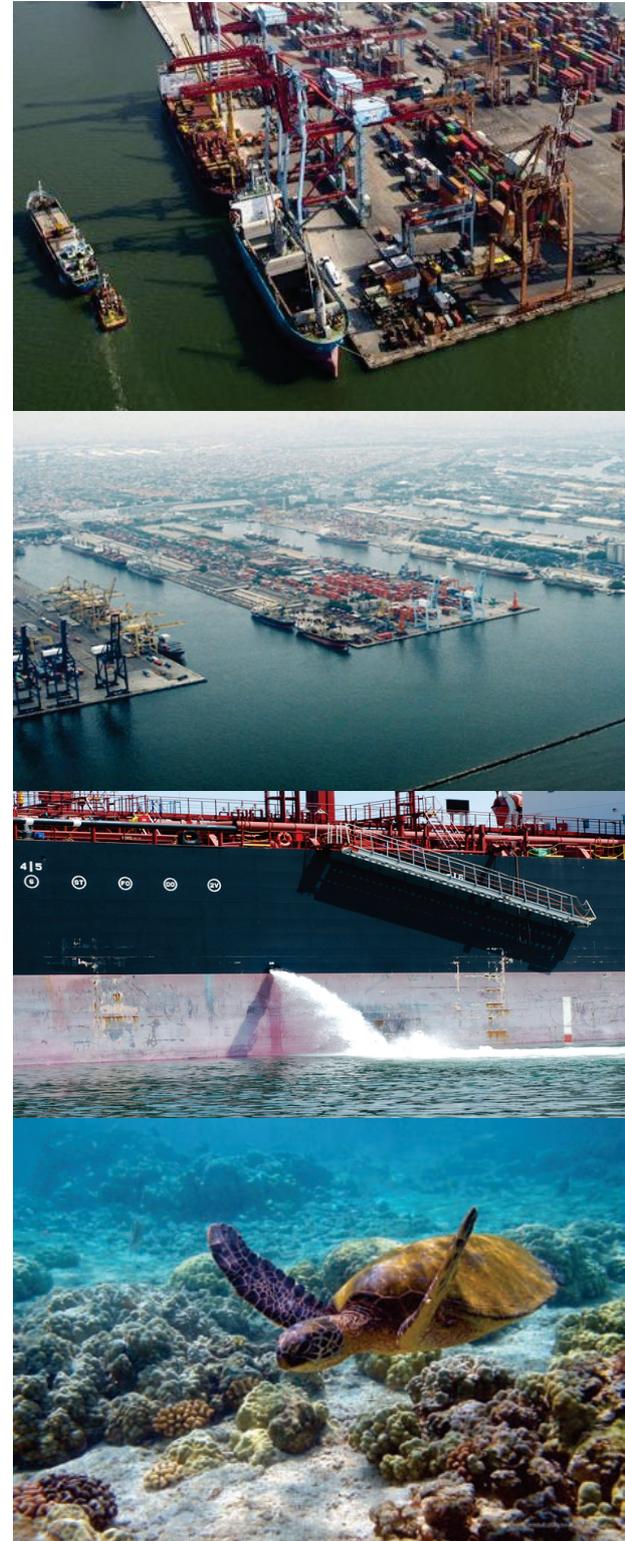
[www.imo.org](http://www.imo.org)  
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# MOP MODEL TO DESCRIBE INDONESIAN SHIP ACCIDENTS

Wanginingastuti Mutmainnah and Masao Furusho

## Abstract

Research has shown that human factors are the main cause of ship accidents around the world. However, it does not seem true for Indonesia. The National Transportation Safety Committee (NTSC) of Indonesia published its maritime report in 2013, which showed that human factors caused 35% of the accidents while the others (65%) were attributed to technical factors. This means that the human factors were not the main contributing factor in Indonesian maritime accidents. The objectives of this study are to find the dominant factor, whether Man, Machine, Media or Management, to isolate the most common failure which caused or contributed to the accidents, to understand the characteristics of Indonesian ship accident, and finally to propose some recommendations to reduce the number of accidents. The analyses utilized 4M (Man, Machine, Media and Management) factors which has been developed into 3-Dimensional shaped model, called as MOP (4M Overturned Pyramid) Model.

Keywords : Ship Accidents, MOP Model, Human Factors

## 1. Introduction

Recently, there have been many studies on human error. Almost all the research says that human errors are the most common contributing factor to accidents. In maritime field, The Maritime Safety Authority of New Zealand said that Human Factors cause 49% of accidents, while 35% are caused by technical factors and 16% environmental factors (Hetherington et al, 2006). Baker and Seah (2004) presented some data relating to human error from a number of sources. Data from Australian Transportation Safety Bureau (ATSB) stated that human errors contribute 85% to accidents, and the Canadian Transportation Safety Board (TSB Canada) 84%. Baker and Seah also presented information from the United States Coast Guard database of the top-Level Accident Cited Causation which stated that 44% were caused by Human Factors, while Engineering failure was 40%, Weather 15% and Hazardous material 1%. In another paper, Card (2005) stated that Human Factors and ergonomic design contributed up to 81% of all maritime accidents involving death, based on data from Marine Accident Investigation Branch (MAIB) of the United Kingdom Department of the Environment. Kiriya et al (2011) said in her paper that the percentage of marine casualties in Japan, caused by Hu-

man Factors was about 80% in total. From this data, we can conclude that Human Factors are a major cause of accidents.

In Indonesia, there are two institutions that publish maritime accidents in Indonesia. One is the Marine Court Decision (MCD) and other is National Transportation Safety Committee (NTSC). These two institutions also count the number of causal factors. However, these institutions have different results. According to MCD, human error caused 57% of the 316 accidents that occurred from 2003 to 2012. However, NTSC said that human errors contributed to only 35%, and that 65% were caused by technical factors. Of the 52 accidents, NTSC pursued in the same period, 40% consisted of sinking, 27% fire/explosion and collision for each, and 6% capsizing (IMT, 2013a&b and TAC, 2009). This means that human errors were not the dominant contributing factor in the accidents.

The report of accident investigations is published on NTSC's website. Thus, it is possible to re-analyze the data utilizing a different method. By utilizing the 4M Factors developed by The United States National Transportation Safety Board (NTSB), the author categorize the causal factors of the accidents to see if they can be better explained through a 4M Factor Model analysis.

## 2. Literature Review

### 2.1. Maritime Traffic System (MTS)

Before analyzing the maritime accidents, we have to know about the Maritime Traffic System (MTS). According to Kristiansen (2005), the MTS are actors, effects and deviations. It should be pointed out that the performance, or rather lack of performance from the actors, will be reflected in different types of deviations or non-conformities and result in some effects. While Rothblum (2000) said that MTS is a people system. In this system people interact with technology, the environment, and organizational factors. Since all the elements are connecting and affecting each other, the system is not as simple as dividing all the components to each elements. Mullai and Paulson (2011) say on their paper that the MTS is a very complex and large-scale socio-technical environment (STE) system comprising human and man-made entities that interact with each other and operate in a physical environment.

Grech et al (2008) cite the description of STE System from Furnham in 1997 as "a set of interrelated elements that functions as a unit for a specific purpose". While the main elements of the Maritime Traffic System are objects of transport, means of transport, infrastructures, and facilities, which are linked by the information system and transport-related activities (Mullai and Paulson, 2011). Mullai and Paulson (2011) also says that human is a very import-

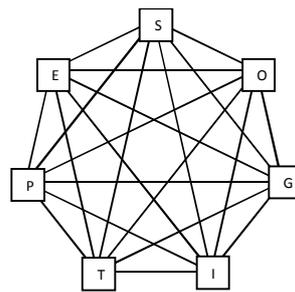
ant element to the Maritime Traffic System. Human designs, develops, builds, operates, manages, regulates, and interacts with all other elements of the system. Due to this interaction, this system can be obvious that ships can be analyzed as a combination of technology (the vessel, engine, equipment, instruments, etc) and a social system (the crew, their culture, norms, habits, custom, practices, etc.) (Grech et al, 2008). This STE system means that analyzing the maritime accidents can be said as system error rather than organizational or human error. Grech et al (2008) purposes that the STE System is consisted of seven domains. This model is also called as "The Septigon Model". Table 1 is the domains and the definition, which originate from Rizzo and Save in 1999.

### 2.2. Accident Models

As was stated before, STE is consisted of several domains, were the domain error, any accident will be happen. There are so many theories describing how the accidents can be happen or the phenomena of the accidents. Those theories can be described into three major phases, i.e. sequential, epidemiological, and systemic (Underwood and Waterson, 2013; Mullai and Paulsson, 2011). The Sequential Accident Model is the simplest types of accident models describing the accident as the result of time-ordered sequences of discrete events. The Epidemiological Accident Model describe the accident is like a disease, an outcome of any combination of factors, some manifest and some latent, that happen to exist together in space and time (Hol-

**Table 1 : The Septigon Model Term Definitions**

Term	Definition
Society and culture	It refers to the sociopolitical and economic environment in which the organization operates.
Physical Environment	It refers to the surrounding environment, such as weather, visibility conditions, obstructions to vision, physical workspace environment (air quality, temperature, lighting conditions, noise, smoke, vibration, ship motion, etc.)
Practice	It refers to such aspects as informal rules and custom. However, these are not related to written procedures or instructions.
Technology	It refers to equipment, vehicles, tools, manuals, and signs, and also deals with human machine interaction issues.
Individual	It refers to the human component, and incorporates such aspects as individual physical or sensory limitations, human physiology, psychological limitation, individual workload management and experience, skill, and knowledge.
Group	It refers to the relational and communication aspects, such as communication, interactions, team skills, crew/team resource management training, supervision, and regulatory activities. Group also deals with leadership, and teamwork.
Organizational environment	It refers to the company and management as well as the procedures, policies, norms, and formal rules.



**Figure 1 :** The Septigon Model: Society and culture, Physical Environment, Practice, Technology, Individual, Group, and Organizational environment Network (Revised, Grech et al, 2008)

Inagel, 2002), or in other words, the contributing failures are 'latent' and 'active' failures (Underwood and Waterson, 2013), as well as barriers. The Systemic Accident Model is design to describe the characteristic performance on the level of the system as a whole, rather than on the level of specific cause-effect "mechanisms" (Hollnagel, 2002). It describes the losses as the unexpected behavior of a system caused by uncontrolled relationships between its constituent parts (Underwood and Waterson, 2013).

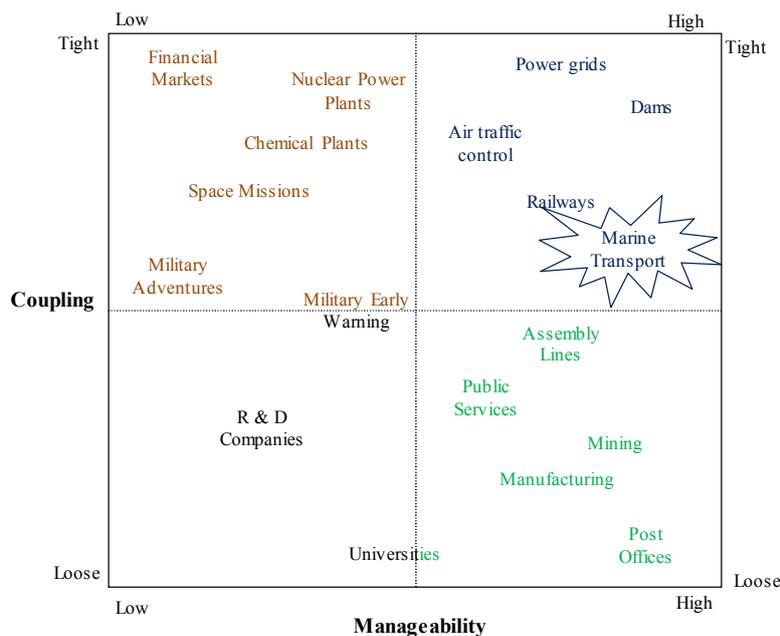
Even though Systemic Accident Model provides a depth understanding of complex accidents better than other models, it will not be efficient to apply this model for the simple accidents (Underwood and Waterson, 2013). Therefore, the model should be utilized correctly based on the complexity of the accident or the system. In order to determine the system's characteristic, Hollnagel (2008) propose a means of characterizing system, modifying the work of

Perrow (1984), which describes a system using the dimensions of coupling and manageability as shown on Figure 2. In that figure, Maritime Transport is better explained by Epidemiological Accident Model. This means that the accidents in the MTS can be analyzed by their Latent conditions, Barriers, and Active conditions.

### 3. Methods

#### 4M FACTOR MODEL

4M Factors is one kind of methodology used to analyze accident. This 4M Factors was found by the United States National Transportation Safety Board (NTSB). The factors are Man, Machine, Media, and Management. These term is much easier to be remembered for the interaction among the Maritime Traffic Systems' elements. By relating the Maritime Traffic System effect-people to



**Figure 2 :** Accident Model Categorization, whether Sequential, Epidemiological, or Systemic (adapted from Underwood and Waterson, 2013)

the 4M factors, the term of each element become as follows: People means Man, Technology means Machine, Environment means Media and Organization means Management. Table 2 explain how the term of Maritime Traffic System from Rothblum changed to be 4M Factors. Canale et al (2005) said that these 4M Factors can be utilized as

individual (self) centered properties, as well as relations among these factors (Furusho, 2000, 2013). However, the IM Model is designed for the navigational domain (Figure 3). All the relation whether are internal or intermediate concept are the interaction among the system to the safe in navigational activity. Since the Maritime Traffic System is

**Table 2 : MOP Model definition**

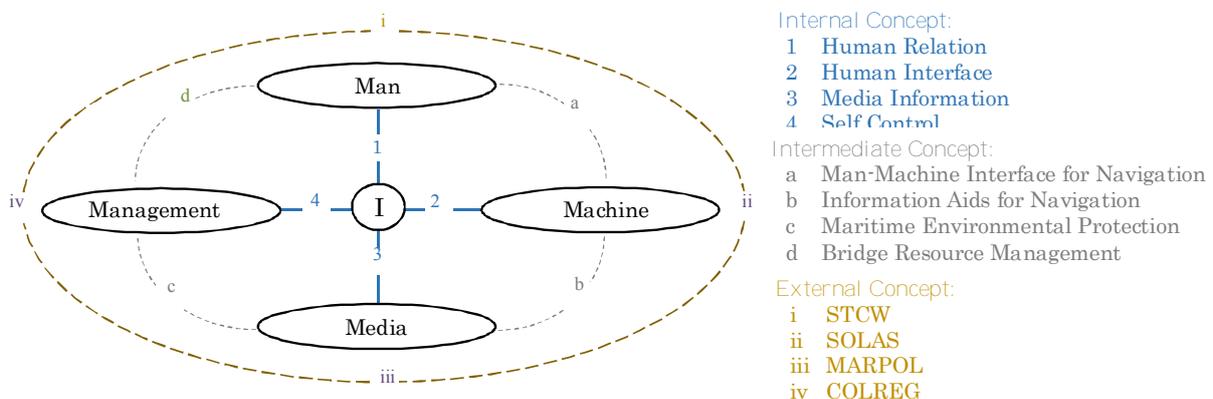
4M Factors	Definition	Example	Maritime Traffic System (Rothblum, 2000)	The Septigon (Grech et al, 2008)
Man (M1)	All elements that affect people doing their tasks	Knowledge, Skills, Abilities, Memory, Motivation, Alertness, Experience, etc.	People	Individual, Practice
Machine (M2)	All elements, including technology, which help people to complete their tasks	Equipment, Information display, Environmental design, Crew complements, Construction, etc.	Technology	Technology
Media (M3)	All environments that affect the system and/or people	Climatic/weather condition (temperature, noise, sea state, vibration, wave, tide, wind, etc.), Economic condition, Social politics, Culture, etc.	Environment	Society and Culture, Physical environment
Management (M3)	All elements that can control the system and/or people	Training scheme, Communication, Work schedule, Supervising/monitoring, Regulatory activities, Procedures, Rules, Maintenance, etc.	Organization	Group, Organizational environment

the first step of risk assessment which is termed hazard identification. These factors provide a basic framework for analyzing systems and determining the relationships between composite elements that work together to perform the mission.

wider than navigational activity, this model can be developed to a wider activity including the process of the preparation activity before sailing, the regulation, maintenance of the ships, and so on.

Related to this 4M Factors, Prof. M. Furusho designed the IM-Model which has an underlying concept based on the

The author modified the Maritime Traffic System (Rothblum, 2000), The Septigon (Grech et al, 2008) (Figure 2) and IM model from Furusho (2013) (Figure 3) become sim-



**Figure 3 : IM Model (revised Furusho, 2000, 2013)**

pler. Table 2 is the MOP Model description of each factor which is adapted from Rothblum (2000), Grech et al (2008) and some modification purposed by the author.

The simplification purposed by the author can be seen in Figure 4 as 3 Dimensional relationship. This model is drawn as 3 Dimensional relationship looking like 3 sided inverted pyramid, where each factor is connected and affecting each other. Man Factor should always be at the bottom. This because Man Factor is the intrinsic factor that the most affecting matter to other. Everybody has admitted that the core of the system is man, who design di equipment layout, decide the regulation, design the training scheme, design and construct the physical workspace, etc.

In that inverted pyramid, each 4M Factor becomes the corner which is connected to other factor by the edge. The edge line relation mean that each factor is affecting each other and of course affect to MTS. Since this inverted pyramid has 4 corners, there are 6 line relations that affect to MTS.

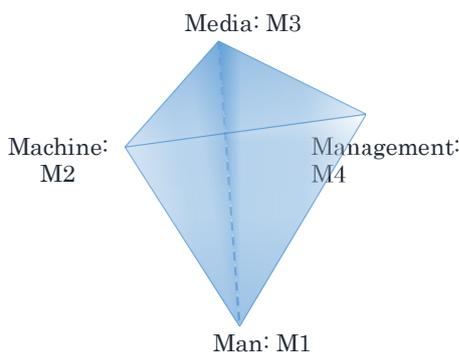


Figure 4 : MOP Modelx

#### 4. Analysis and Discussion

The data which is analyzed in this research is only 30 cases from 2007 to 2012. It consists of 13 fire, 8 collision, 6 sinking, and 3 capsizing cases. From the analysis, we can discuss several items as follows :

##### a. The Most Dominant Factor and Common Failures

The analysis results shows that the most dominant factor is Machine Factor with percentage of 35%, while Management Factors is 31%, Man Factor is 25%, and Media Factor is only 9%. It means that of all the investigated accident in 2007 until 2012, machine failure is the most dominant. This result is in accordance with the analysis which was carried out by NTSC that technical factor is the dominant cause for accident with

percentage of 65% compared to Human Factors which is only 35%.

Figure 5 is the detail failure classified to each factor. There are 7 types of causative factors in Machine Factor with total number of failure is 51. However, no one failure caused collision cases. All the failure was happened in fire, sinking, and capsizing cases (see Figure 5b). These causative factors are dominated by fire cases, with total number is 35 of 51 failures, since the dominant cases which were investigated by NTSC are fire. It makes sense that in all factor, fire is the dominant cases. However, the most common failure causing to fire accident is in this Machine Factor which is equipment failure. The total equipment failure of fire cases is 11 (see Figure 5b).

Equipment failure is not only dominating fire cases, but also all accidents. From 30 cases of accidents, there were 144 failures where equipment failure is one of the most common failure with total number of failure is 19. The most common failure in this equipment failure is exceeding passenger, cargoes or seafarer which were happen to 1 cases of fire, 4 cases of sinking, and 2 cases of capsizing. In case of collision, there were no machine failure causing the accident.

The collision is caused by Management Factor, with number of failure is 14, Man 11 failures, and media 5 failures. However, the most common causing failure to this collision cases is slipshod workmanship with total number of failure is 9. This causative factor is also one of the most common failure for all accident, the same as equipment failure, with number of failure is 19. In this slipshod workmanship, the most common failure is captain's decision was wrong which was happen to 5 cases of collision and 2 cases of sinking.

If we see each common failure, the cause is not only from one factor. For example, the exceeding passenger cargoes or seafarer can be caused by other factor, whether Man, Media or Management Factors, as well as the captain' decision was wrong. In other words, simply categorizing the causative factor to each factor is not enough because those causative factor is also caused or affected by other factors. The interaction of 2 M factors will be discussed in the next part.

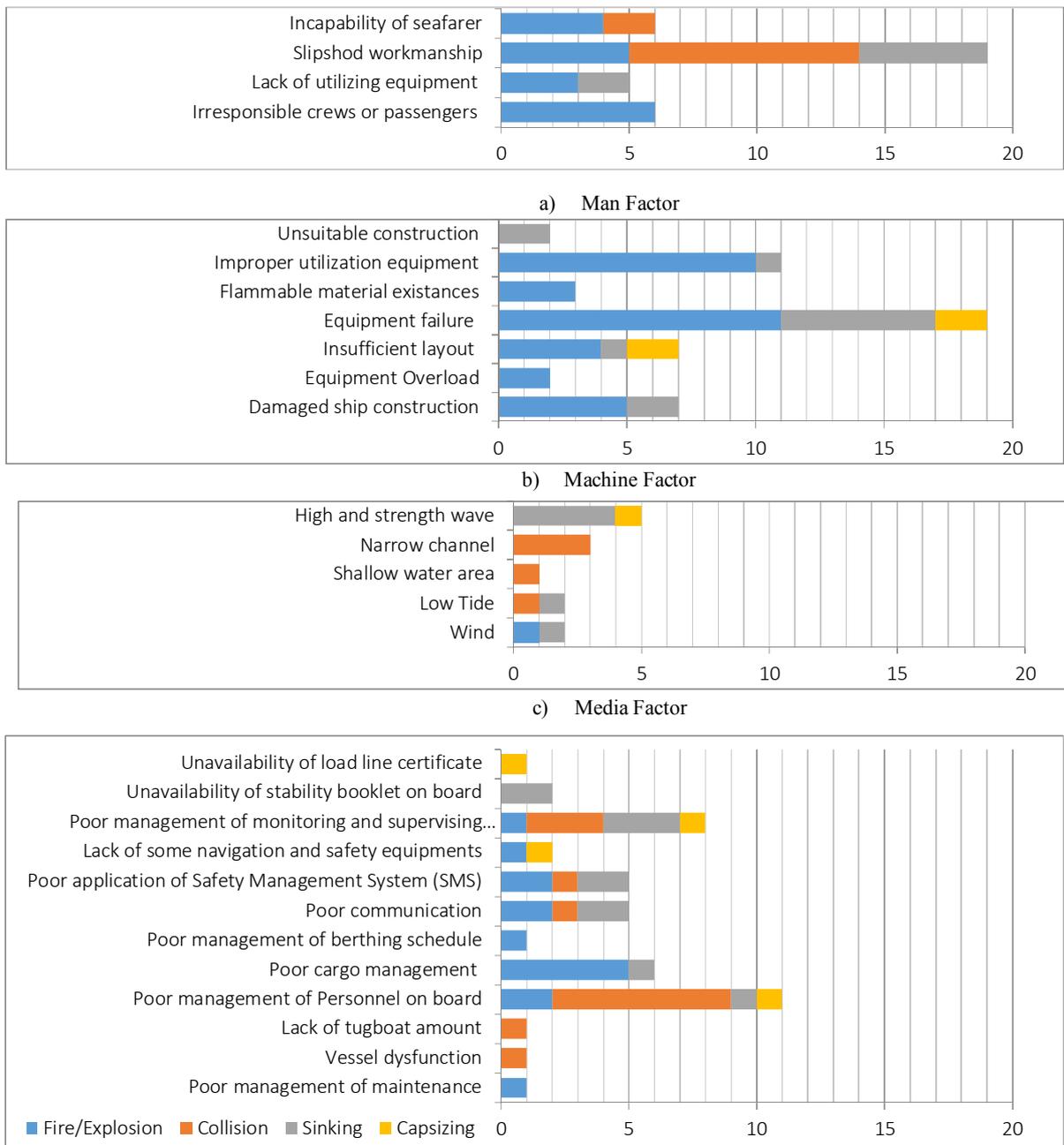


Figure 5 : Causative Factors for All Ship Accidents in Indonesia (2007-2012) (Unit: Number of Failures)

**b. The Characteristics of The Indonesian Ship Accidents**

As was known, failures happen were caused by not only one factor but also several factors play some roles. For example, the failure belonging to Man Factor can be affected by Machine, Media, or Management Factors. All the 4 M Factors are relating each other. Table 3 shows the relation matrix how the causative factors, which have been classified, are affected by other M factors.

Since the failure is affected by other factors, it seems that the relation between all factors is described. For

example, the first causative factors from Man Factors, that is Irresponsible crews or passengers. This item is classified as Man Factor since the crew or passenger did something that irresponsible. However, that irresponsible is affected by the Management Factors. One of the irresponsible crews which happened was some crew members were not on board when cargo loading was being done. This fault would not be happened if the monitoring was well done. The monitoring is belongs to Management Factors.

**Table 3 : 4M Factors Relation Matrix of Causative Factors for All Ship Accidents in Indonesia**

No.	4M Fact	Causative Factors	M1	M2	M3	M4
1	Man (M1)	Irresponsible crews or passengers (6)	o			o
2		Lack of utilizing equipment (5)	o	o		o
3		Slipshod workmanship (19)	o			o
4		Incapability of seafarer (6)	o		o	o
Total of affected causative factors (n)			4	1	1	4
Affecting Ratio (n/the number of causative factors = n/4)			1.00	0.25	0.25	1.00
1	Machine (M2)	Damaged ship construction (7)	o	o		o
2		Equipment Overload (2)	o	o	o	
3		Insufficient layout (7)	o	o		
4		Equipment failure (19)		o		o
5		Flammable material existences (3)	o	o		
6		Improper utilization equipment (11)		o		o
7		Unsuitable construction (2)	o	o		
Total of affected causative factors (n)			5	7	1	3
Affecting Ratio (n/the number of causative factors = n/7)			0.71	1.00	0.14	0.43
1	Media (M3)	Wind (2)			o	
2		Low Tide (2)			o	
3		Silting area (1)			o	
4		Narrow channel 3)			o	
5		High and strength wave (5)			o	
Total of affected causative factors (n)			0	0	5	0
Affecting Ratio (n/the number of causative factors = n/5)			0.00	0.00	1.00	0.00
1	Management (M4)	Poor management of maintenance (1)	o	o		o
2		Vessel dysfunction (1)	o			o
3		Lack of tugboat amount (1)			o	o
4		Poor management of Personnel on board (11)	o			o
5		Poor cargo management (6)	o	o		o
6		Poor management of berthing schedule (1)	o			o
7		Poor communication (5)	o	o		o
8		Poor application of Safety Management System (SMS) (5)	o			o
9		Lack of some navigation and safety equipment (2)		o		o
10		Poor management of monitoring and supervising from company/port (8)				o
11		Unavailability of stability booklet on board (2)	o			o
12		Unavailability of load line certificate (1)	o			o
Total of affected causative factors (n)			10	4	1	12
Affecting Ratio (n/the number of causative factors = n/12)			0.83	0.33	0.08	1.00

\*Note: 'o' means affected or related to the factor

As can be seen from MOP Model (Figure 4), all the factor is related each other which is shown by the edge of the volume. In the case of Indonesian ship accidents, those relationship can be shown by Table 4, which is another version of Table 3. The number inside the bracket are the number of failure happened in Indonesian ship accidents.

Let we see the causative factors in Machine Factors, which is damaged construction. This failure is also

caused by Man, and Management Factors. One example is leakage of high pressure fuel pipe happened in 2 accidents in fire case. This failure is belong to machine failure. However, the failure can be caused by the poor application of maintenance. The maintenance itself is belong to Management Factor while the one who do maintenance is belong to Man Factor. This relation can be illustrated into Man-Machine line (M12) which means the seafarer did not take care the pipe, Man-Management line (M14) which means the

**Table 4 :** Line Relation Matrix of Causative Factors for All Ship Accidents in Indonesia

No	4M Fact	Causative Factors	M12	M13	M14	M23	M24	M34
1	Man (M1)	Irresponsible crews or passengers (6)			o			
2		Lack of utilizing equipment (5)	o		o		o	
3		Slipshod workmanship (19)			o			
4		Incapability of seafarer (6)		o	o			o
1	Machine (M2)	Damaged ship construction (7)	o		o		o	
2		Equipment Overload (2)	o	o		o		
3		Insufficient layout (7)	o					
4		Equipment failure (19)					o	
5		Flammable material existences (3)	o					
6		Improper utilization equipment (11)					o	
7		Unsuitable construction (2)	o					
1	Media (M3)	Wind (2)						
2		Low Tide (2)						
3		Silting area (1)						
4		Narrow channel (3)						
5		High and strength wave (5)						
1	Management (M4)	Poor management of maintenance (1)	o		o		o	
2		Vessel dysfunction (1)			o			
3		Lack of tugboat amount (1)						o
4		Poor management of Personnel on board (11)			o			
5		Poor cargo management (6)	o		o		o	
6		Poor management of berthing schedule (1)	o					
7		Poor communication (5)	o		o		o	
8		Poor application of Safety Management System (SMS) (5)			o			
9		Lack of some navigation and safety equipment (2)					o	
10		Poor management of monitoring and supervising from company/port (8)			o			
11		Unavailability of stability booklet on board (2)			o			
12		Unavailability of load line certificate (1)			o			
Total of affected causative factors (n)			10	2	14	1	8	2
Affecting Ratio (n/the number of causative factors= n/28)			0.36	0.07	0.50	0.04	0.29	0.07

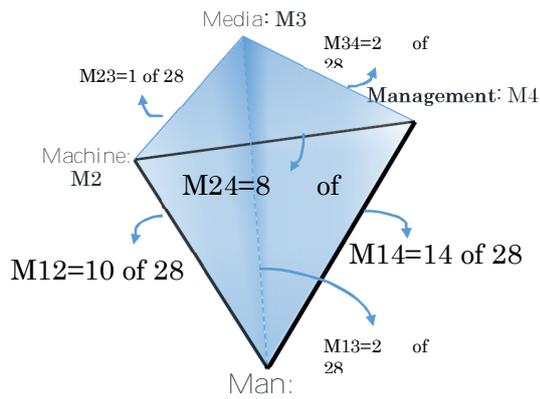
\*Note: 'o' means affected or related to the factor

seafarer did not run the maintenance well, and Machine- Management line (M24) which means the maintenance plan was not really effective to the pipe so that the pipe was failure.

As was stated in the previous part, the most common failure among all accidents are slipshod workmanship and equipment failure. Those factor are also affected by other factor that is Management Factor (see Table 3). As in captain's decision was not appropriate, it can be caused by lack of the communication among captain, other seafarers, etc. this communication is belong to Management Factor. As in equipment failure, the exceeding passengers, cargoes, and seafarers is also can be caused by Management Factor, such as lack of

supervising or monitoring by the company.

Table 3 and 4 is made due to the 4M Factor model in Figure 4 All the factors are related and affecting each other. In the case of the most common failures, both of them are affected by Management Factor which is in latent condition. Table 3 shows that Man and Management Factors affect most of the causative factors, then Machine Factor is moderate and Media Factor is not really affects. The relation between 2 M Factor is provided by Table 4. From this table we can see that the relational factor which is affected to the accidents in Indonesia are Man-Management Line, Man-Machine Line, and Machine-Management Line. The relation lines can be drawn to the 4M Factor model as in Figure 6.



**Figure 6 :** Line Relation illustration to the Indonesian Ship Accident

From that result, the characteristic of Indonesian accident can be obtained. The Man-Management Line is the most influencing relation to the accidents, where the Man-Machine and Machine-Management Lines also influence the accident lower than the Man-Management Factor.

The inverted pyramid is unstable, not like the pyramid. This geometrical can represent the Maritime Traffic System where the errors caused by Man Factor cannot be eliminated because human has tendency to make errors but it can be reduced. To reduce the errors, the system should be kept balance by making all the corners and edges of the pyramid, or all the 4M Factors and the relation between two factors, has the same power.

**c. Recommendations**

The previous part obtains that the interaction between Man-Management, Man-Machine, and Machine-Management Lines are the influence factor to the accidents in Indonesia. Since the Management Factor is latent failure, it has to be considered that the failure in latent condition can be hidden for long time in the system until there is a trigger from barriers into active failures, then the accident can be happened. It should be pointed out that paying more attention to the causative factor which is related to Management Factor should be the first effort to reduce the accidents. By fixing the Management Factor, some of the causative factors in Man and Machine Factors should be able to reduce as well. The next step is fixing the rest of causative factors. Even though the failures cannot be eliminated, at least it can be reduced by some efforts.

The efforts that can be done to reduce the causative factors in management such as: reviewing the available regulations, increase the quality of training so that the communication can be better, increase the supervising or monitoring from the company, and etc. the study about this recommendation will be continued in my Doctoral research activity.

**5. Conclusion**

From the result of the analysis and the discussion, the conclusions obtained are:

**a. Machine Factor is the dominant factor**

By simply categorizing the causative factors into 4M Factors, Machine Factor was seen as the dominant factor in Indonesian ship accidents. This means that the direct cause of most accidents is a failure of a Machine Factor failure. However, these direct causes are also affected by other factors.

**b. Slipshod workmanship and equipment failures are the most common failures**

Of the causative factors, two factors stand out with a large number of active failures, 19 each, slipshod workmanship and equipment failures. The affecting factors that can lead to these kinds of failures are associated with Management Factor. Since the Management Factor is a latent condition, fixing the causative factors in Management Factor will be very important.

**c. Interaction between Man and Management, Man and Machine, and Machine and Management Lines are Vulnerable to Failure**

From Table 4, we can see that 3 lines of interaction are the influencing factors of Indonesian accidents, since the causative factors are also affected by these other factors. These are the barriers that lead to the active failures that happen in Indonesian ship accidents.

The prevention action for reducing the number of accidents can be found in the latent failures, barriers, and active failures. To prevent latent failures, reducing the number of causative factors in Management Factor is needed. Fixing the barriers is also important since barriers can lead to active failures, we need to balance the power of each corner and edge so that they have the same power. The most urgent barrier to be fixed are

the causative factors that are influenced through the Man-Management, Man-Machine, and Machine-Management Lines. A concrete solution for reducing the number of accidents will be the target of future research. A Comparison study of the other countries' accidents would also be of interest to see if any inherent tendencies exist.

### Acknowledgement

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# THE COLLISION ACCIDENT OF THE INDONESIAN RO-RO CAR-PASSENGER FERRY KMP. BAHUGA JAYA VERSUS SINGAPORE GAS CARRIER MV. NORGAS CATHINKA IN SUNDA STRAIT INDONESIAN INNOCENT PASSAGE

Teguh Sastrodiwongso, Aleik Nurwahyudy, Renan Hafsar

## Abstract

The collision of Ro-Ro Car-Passenger Ferry KMP. Bahuga Jaya versus Gas Carrier MV. Norgas Cathinka on 26 September 2012 in Sunda Strait was investigated by NTSC. The Investigator Team in Charge have finished their investigation task and the Final Report. The factual findings and analysis show that short time after collision Bahuga Jaya started to list and then fully sank with 7 fatalities, but on the contrary Norgas Cathinka only suffering minor damage on its bow structure, none of her crew was suffered from injury. The main causal factor of collision is none of both vessel was presenting consistency in the implementation of Collision avoidance regulation.

Keywords : vessel, accident, collision, safety.

## 1. Introduction

The National Transportation Safety Committee of the Republic of Indonesia (NTSC) has conducted investigation into the collision accident of an Indonesian flag Ro-Ro Car-Passenger Ferry KMP. *Bahuga Jaya* versus an Singapore Flag Gas Carrier MV. *Norgas Canthika*. The serious accident occurred on 26 September 2012 in Sunda Strait ferry route crossing the west part of Indonesian water Innocent Passage-ALKI 1.

Bahuga Jaya was collided on the forward starboard side wall structure. Unfortunately, short time later she started to list and fully sank. On the contrary *Norgas Canthika* only suffering minor damage on its bow structure, none of her crew was suffered from injury. The SAR of Indonesia rescued 206 survivors and recovered 7 fatalities i.e. 6 passengers and one crew (Chief Mate) of *Bahuga Jaya*.

NTSC has issued Final Report of the Investigation (KNKT-12-09-03-03). In addition to the conclusion of the accident, NTSC issued recommendations to the involved parties with aim to prevent recurrence in future. NTSC encourages all those parties to take safety action if any, they had carried out or were planning to carry out in relations to each safety issue relevant

to their organization. The material of this paper was based on the NTSC Final Report KNKT-12-09-03-03.

## 2. The Investigation Into The Accident (National Transportation Safety Committee, 2013)

On 26 September 2012, NTSC had received the occurrence. Subsequently, NTSC dispatch investigation team to collect information to the directly involved parties. *Bahuga Jaya* Master, Chief Engineer, helmsman on duty and passengers were interviewed. the shore management of *Bahuga Jaya* also interviewed. NTSC investigator received copy of relevant document including Company SMS, maintenance report, passenger and cargo manifest, crew list and ship certificate.

On 27 September 2012, NTSC Investigators attended the MV. *Norgas Canthika* while ship was anchored near to Suralaya Port, Banten. As the Master Chief Mate and Helmsman on duty were being interviewed by local Authority at shore, NTSC Investigators were interviewing remaining crews aiming their perspective to the accident. Copies of relevant document were obtained included ship's log book, course recorder, master's night order, and company's procedure. With assistance from manufacturer's Technician, VDR data was downloaded.

Additional information also provided by the Merak Ferry Port Management to obtained the STC's ferry activities log data prior to the accident and the Head Office of Biro Klasifikasi Indonesia (BKI) i.e. Indonesian Ship Classification Society for ship's data and its latest Class survey report.

NTSC Investigators attended MV. *Geulis Rauh* to interview the Chief Mate who witnessing the collision.

On 1 October 2012, NTSC conduct joint investigation with Maritime and Port Authority (MPA) of Singapore as *Norgas Cathinka's* flagstate. NTSC Investigators and MPA Investigator attended *Norgas Cathinka* to interview the Master, Chief Mate and Helmsman on Duty.

To obtain additional data of manoeuvring pattern of Ferries that servicing Merak – Bakauheni ferry route, on 1 – 4 January 2013 NTSC conduct survey. NTSC conducted survey to 25 ships that servicing the route with aim to identify the likelihood of ship manoeuvring when in crossing situation with the other ship.

### 3. The Technical Information Of The Vessels (National Transportation Safety Committee, 2013)

#### 3.1. KMP. Bahuga Jaya ex Tri Star 8 (Figure 1)

##### Main Particulars of the Vessel

KMP. *Bahuga Jaya* (IMO No. 7206392/Call sign YEBA) was an Indonesian flag Ro-Ro Car Passenger Ferry. She was of steel construction and was built in 1972 by Ulstein Mek. Verksted AS at their Ulsteinvik Yard, Norway.



**Figure 1** : KMP. Bahuga Jaya (National Transportation Safety Committee, 2013)

The main particulars of the vessel : an overall length of 92.30 m, a moulded breadth of 16.20 m, a moulded depth of 5.23 m and a deadweight of 765 tonnes at its summer draft of 5.23 m.

The vessel was owned and operated by PT. Atosim Lampung Pelayaran and had been operating on the Merak to Bakauheni ferry route since 2007. The vessel was registered and classed by Indonesian Ship Classification Society, Biro Klasifikasi Indonesia (BKI).

The vessel had two car decks and one passenger accommodation deck. The car decks had a capacity of 200 vehicles of various types and the accommodation deck could carry 351 passengers.

##### Machinery and Propulsion System

2 (two) unit four stroke, single acting, Stork Werkspoor 8TM410 Diesel engine were installed in the Twin Screw *Bahuga Jaya* as her main engines with a maximum continuous rating of 3,235 kW at 530 RPM respectively. The screw propellers were of controllable pitch propeller type (CPP) and the vessel was also fitted with a bow thruster. The service speed of the vessel was about 19 knots.

##### The Navigational and Telecommunication Equipment

*Bahuga Jaya* equipped with navigational equipment in comply with the Indonesian Safety Sstandard. Radio Facilities : VHF: Encoder DSC, DSC with Receiver, Radio Telefony; MF: Radiotelefony;

Navigational system & equipment : Secondary Means of Alerting; Navtex Receiver;COSPAS SARSAT;

Radar transponder ; Standard Magnetic Compass & Spare; Means of Correcting headings & Barring; Nautical Chart & Nautical Publication; Global Navigation Satellite system Receiver AIS;

Radar 9 GHz and secondary; Electronic Plotting Aid; Emergency Telephone; International Code of Signals

##### The Cargo and Passenger Manifest

At the time of accident, KMP. *Bahuga Jaya* carrying Passengers and 78 various type of vehicles. According to the passenger list, but there were only 12 registered passengers.

Vehicles onboard : Upper car deck : 10 unit motor cycles; 22 unit small cars; 11 unit trucks; Lower car deck: 17 unit medium size lorries; 18 unit heavy lorries.

### 3.2. MV. Norgas Cathinka (Figure 2)

#### Main Particulars of the Vessel

MV. *Norgas Cathinka* (IMO No. 9370654) is a Singapore registered gas carrier. The ship is of steel construction and was built in 2009 by Taizhou Wuzhou Shipbuilding Industry Co Ltd at their Taizhou ZJ Yard, China. It has an overall length of 109.5 m, a moulded beam of 21.0 m a draught of 8.0 m and a displacement of 14,781 tonnes



**Figure 2 :**

MV. *Norgas Cathinka* anchoring at Suralaya, Banten (National Transportation Safety Committee, 2013)

At the time of accident, MV. *Norgas Cathinka* was owned by Taizhou Hull No. WZL0502 L.L.C and chartered by I.M Skaugen Marine Services Pte, Ltd, Norway.

She was classed with Germanischer Lloyd (GL). The ship's bridge and accommodation were located aft of four cylinder type 'C' cargo tanks that had a total capacity of 9,626 m<sup>3</sup>.

At the time of the accident, the ship was carrying 3,045 MT of Polymer Grade Propylene that had been loaded in Brazil for delivery to China.

#### The Propulsion and Machinery System

Propulsive power was provided by two four stroke, single acting, Daihatsu 8DKM-28 diesel engines each with a maximum continuous rating of 2,500 kW at 750 RPM. Each engine was clutched into a reduction gearbox which, in turn, drove a fixed pitch propeller. The ship had a service speed of 13.5 knots at a shaft rotation speed of 190 RPM.

#### The Navigational and telecommunication equipment

The navigation bridge was equipped with navigational equipment consistent with SOLAS Requirement. This included an auto gyro pilot, ARPA equipped radars, GPS plotter, echo-sounder, AIS, ECDIS, VHF radios, satellite telephone and Furuno VR-3000 voyage data recorder (VDR).

#### The Cargo Information

At the time of the accident, MV. *Norgas Cathinka* was carrying Polymer Grade Propylene in Bulk with total of 3.045 MT. The cargo was loaded in Brazil and will be transported to China.

#### The Ship Passage Plan

*Norgas Cathinka's* passage plan from Brazil to China was divided into 3 passages i.e. Brazil to Durban, South Africa (1st bunkering port), Durban to Singapore (2nd bunkering port) and Singapore to China.

The passage plan from Durban to Singapore prepared on the 6 September 2012 was approved by the Master. The passage plan indicated that NC will transit Sunda Strait at Way-point 6 and 7. At the time of the incident, NC was proceeding towards Way-point 7.

The passage plan's information for travelling through Sunda Strait includes heavy crossing traffic and to maintain standing watch 1 or 2 (watch level) at the discretion by the Master. On this voyage through the strait, the Master decided to maintain standing watch 2.

## 4. Indonesian Innocent Passage And Merak - Bakauheni Ferry Route (National Transportation Safety Committee, 2013)

The Merak to Bakauheni ferry route, crossing the Sunda Strait between the islands of Jawa and Sumatera, is Indonesia's busiest passenger/vehicle ferry route (Figure 3). The Sunda Strait also sees the passage of a large number of domestic and international trading ships as the strait is part of one of three designated Indonesian Archipelagic Sea Lanes (ALKI) that are used by north/south bound ships when transiting through Indonesian waters. As a result, the British Admiralty navigational chart 2056 covering the Sunda Strait and its approaches contains the following warning 'Mariners are warned that ferries cross

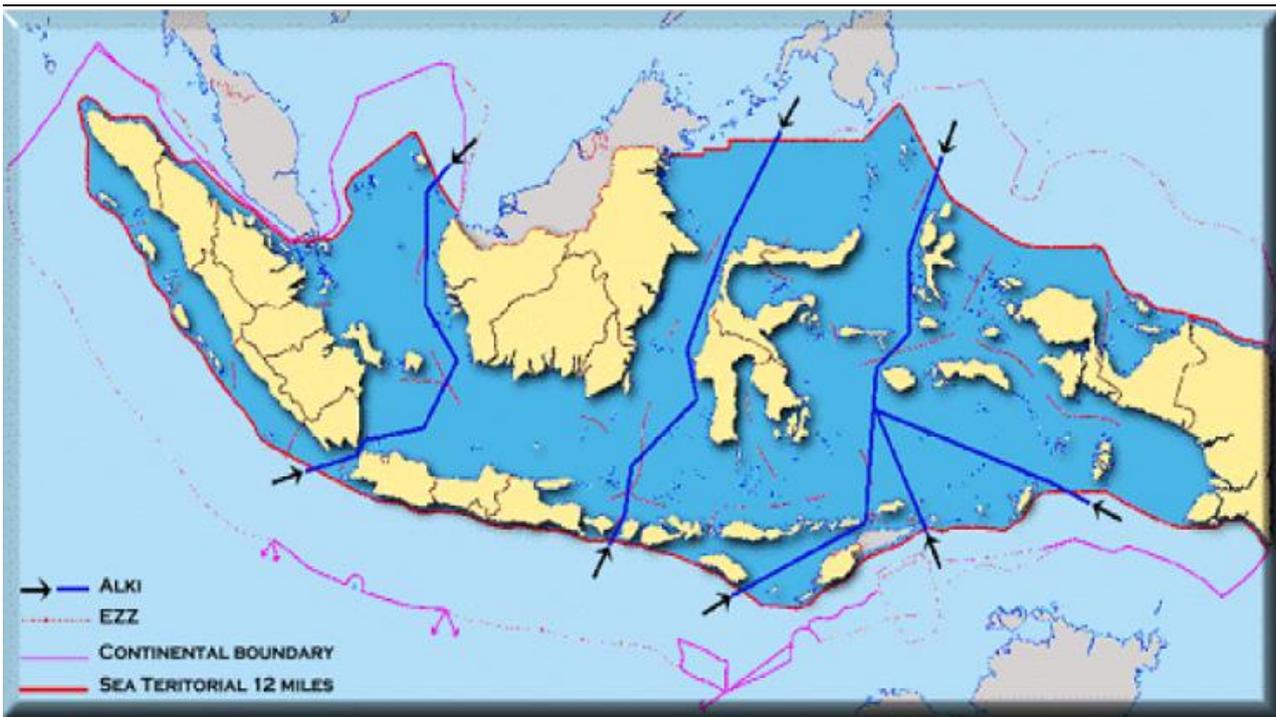


Figure 3 : Indonesia Innocent Passage (National Transportation Safety Committee, 2013)

Selat Sunda [Sunda Strait] between Bakauheni (5°52'S 105°45'E) in Sumatera and ports on the north coast of Jawa'.

According to the statistics data issued by the Ministry of Transportation, there were 26,291 ferry trips from Merak to Bakauheni in 2011. This translates to about 76 trips per day or about 3 every hour. According to the statistical data, 1,400,986 people and 1,773,672 vehicles were transported by the various ferries operating on this route.

The route is about 15 nautical miles in length and ferries normally complete the journey in about 2 to 3 hours. According to 2012 data, the route was serviced by 41 ships which were operated by 5 shipping companies.

Ferry Port Management provides a Ship Traffic Controller (STC) whose main function is to control and supervise the arrival and departure of ferries at the ports. The STC is equipped with radar and AIS monitoring systems and uses frequency 8250 to communicate with the local ferries and channel 16 to communicate with other shipping.

### 5. The Collision Accident (National Transportation Safety Committee, 2013)

At 0305<sup>1</sup> on 26 September 2012, *Bahuga Jaya* sailed from Merak bound for Bakauheni. The ferry was on a scheduled, regular, westbound crossing of Sunda Strait. The passage would be made at its usual speed of about 10 knots and would take about 2 hours. The master, chief mate and a helmsman were on the ferry's bridge. The weather in the area was good with light to moderate winds and good visibility.

The chief mate was on the look-out and the helmsman was on the con. The chief mate observing the route situation at the wing bridge. Meanwhile, *Norgas Cathinka* was approaching Sunda Strait from the south on a northeasterly course. The chief mate and a seaman were on the bridge. The chief mate was using the ARPA radar on a north-up, relative motion display on the 6 mile range scale. The centre of the display had been offset to enable the chief mate to see further in the ahead direction.

At 0420, *Norgas Cathinka* was on a heading of 049 (T) and making good a course of about 051 (T) and a speed of about 12 knots. The ship was in a location about 2 Nmiles from Kandang Balak Island and there were a number of vessels in the area. The radar's trails function was being used by the chief mate to continuously indicate the relative movement of targets. The traffic being monitored more closely was acquired either as an ARPA or an AIS target.

<sup>1</sup>All times referred to in the paper are local time, Indonesian Western Time, (UTC+7, The time being kept on board *Norgas Cathinka* was UTC+8.

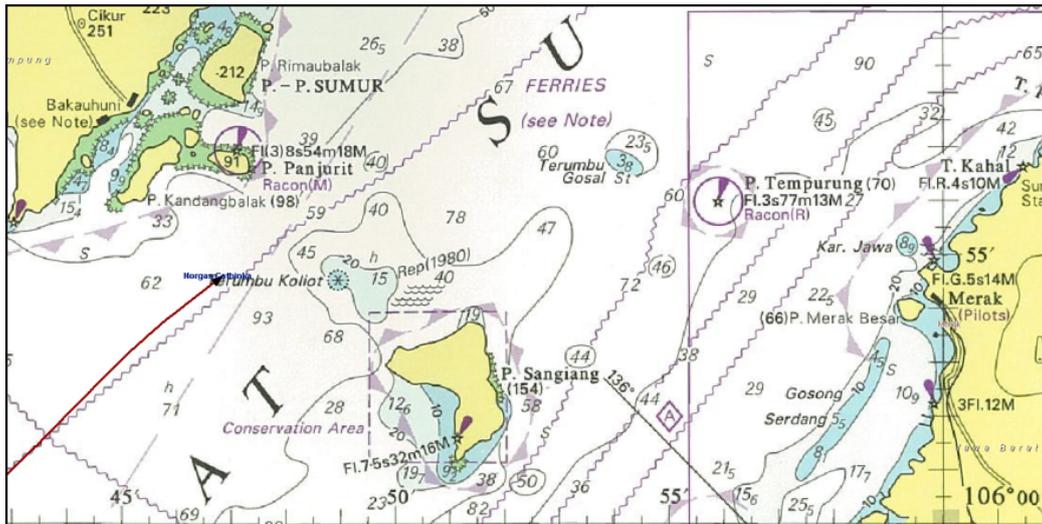


Figure 4 : Norgas Cathinka approached the Strait at 0400 (National Transportation Safety Committee, 2013)

At the time, three eastbound radar targets on *Norgas Cathinka's* port bow would have been of paramount interest (Figure 4). These vessels were on east-south-easterly courses and could have been ferries. They were between about one and three points on the port bow and about 3 to 4 miles distant. A target on a south-westerly course, about three points to starboard and over 2 miles off, was passing clear. Two westbound targets on the same bearing over 6 miles off had just started to appear on the radar display.

At 0426, one of the eastbound targets (ARPA target 98 in Figure 4) crossed *Norgas Cathinka's* bow more than 3 miles off. The other eastbound targets were also acquired (targets 99 and Caitlyn).

At 0429, target 99 crossed *Norgas Cathinka's* bow at a distance of more than 1.5 miles. The ARPA was indicating that *Caitlyn* would also cross ahead and clear of the ship.

At 0432, *Norgas Cathinka's* chief mate used the radar's electronic bearing line (EBL) to check the bearing of one of the two westbound targets that had appeared on the display more than 12 minutes earlier. The target's bearing was 075 (T) and its relative trail indicated that it would pass close to the ship. The target was 3.3 miles off and acquired as an AIS target. Its name, *Bahuga Jaya*, appeared on the radar display. The ferry was making good a course of about 285 (T) at a speed of 9.7 knots. Its closest point of approach (CPA) indicated nearly zero after about 11 minutes.

The ferry was on a collision course with the ship.

At 0434, *Norgas Cathinka's* chief mate acquired the other westbound target. This AIS target was also a ferry, *Gelis Rauh*, and the ARPA indicated it would pass about a mile astern.

At 0436, target 100 crossed *Norgas Cathinka's* bow at a distance of about 1 mile. Target 99 was nearly abeam to starboard and passing clear while target 98 was well clear. *Bahuga Jaya* was still on a collision course on a bearing of about 074 (T).

At 0439½, *Norgas Cathinka* was in position 5 53.1' S, 105 49.6' E, just past a 031 (T) course alteration as per its passage plan. The ship was still on a heading of 049 (T) and *Bahuga Jaya* was 1.3 miles off. There had not been any appreciable change to its bearing which were now 072 (T). The ARPA predicted a CPA of 0.1 of a mile (i.e. a close quarters situation or collision) after 5 minutes.

At about 0440, *Norgas Cathinka's* chief mate decided to take action to avoid collision. Using the autopilot, he adjusted the heading order to 050 (T).

At about the same time, *Bahuga Jaya's* chief mate also decided to take action to avoid collision. He ordered port 20 and the helmsman executed his order.

At 0440½, *Norgas Cathinka's* heading was 050 (T). The chief mate then began adjusting the heading order further to starboard on the autopilot. At about the same time, *Bahuga Jaya's* course change to port became apparent to him.

By 0441, *Norgas Cathinka's* heading was 055 (T) and turning to 060 (T) as set on the autopilot. The helmsman was standing near the steering stand and could see *Bahuga Jaya's* change of course to port. The ferry was now less than a mile off.

At 0442, *Norgas Cathinka's* heading was 060 (T) and *Bahuga Jaya* was less than 0.7 of a mile and nearly ahead. *Norgas Cathinka's* chief mate saw that the ferry was still turning to port.

At about 0442½, *Bahuga Jaya's* chief mate ordered hard a port. *Norgas Cathinka* was less than half a mile ahead. By this time, the ship's chief mate had changed to hand steering mode and had turned the wheel to starboard to alter course more quickly.

At 0443, *Norgas Cathinka's* heading was 066 (T) and turning to starboard. *Bahuga Jaya* was 0.3 of a mile directly ahead of the ship and turning quickly to port. The two vessels were closing rapidly at a speed where they would meet in about 1 minute.

*Gelis Rauh*, the other ferry, was half a mile away from the close quarters situation. It had altered course to port to keep clear of both vessels and pass further astern of *Norgas Cathinka*.

At 0443¼, *Bahuga Jaya's* chief mate made a hurried attempt to contact *Norgas Cathinka* on VHF radio channel 16. He called the ship's name three times, but he received no response.

*Norgas Cathinka's* chief mate was still at the steering stand and he did not understand the radio call. At 0443¾, with *Bahuga Jaya* about 100 m away, he turned the wheel hard over to starboard.

At 0444¼, *Norgas Cathinka's* heading was 135 (T) and turning quickly to starboard. A few seconds later, the port bow of the ship collided with *Bahuga Jaya's* port side, aft of the bridge.

At 0444½, aware of the collision, *Gelis Rauh* made a distress (Mayday) call on VHF radio channel 16.

At 04.44.57, *Norgas Cathinka* heading 161 at 7 knot and maintain its heading and speed. MV. *Bahuga Jaya* started to list to its Port. The master of *Bahuga Jaya* went to

the bridge to identify the event. After assessing the situation, the Master requesting assistance to the Ship Traffic Controller station of Bakauheni Port. About 10 Ferries approaching the *Bahuga Jaya* position to provide assistance. The Navy boat and Marine Police ship also approaching to secure the location.

*Bahuga Jaya* continued to list. The master ordered to abandon the ship and ask the crew provide assistance to passengers.

Number of ferries that crossing the route approached *Bahuga Jaya* to provide assistant to the survivors. Local Marine Police and Navy boats also presents on site to help in securing the collision site. One marine police boat approaching *Norgas Cathinka* and requesting the ship to stop. Later the boat berthed alongside the ship.

At 05.25, AIS of MV. *Bahuga Jaya* no longer appears. The ship fully sank at 05 49.24 S/105 53.29 T at 79 m deep.

At 05.30, after moving 5 Nm from the collision position, *Norgas Cathinka* alters her course to the starboard and returns to the collision position soon after drop its anchor in the area.

## 6. NTSC Analysis (National Transportation Safety Committee, 2013)

### 6.1. Action to avoid the Collision

At 0420 on 26 September 2012, *Norgas Cathinka* was approaching the part of Sunda Strait where ferries frequently cross the strait in an east-west direction between Merak and Bakauheni. Shortly thereafter, the ship encountered the crossing traffic that could be expected there from both directions. Rule 15 of the COLREGS (Crossing situation) states :

*When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.*

Therefore, the northbound *Norgas Cathinka* was required to keep out of the way of a westbound vessel on its starboard side if a risk of collision was involved. Similarly, an eastbound vessel on the ship's port side was required to keep out of its way if there was a risk of collision.

On 26 September 2012, *Norgas Cathinka* encountered five crossing vessels, three eastbound and two westbound. All the eastbound vessels crossed ahead of the ship, the closest crossing about 1 mile from its bow. Given the area, traffic, weather and the size, type and speed of the vessels involved, it was not considered that risk of collision existed, and no avoiding action was necessary. Rule 16 of the COLREGS (Action by give-way vessel) states :

*Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear.*

This meant that *Norgas Cathinka* was required to take appropriate action if a risk of collision was involved with either of the two westbound vessels. A developing situation involving a risk of collision with either vessel could have been identified as early as about 0420, shortly after they appeared on the radar display. Over the next 10 minutes, the risk of collision could have been determined and avoiding action taken.

The first vessel, *Bahuga Jaya*, remained on a nearly steady compass bearing indicating risk of collision. The slightly opening bearing of the other vessel, *Gelis Rauh*, indicated that it would pass astern of the ship but would still need to be closely watched.

Appropriate action taken by a give-way vessel must take into account any action by the stand-on vessel. Rule 17 of the COLREGS (Action by stand-on vessel) states:

*(a)(i) Where one of two vessels is to keep out of the way the other shall keep her course and speed.*

*(a)(ii) The latter vessel may however take action by her manoeuvre alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules.*

*(b) When from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision.*

*(c) A power-driven vessel which takes action in a crossing situation in accordance with sub-paragraph (a)(ii) of this Rule to avoid collision with another power-driven vessel shall, if the circumstances of the case admit, not alter course to port for a vessel on her own port side.*

*(d) This Rule does not relieve the give-way vessel of her obligation to keep out of the way.*

Therefore, any action taken by *Norgas Cathinka* to avoid collision had to take into account compliance with the above Rule by *Bahuga Jaya* and *Gelis Rauh*. From about 0420, *Norgas Cathinka's* chief mate monitored the eastbound crossing vessels. The last of the three vessels crossed the ship's bow at 0436. It was not until 0432 that he checked the compass bearing of *Bahuga Jaya* and acquired it as a target followed, 2 minutes later, by the other target, *Gelis Rauh*. This indicates that there was significant delay in determining risk of collision with the westbound vessels, and with *Bahuga Jaya* in particular.

While no action had been taken or considered with respect to the westbound vessels, *Norgas Cathinka's* chief mate could have initiated action at 0436, when the eastbound vessel crossed the ship's bow. However, even at 0437½, when the eastbound vessel was well clear and on the same bearing as *Bahuga Jaya*, no action had been taken on board *Norgas Cathinka*.

It was not until after 0440, that *Norgas Cathinka's* course was altered to starboard. In the circumstances, this action was neither early nor substantial and, hence, was not appropriate. After more than 2 minutes, the further action taken to alter course quickly was probably taken in confusion and panic with the collision imminent.

*Bahuga Jaya's* chief mate took action to avoid collision at about 0440, the same time as *Norgas Cathinka's* course alteration was started. However, *Bahuga Jaya's* course was altered to port and this was not consistent with Rule 17.

According to the survey result, most of the ship officers aware that the ferry route was also crossed by numbers of foreign ship. In some occasion, they noted that the bigger ship was tending to reluctantly alter neither their course nor the speed. Most of the ferry Deck Officer state that the ferry have more ability to manoeuvre or reduce the speed instantly. Therefore they tend to avoid the bigger or foreign ship by altering its course more likely to aim the stern.

*Bahuga Jaya's* chief mate had probably concluded that *Norgas Cathinka* would maintain its course. It is also possible that he may have taken such action in the past in similar circumstances and that this may not be uncommon on board ferries in the area.

Other than *Bahuga Jaya's* chief mate's brief attempt to contact *Norgas Cathinka* about a minute before the collision, there was no communication between the ships. Rule 34 of

the COLREGS requires that whistle signals, which may be supplemented by light signals, be used by ships when taking action to avoid collision. Neither *Norgas Cathinka* nor *Bahuga Jaya* made any whistle or light signals. However, given the avoiding action taken on board both vessels, it is unlikely that the signals could have prevented the collision.

As a give-way vessel, *Norgas Cathinka* had a number of options available for taking action by altering its course and/or speed. After assessing the situation after 0420, the chief mate could have reduced the ship's speed to allow the crossing traffic to pass ahead of it. This could have been the most effective action but it is unlikely that the chief mate considered a speed reduction. He knew the main engine was not ready for immediate manoeuvre, the engine room was not manned and the master was asleep in his cabin.

Alternatively, to achieve the same result as a speed reduction, *Norgas Cathinka* could have been turned around to a reciprocal course for a short time. This could have been done by turning to starboard in ample time, to avoid confusing the three eastbound crossing vessels on the port side.

However, the lack of early assessment and action resulted in *Norgas Cathinka's* chief mate finding himself in a complicated traffic situation. Within a period of less than 20 minutes, five crossing vessels would pass close to the ship. In this situation, the chief mate did not take the urgent action that he could have taken. Instead, as discussed above, the action he took was too little and too late. The situation was further complicated when *Bahuga Jaya's* course was altered to port by its chief mate.

While the collision was the direct result of actions on both vessels that were inappropriate or inconsistent with the COLREGS, a number of underlying factors influenced those actions.

## 6.2 The Passage Plan of *Norgas Cathinka* (National Transportation Safety Committee, 2013)

*Norgas Cathinka's* sailed from Durban, South Africa, about 10 days before its transit of Sunda Strait. The ship would therefore be making landfall after a long ocean passage and would transit a narrow passage where the charted hazards include rocks and shoals. In addition, crossing traffic can be expected in Sunda Strait. A notation on the chart

(BA 2056) in the centre of Sunda Strait states 'FERRIES (see Note)'. The note on the chart states the following:

### SELAT SUNDA – FERRIES

Mariners are warned that ferries cross Selat Sunda between Bakauheni (5°52'S 105°45'E) in Sumatera and ports on the north coast of Jawa.

The Admiralty Sailing Directions (Indonesia Pilot, Volume 1) provides further information and guidance for transiting Sunda Strait. Under the title 'Hazards', it states:

*Ferries ply on a regular basis at the E end of Selat Sunda between Merak (5°56.00'S 105°59.70'E), Jawa and Panjang (5°38.03'S 105°18.99'E), Sumatera; also between Bakauheni (5°52.30'S 105°45.30'E), Sumatera, and ports on the N coast of Jawa.*

Therefore, there is sufficient guidance for transiting ships with regard to crossing traffic in Sunda Strait. A ship's passage plan should take into account this guidance and the master must have preparations in place for encountering crossing traffic and other hazards that can always be expected.

*Norgas Cathinka's* passage plan contained the following information for course leg through Sunda Strait.

*Normal sea watch. Follow COLREGS. Primary fixing method - radar, secondary - GPS. Plot ship's position every 30 minutes. Keep sharp look-out. Ship's squat 0.5 m. PI=1.3' to P.Panjurit. Heavy traffic crossing course. Standing watch 1 or 2.*

'Standing watch 1 or 2' for a 'normal sea watch' meant an officer of the watch at all times and a duty seaman only at night. There was no additional planning for transiting Sunda Strait. The master did not intend to be present on the bridge for the transit. His night orders on 25 September were similar to the previous nights with no specific guidance for Sunda Strait or crossing traffic. He required a minimum CPA of 2 miles and that he should be called if in doubt. There was no mark on the chart indicating that he required to be called at any particular place or time. In addition, there was no plan to either have the main engine on standby or the engine room to be manned. This would have ensured that a change in the ship's speed was not only immediately possible at any time but that there was no doubt in the mind of the officer of the watch in this regard.



**Figure 5 :** Typical Merak – Bakauheni Ferry Passage (National Transportation Safety Committee, 2013)

The *Norgas Cathinka* passage plan indicating that the ship transit Sunda Strait at way point 6 - 7. The passage plan at way point-6 provides information for travelling through the strait includes normal sea watch, follow the COLREG and heavy crossing traffic course. The master had been crossing the Sunda strait for several times. He was aware that the ship would transit heavy ferry traffic. However, when the Master decides to maintain standing watch level 1 or two, he was not fully expected with the complexity of the ferry route. Before the accident happen, there were 6 ships that was in crossing situation. The bridge was manned in compliance with passage plan of standing watch level 2.

To determine the standing level, the company has issued the company poster 037 of instruction for the watch at sea, bridge watch composition. The company poster states the description of sea and traffic state in which standing level need to be held from level 1 to level 5.

Watch level 5 is purposed for Port Arrival/Departure or confined waters in restricted visibility and high traffic density. Watch level 5 requires the bridge to be manned by 6 persons comprising the master, two navigating officers, helmsman and lookout. By adopting fully manned bridge, any risk or hazard that may endanger ship could have been easily identified. When determining watch level, the master of *Norgas Cathinka* should consider any notification listed including hazard and risk that may exist so the ship would pass the area safely. According the policy, the master should have consider to determine to maintain watch level 5 when the ship transiting the ferry route.

### 6.3. Communication Ship to Ship (National Transportation Safety Committee, 2013)

Generally, ship's approaching each other on reciprocal course do not communicating each other but rely on their compliance with the COLREG and the usual practise of good seamanship.

According to the survey result, it is more likely that the ferries were tend to established communication to the other ferries or other ship in determining how both ships crossing or passing.

At 0443, the chief mate of *Bahuga Jaya* was calling *Norgas Cathinka* to have their attention in regard with crossing situation. The chief mate was stating the *Norgas Cathinka* for three times repeatedly. The radio communication was made at the time both ship had started turning and at a distance of 0,2 Nm.

The Chief Mate and Helmsman of *Norgas Cathinka* heard about the calling but could not understand about the request. At that time, both ships still maintain their turning and speed.

The communication was made when a potential collision became apparent. When the chief mate saw the green light of the *Norgas Cathinka* and subsequently order the helm to port, he was in doubtful with the *Norgas Cathinka's* manoeuvre.

Hence, he called the *Norgas Cathinka* to confirm their manoeuvre intention. As the calling was not responded, the chief mate of *Bahuga Jaya* decided to maintain its speed and keep turning hard to port.

He should have utilised the VHF radio to confirm the other ship manoeuvre before he ordered to turn and satisfy his doubt.

The chief mate of *Norgas Cathinka* was not expected that the *Bahuga Jaya* would turn to port. He was relied to the other ship compliance with the COLREG.

#### 6.4. Merak – Bakauheni Route FERRY TRAFFIC Management (National Transportation Safety Committee, 2013)

According to the ferry traffic data, number of ferry servicing the Merak – Bakauheni Route has been increasing. In 2011, the route was serviced by 33 ships comprising 22 ships were operational and 11 others scheduled for routine maintenance or annual inspection. Data 2012 indicating that the route was serviced by 41 ship comprising 33 ships operational and 7 others for routine and annual inspection.

The trip productivity also indicating an increment. In 2006, total ferries trip in the particular route was 42.700 trips or 117 trips per day. The number had been increased in 2011, indicating by total of 57.248 trips or 156 trips per day was produced. Hence, in average there were 6-7 ship was servicing the route in every hour. There were also number of facilities in area near of Sunda Strait i.e.: steam generated power plant Suralaya which rely on coal supply carried by barges, and other factories which also demanding supply through ship transport. On the other side, as innocent passage, ALKI 1 would always be transited by international voyage.

When *Norgas Cathinka* approached the Merak - Bakauheni ferry route, there were 5 other ships crossing its heading. Number of other ship was also had been identified manoeuvring within the area.

Local Ferry Port Authority has established Ship Traffic Controller (STC) with limited capability STC main objective is to control all ferry traffic. To maintain the safe passage on the area, there should be a traffic management as it to

inform the situation and control the ship movement. STC had small coverage to monitor all Sunda strait. STC should have more authorities to inform about situation that might risk ferry operation.

## 7. CONCLUSION

### a) Main Casual Factor the Collision Accident

According to the evidence available, the main causal factor of collision is none of both vessel was presenting consistency in the implementation of Collision avoidance regulation. The following factors has been identified to be contributes to the action states above.

### b) Contributing Factors

- After ship #100 pass clear ahead *Norgas Cathinka*, the chief mate of *Norgas Cathinka* was not sufficiently utilise time available to take a clear and substantial action to avoid collision. The course alteration was too slow to indicate ship movement to the other ship.
- The *Bahuga Jaya's* chief mate had made assumption based on scanty information that there was no significant course alteration made by *Norgas Cathinka*. Hence, he took action to alter helm to port to avoid collision;
- *Bahuga Jaya* action to alter its course to port was not consistent with the collision avoidance regulation;
- The Master of *Norgas Cathinka* through his night order was not provide sufficient guidance to the Chief Mate to safely transit the way point. The night order was not sufficiently adopt the risk notification provided in the chart.
- The *Norgas Cathinka* master's discretion to maintain watch standing level 1 or 2 on heavy traffic ferry route was not consistent with the ship procedure. Hence when the ship on the multiple risk of collision, no sufficient guidance provided to the bridge crew to adequately maintain watchkeeping and lookout.
- Communication made from *Bahuga Jaya* was not taken at appropriate time and insufficiently broadcast

### c) Other Factor

Ferry traffic had resulting both ship in multiple risk of collision.

## REFERENCE

National Transportation Safety Committee (2013), Final Report KNKT-12-09-03-03, Investigation Into the Collision Between The Indonesian Ro-ro Ferry MV. Bahuga Jaya and Singapore Gas Carrier MV. Norgas Cathinka in Sunda Strait (4 Nm eastern Rimau Balak Island), Indonesia 26 September 2012.

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# GREEN PADMA

## EEDI and EEOI

Design & Operation Calculation and Analysis system

Green PADMA consist of two specialized application : EEDI calculation analysys for design & final stage, and EEOI calculator and analysis for operational voyage.



### Key Features :

- EEDI Calculations verified in compliance with IMO with IMO guidelines (Resolution MEPC.245(66))
- EEOI Calculations performed in compliance with IMO guidelines (MEPC.1/Circ.684)
- Ease and shorten the registration, verification, and certification
- Free for use

Green PADMA EEDI & EEOI is an application tool used for the calculation and analysis for both design as well as operational index of a ship regarding to the GHG level.

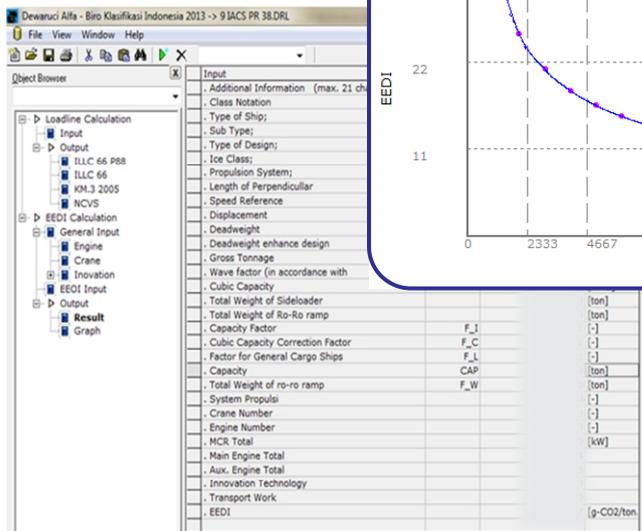
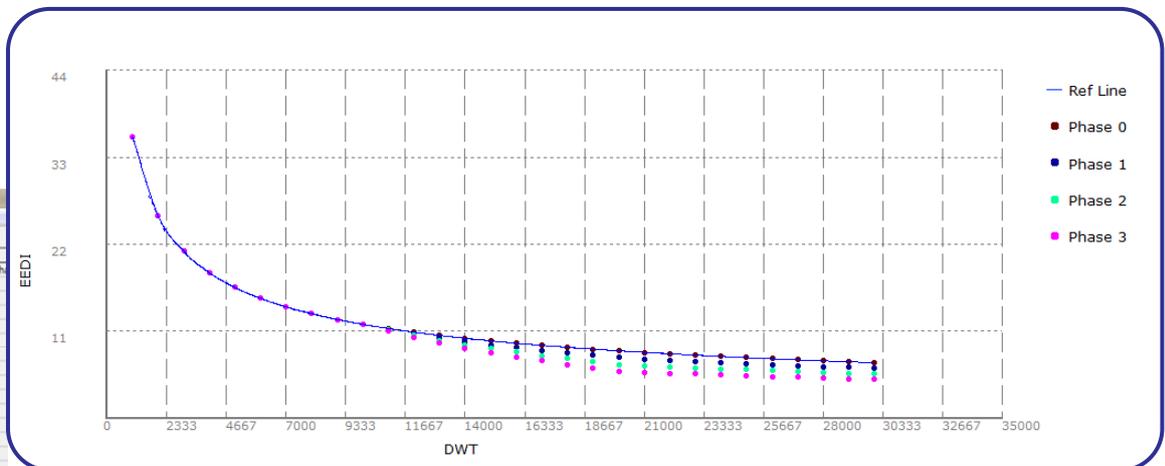
### Main Function

#### Green PADMA EEDI :

- The comprehensive application to calculate the EEDI that covers ship types and other requirements related to the IMO regulation
- Data and index display directly on the IMO reference line
- Accommodate the using of innovative technology such as: Air Lubrication System, Waste Heat Recovery, etc.
- Provide convenient visual checking
- Opportunity for the issuance of "statement of compliance certificate for the EEDI" from BKI

#### Green PADMA EEOI :

- Registration of voyage information
- The comprehensive input for the input of operational data
- Graph of trend or chart data display
- Provide convenient visual monitoring



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# APLIKASI BKI-GREENPADMA SEBAGAI SOLUSI PENERAPAN REGULASI ENERGI EFISIENSI

Tribuana Galaxy

## Abstract

International maritime shipping was appraised to have emitted 1046 million tonnes of CO<sub>2</sub> in 2007, representing 3.3 per cent of the world global CO<sub>2</sub> emission. It is foreseen to increase by factor two to three in 2050 in absence of reduction action (Buhaug, et al., 2009). In line with those issue, the International Maritime Organization (IMO) has required implementing energy efficiency instruments included in Chapter 4 of MARPOL Annex VI. Hence, having Ship Energy Efficiency Management Plan (SEEMP) for all existing ships over 400 GT and attained Energy Efficiency Design Index (EEDI) for new building of several ship types are mandatory from 1st January 2013. To address these challenges, BKI has released the newest service namely the issuance of the Statement of Verification (SoV) for EEDI and SEEMP, including EEOI. This service is robustly supported by the GreenPADMA software to help the calculation and verification for the index of EEDI and EEOI. This calculator software was mainly equipped by reliable features that have been updated by using the latest regulation either from IMO or IACS. Some examples for these features are: the software provides 12 (twelve) different ship types in accordance with the newest regulation requirement; it has specification to calculate power from conventional propulsion system, dual fuel engine, as well as diesel electric. In addition, the software also able to calculate the installation of innovative technology in ships which was expected to facilitate the application of the energy efficiency means. By providing those new service, BKI as a state-owned classification society shows the commitment to continuously assist customers especially the shipping industries, in order to implement new regulations effectively through the development of support tools.

Keywords : IMO, AnnexVI, EEDI, SEEMP, GreenPADMA, Statement of Verification

## 1. Pendahuluan

Salah satu konvensi internasional yang selalu menjadi perbincangan hangat di dunia adalah konvensi yang mengatur mengenai pencemaran udara di lingkungan laut. Konvensi tersebut dikeluarkan oleh IMO (*International Maritime Organization*) dan diakomodir pada regulasi MARPOL 73/78 Annex VI. Seiring dengan perkembangan isu pemanasan global, maka per 1 Januari 2013 IMO mengamandemen Annex VI dengan menambahkan regulasi efisiensi energi terkait upaya untuk membatasi emisi CO<sub>2</sub> baik untuk kapal bangunan baru maupun bangunan lama. Upaya pembatasan emisi CO<sub>2</sub> pada regulasi tersebut selanjutnya ditunjukkan dengan penerbitan sertifikat efisiensi energi yaitu IEEC (*International Energy Efficiency Certificate*). Konsep utama dari regulasi efisiensi energi adalah dengan mengurangi konsumsi bahan bakar karbon pada kapal, sehingga emisi CO<sub>2</sub> akan berkurang. Skema regulasi tersebut dirangkum sebagai berikut :

### a. SEEMP (*Ship Energy Efficiency Management Plan*).

SEEMP merupakan skema pengurangan emisi dengan menitik beratkan pada manajemen operasional kapal sehingga konsumsi bahan bakar dapat dioptimalkan. SEEMP berbentuk manual atau booklet yang berisi tentang perencanaan manajemen operasional dan wajib tersedia diatas kapal, baik untuk bangunan baru maupun lama. Manual tersebut harus dilengkapi dengan indikator emisi guna mengkuantifikasi dan memonitor efektifitas perencanaan manajemen operasional yang telah dibuat. Hingga saat ini, jenis dan metode indikator emisi untuk SEEMP masih dibebaskan untuk dikembangkan oleh pemilik maupun operator kapal. Namun, IMO mewacanakan untuk mewajibkan penggunaan EEOI (*Energy Efficiency Operation Indicator*) sebagai indikator emisi. EEOI merupakan indeks besaran emisi CO<sub>2</sub> yang dihitung dari fungsi total konsumsi bahan bakar dibanding dengan jumlah kargo yang diangkut pada satu satuan jarak pelayaran kapal.

b. EEDI (Energy Efficiency Design Index).

Berbeda dengan SEEMP, regulasi ini mengatur mengenai optimalisasi desain pada kapal berkaitan dengan efisiensinya dan diukur secara kuantitatif dengan menggunakan suatu indeks desain. Karena pengkajiannya hanya dilakukan pada desain, maka regulasi ini hanya berlaku untuk kapal bangunan baru.

2. Regulasi Efisiensi Energi Pada Kapal

The fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC, 2007) menyatakan bahwa peningkatan temperature sebesar 2°C dapat menyebabkan dampak yang bersifat katastrofik terhadap kondisi iklim dan lingkungan secara global. Sehingga untuk menjaga stabilitas temperatur tersebut, emisi GHG (Green House Gasses) harus diturunkan sebesar 50 hingga 85 persen pada tahun 2050 dengan acuan level GHG saat ini.

Komponen GHG utama yang dikeluarkan oleh aktivitas kapal melalui gas buang adalah karbon dioksida (CO<sub>2</sub>). Hal ini dikarenakan, dalam konteks kuantitas dan potensi efek gas rumah kaca, CO<sub>2</sub> disinyalir dapat menyebabkan dampak yang besar terhadap lingkungan. Sedangkan komponen gas buang lain dianggap mempunyai kontribusi yang lebih rendah terhadap lingkungan dikarenakan siklus hidup di udara yang cenderung lebih pendek sehingga lebih cepat terurai.

Berangkat dari landasan tersebut, IMO melakukan studi terhadap efek gas rumah kaca yang diakibatkan oleh aktivitas dunia maritim khususnya kapal. Studi tersebut terangkum dalam IMO GHG Study yang telah dilaksanakan secara berkesinambungan dari tahun 2000 hingga saat ini. Dan pada IMO GHG Study yang kedua tahun 2009, IMO mulai menyusun pemberlakuan regulasi yang mengatur upaya pengurangan konsumsi bahan bakar karbon sehingga dapat mengurangi emisi gas buang berupa CO<sub>2</sub>.

Konsep dasar dari regulasi tersebut adalah dengan optimalisasi penggunaan energi pada kapal baik ditinjau pada level desain maupun operasional. Regulasi pada level desain adalah EEDI, sedangkan yang mengatur operasional kapal adalah SEEMP (Ship Efficiency Management Plan). Kedua item mandatory tersebut termaktub dalam MARPOL 73/78 Annex VI "International Convention on the Prevention of Pollution from Ships" dan mulai diberlakukan per 1 Januari 2013. IMO menyatakan bahwa re-

gulasi tersebut akan terus dikembangkan sejalan dengan peningkatan fokus dunia terhadap isu efek rumah kaca.

Konsep dasar mengenai regulasi EEDI dan SEEMP tersebut selanjutnya akan dideskripsikan pada penjelasan berikut dengan mengutip resolusi IMO-MEPC, adapun pengecualian dan pernyataan tambahan akan disebutkan sumber pustakanya.

- Resolution MEPC.212 (63) ; 2012 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships
- Resolution MEPC.213 (63) ; 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)
- MEPC.1/Circ.684 ; 17 August 2009 Guidelines For Voluntary Use Of The Ship Energy Efficiency Operational Indicator (EEOI)

2.1. Energy Efficiency Design Index (EEDI)

EEDI merupakan sebuah regulasi yang menerapkan mekanisme berbasis performa desain kapal dan memberikan kebebasan bagi pemilik maupun operator kapal untuk menerapkan berbagai desain ataupun teknologi terapan guna mencapai penghematan energi pada level tertentu. Tujuan utama regulasi ini adalah mendorong penerapan teknologi baik yang sudah proven maupun yang masih novel pada pendesainan dan pembangunan kapal. EEDI merupakan pendekatan berbasis desain, sehingga indeks efisiensi untuk dua kapal identik atau kapal sister dapat bernilai sama. Hal ini disebabkan karena indeks yang didapat berasal dari desain kapal saat dibangun dan mengesampingkan kondisi operasional kapal. EEDI akan diberlakukan untuk kapal dengan gross tonnage 400GT atau lebih dan indeks EEDI (g/(t.nm)) dapat dihitung dengan rumus dibawah ini.

$$\frac{\overbrace{\left(\prod_{j=1}^n f_j\right) \left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right)}^a + \overbrace{\left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE*}\right)}^b}{\overbrace{\left(\prod_{j=1}^n f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEff(i)}\right) C_{FAE} \cdot SFC_{AE}}^c} + \overbrace{\left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}^d}$$


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$$\frac{f_i \cdot f_c \cdot Capacity \cdot f_w \cdot V_{ref}}{\text{Transport Work}}$$

Dimana:

$C_F$	Faktor konversi jenis bahan bakar terhadap emisi CO <sub>2</sub>	$\frac{gCO_2}{g\ fuel}$
$V_{ref}$	Kecepatan	Nm/jm : knot
$capacity$	Kapasitas kapal yang diatur sesuai dengan masing masing jenis kapal	
$P$	Power baik untuk mesin induk dan mesin bantu maupun output power yang dihasilkan oleh energi efisiensi terapan	kW
$SFC$	<i>Spacific Fuel Oil Consumption</i>	$\frac{g}{kWh}$
$f_i$	Faktor koreksi elemen desain kapal yang dihitung tergantung dari tipe kapal dan jenis notasi : ice class	[-]
$f_w$	Faktor koreksi yang menindikasikan penurunan kecepatan kalap akibat kondisi <i>seaway (wave and wind condition)</i>	[-]
$f_i$	Faktor kapasitas	[-]
$f_{eff}$	Faktor teknologi energy efisiensi terapan	[-]
$f_c$	Faktor koreksi kapasitas kubik	[-]
$f_i$	Faktor koreksi berkaitan dengan peralatan kapal seperti <i>crane</i> ,dll	[-]

pembagi atau *transport work*. Simbol untuk mesin utama atau *Main engine(s)*, mesin bantu atau *Auxiliary engine(s)*, dan penggunaan teknologi energy efisiensi dilambangkan oleh subscripts; ME, AE, dan eff. Selanjutnya EEDI dapat disimpulkan sebagai rasio perbandingan antara total emisi CO<sub>2</sub> yang dihasilkan oleh kapal per satuan *transport work*.

Salah satu *topside module* yang ada pada FSO adalah *crane*. Konstruksi *crane*, terutama pada bagian pondasi *crane (crane seating)* haruslah kuat, karena selain harus menumpu struktur di atasnya, pondasi *crane* juga harus kuat menerima beban operasional dan beban-beban lain akibat gerakan FSO (Sujiatanti, 2010).

$$EEDI = \frac{CO_2\ emission}{transport\ work}$$

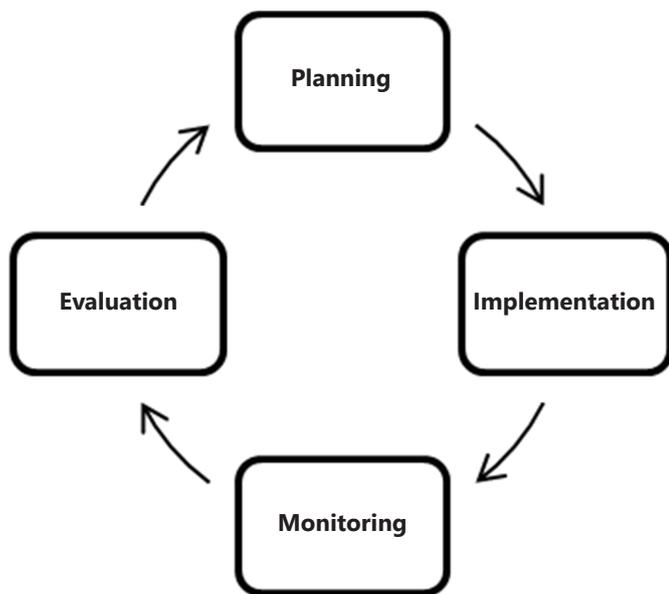
## 2.2. Ship Energy Efficiency Management Plan (SEEMP) dan Energy Efficiency Operational Indicator (EEOI)

SEEMP merupakan regulasi berbasis operasional yang menitik beratkan pada monitoring performa aktual kapal pada saat berlayar dengan memperhitungkan metode-metode yang mungkin diterapkan untuk mengurangi konsumsi energi. Implementasi SEEMP juga memberikan manfaat langsung kepada operator dan pemilik kapal berupa pengurangan biaya operasional sebagai akibat dari berkurangnya konsumsi bahan bakar karena penghematan energi. Berkebalikan dengan EEDI, SEEMP menunjukkan bahwa setiap kapal mempunyai pola efisiensi yang berbeda dikarenakan beroperasi pada kondisi lingkungan yang berbeda. Dengan kata lain, jika *sister ship* dapat mempunyai EEDI yang sama, namun pada SEEMP sudah pasti akan berbeda.

SEEMP diwajibkan untuk semua kapal baik bangunan baru maupun bangunan lama dengan kapasitas 400 GT keatas. Garis besar penerapan SEEMP sebagaimana dilustrasikan pada gambar 1, meliputi 4 siklus fase yang saling ketergantungan yaitu; perencanaan (*planning*), penerapan metode pengurangan energi (*implementation*), *monitoring*, dan evaluasi atau *improvement*. Dikarenakan 4 siklus fase ini saling ketergantungan, maka jika terdapat perubahan disalah satu fase, maka akan mempengaruhi fase yang lain.

Tahap pertama adalah *planning* yang meliputi penentuan kondisi awal kapal saat sebelum mengimplementasikan SEEMP dan penentuan target efisiensi yang diharapkan.

Selanjutnya nilai EEDI harus lebih rendah dari *reference line* yang dipersyaratkan oleh IMO. Rumusan tersebut pada dasarnya dibagi menjadi 5 parameter utama yaitu; [a] emisi CO<sub>2</sub> oleh mesin induk atau *Main Engine*, [b] dan [c] emisi CO<sub>2</sub> oleh mesin bantu, [d] pengurangan emsisi CO<sub>2</sub> yang dapat dicapai dengan penerapan teknologi, dan parameter



Gambar : Fase SEEMP

Pada fase ini juga meliputi pendokumentasian metode-metode penghematan energi yang akan diaplikasikan pada kapal. Tahap kedua adalah implementasi metode metode yang sudah dideskripsikan pada tahap pertama. Tahap ketiga adalah *monitoring* yang merupakan upaya untuk mengetahui apakah metode yang telah diaplikasikan benar benar dapat memenuhi target atau tidak. Hasil *monitoring* selanjutnya digunakan untuk mengevaluasi SEEMP secara keseluruhan.

Untuk saat ini, metode untuk *monitoring* belum di standarisasi oleh IMO. Namun, sudah terdapat wacana jika IMO akan mengeluarkan regulasi berkaitan dengan indeks *monitoring* yaitu *Energy Efficiency Operational Indicator* (EEOI). EEOI merupakan sebuah indeks hasil perbandingan antara jumlah emisi CO<sub>2</sub> yang di sebabkan oleh konsumsi bahan bakar per satuan kargo yang diangkut dan jarak tempuh kapal. Dan konsep utama EEOI dapat dirumuskan sebagai berikut :

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D}$$

Jika EEOI digunakan sebagai indeks *monitoring* untuk beberapa kali pelayaran misalnya *monitoring* tahunan pelayaran suatu kapal, maka EEOI dapat dirumuskan sebagai berikut :

$$Average\ EEOI = \frac{\sum_i \sum_j FC_j \times C_{Fj}}{\sum_i m_{cargo,i} \times D_i}$$

Dimana:

- i : Jumlah pelayaran
- j : Tipe bahan bakar
- C<sub>Fj</sub> : Faktor konversi CO<sub>2</sub> untuk jenis bahan bakar j
- D : Jarak pelayaran [nm]
- F<sub>Cj</sub> : Konsumsi bahan bakar j pada pelayaran i
- m<sub>cargo</sub> : Kargo yang diangkut kapal [tonnes] atau TEU atau n penumpang

### 3. Sertifikasi dan Verifikasi

Berkaitan dengan regulasi MARPOL Annex VI mengenai pemberlakuan SEEMP dan EEDI, terdapat jenis sertifikat baru yang diterbitkan yaitu *International Energy Efficiency Certificate* (IEEC). IEEC merupakan sertifikat statutoria yang akan diterbitkan satu kali oleh pemerintah atau *Recognized Organization* (RO) untuk tiap tiap kapal dan valid selama kapal masih beroperasi atau sepanjang umur kapal. Sertifikat tersebut harus tersedia diatas kapal untuk keperluan inspeksi dan audit (IACS, 2012).

Bagi kapal bangunan baru, IEEC akan dikeluarkan saat *survey initial* dengan syarat bahwa EEDI sudah diverifikasi serta SEEMP telah tersedia diatas kapal. Sedangkan untuk kapal bangunan lama (*existing ship*) sertifikat tersebut akan diberikan pada *survey International Air Pollution Prevention (IAPP) intermediate* atau *renewal* yang pertama, dengan syarat SEEMP tersedia diatas kapal. Untuk kasus tertentu seperti jika suatu kapal melakukan konversi mayor, maka IEEC harus dibuat ulang menyesuaikan dengan kondisi kapal yang terbaru.

Sebagai bahan validasi penunjang penerbitan IEEC oleh pemerintah atau RO, BKI memberikan layanan berupa penerbitan *Statement of Verification* (SoV) untuk EEDI dan EEOI, serta *pre-assesmen* terhadap SEEMP. Dalam proses penerbitan SoV, BKI akan melakukan review terhadap EEDI technical file maupun manual SEEMP serta verifikasi terhadap indeks hasil perhitungan untuk EEDI dan EEOI.

Untuk mendukung *assesment* dan verifikasi yang valid, BKI telah memublikasi *guidelines* terkait yaitu; *Guidelines for Determination of Energy Efficiency Design Index* dan *Guidelines for Ship Energy Efficiency Management Plan* (SEEMP). Kedua *guidelines* ini selanjutnya dipergunakan sebagai salah satu acuan untuk penerbitan SoV. Untuk memberikan assesmen yang valid, BKI juga menggunakan regulasi terbaru dari IMO maupun IACS diluar kedua

guidelines tersebut. Sedangkan secara teknis perhitungan BKI telah mengembangkan dan merilis perangkat lunak terbarunya yaitu GreenPADMA. Aplikasi ini diharapkan dapat membantu proses assesmen maupun *approval* yang valid guna penerbitan SoV.

#### 4. BKI-GreenPADMA

GreenPADMA merupakan *software* terbaru yang diluncurkan BKI pada tahun 2015 yang berupa perangkat yang digunakan untuk menghitung nilai EEDI dan EEOI pada suatu kapal. *Software* ini dikembangkan secara internal oleh Divisi Riset dan Pengembangan dan Divisi Statutoria dengan tujuan untuk memberikan pelayanan yang valid dan efisien terkait regulasi efisiensi energi dari IMO.

Dalam pengembangannya, GreenPADMA diciptakan untuk sedapat mungkin mengakomodir semua ketentuan dan kriteria regulasi terkini. Adapun fitur - fitur yang ditawarkan telah divalidasi sesuai dengan update regulasi IMO maupun IACS. Fitur unggulan untuk EEDI misalnya antara lain; pengakomodiran 12 jenis kapal yang termasuk dalam kriteria regulasi, sistem propulsi konvensional maupun diesel *electric*, mesin *dual fuel*, perangkat tambahan untuk kapal LNG, penggunaan *innovative technology* seperti *Air Lubrication System* dan *Waste Heat Recovery*.

Selain fitur yang reliable tersebut, GreenPADMA juga menawarkan tampilan hasil perhitungan yang *user friendly* berupa posisi indeks emisi CO<sub>2</sub> terhadap batas emisi yang telah ditetapkan oleh IMO dalam bentuk plot grafik.

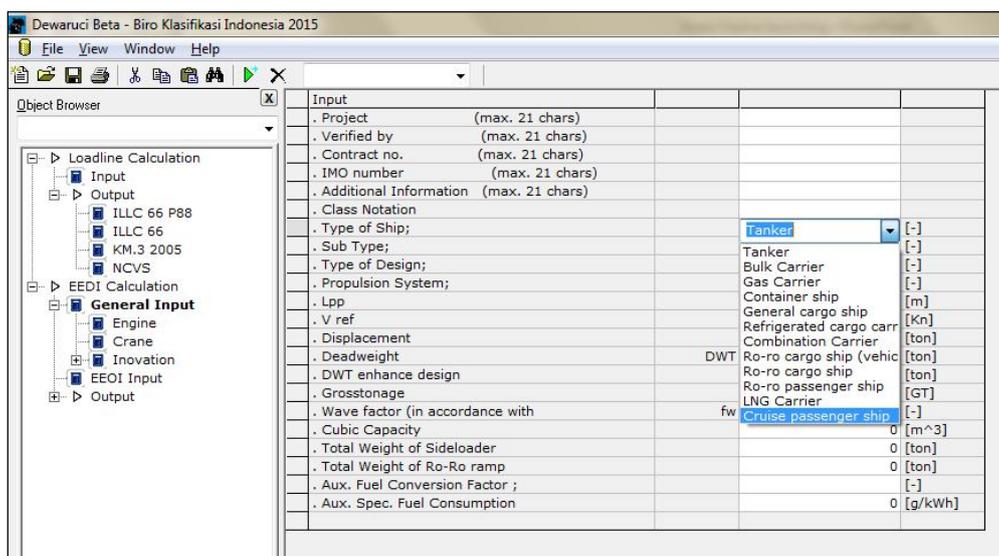
#### 4.1. Fitur Aplikasi EEDI

Secara umum, pada menu EEDI kalkulator, terdapat beberapa fitur utama seperti tipe kapal, jenis sistem permesinan dan penerapan *innovative technology*. Berikut merupakan penjabaran singkat terkait keunggulan fitur fitur utama tersebut.

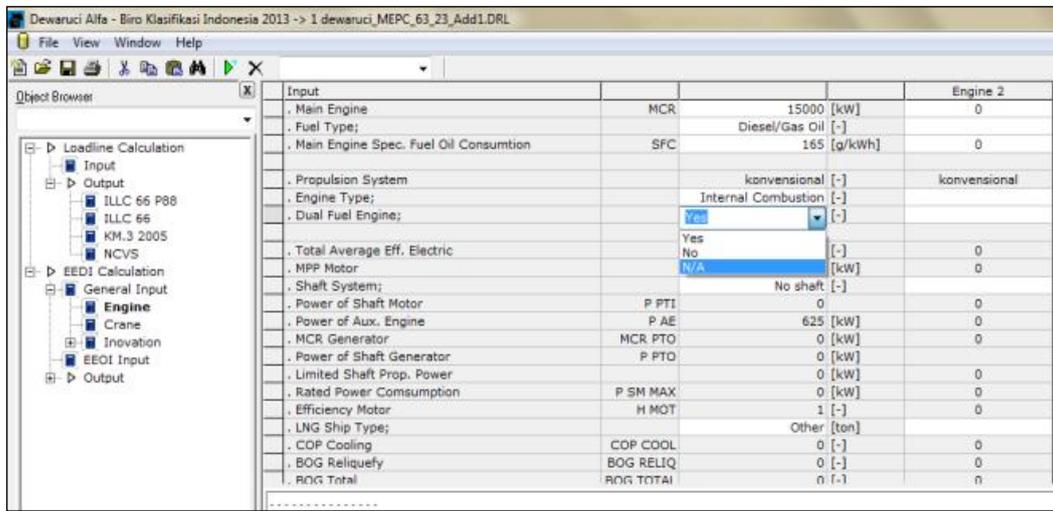
##### 4.1.1. Tipe kapal

GreenPADMA dikembangkan seiring dengan perkembangan regulasi IMO yang terkini. Khususnya untuk tipe kapal, GreenPADMA sudah dapat mengakomodir 12 (dua belas) jenis kapal yang termasuk dalam regulasi EEDI, lihat Gambar 2. Dimana sebelumnya IMO hanya menentukan 8 (delapan) jenis kapal yang wajib EEDI. Kedua belas jenis kapal tersebut antara lain:

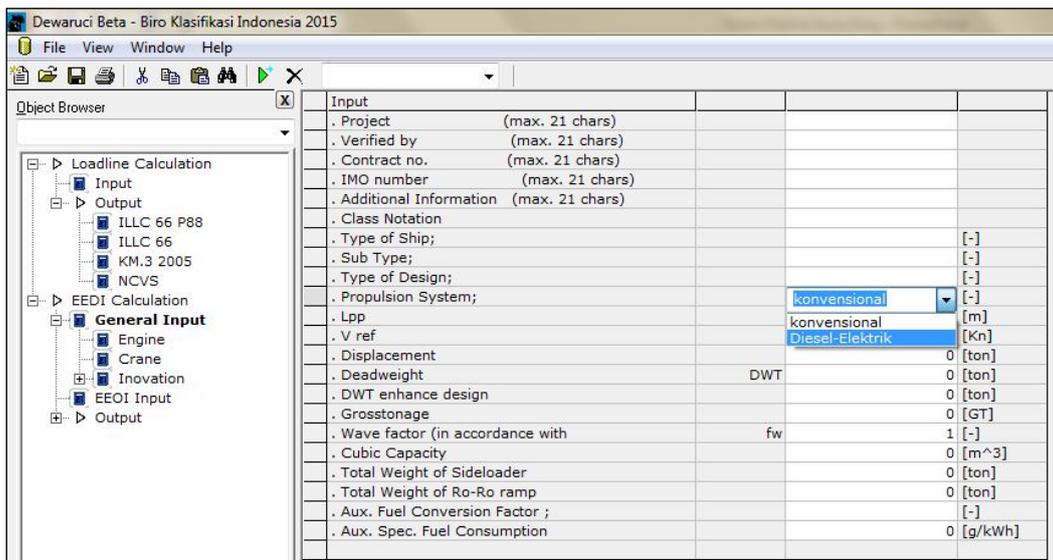
- (1) Bulk carrier,
- (2) Gas carrier,
- (3) LNG carrier,
- (4) Tanker,
- (5) Container ship,
- (6) General cargo ship,
- (7) Refrigerated cargo carrier,
- (8) Combination carrier,
- (9) Ro-ro cargo ship (vehicle carrier),
- (10) Ro-ro cargo ship,
- (11) Ro-ro passenger ship,
- (12) Cruise passenger ship.



Gambar 2 : Tipe Kapal



Gambar 3 : Dual Fuel



Gambar 4 : Sistem Propulsi

Untuk lebih melengkapi kedua jenis kapal tersebut diatas, GreenPADMA juga dikembangkan dengan memperhatikan kriteria tambahan untuk beberapa *sub-type* kapal. Beberapa contoh *sub-type* kapal yang sudah terkomodir dalam perangkat ini antara lain :

- Kapal dengan atau tanpa *voluntary structural enhancements* (VSE).
- Kapal *General Cargo* akan dibedakan menjadi; *General Cargo* dengan dan tanpa *ramp*, *crane*, dan *side loader*.
- Kapal Tanker akan dibedakan menjadi *Oil Tanker* dan *Chemical Tanker*, atau menggunakan CSR atau tidak.
- dan lain sebagainya.

#### 4.1.2. Sistem Permesinan

Dalam sistem permesinan dan propulsi, GreenPADMA telah mengakomodir kriteria tambahan seperti: penggunaan *shaft generator* dan motor, kapal dengan *dual fuel engine* (lihat gambar 3), kapal *LNG carrier* dengan sistem propulsi *diesel electric* (lihat gambar 4) serta kriteria tambahan untuk kapal *LNG carrier* yang menggunakan *relief-uefaction system* atau compressor.

Secara lebih detail lagi terdapat opsi tambahan lagi pada sistem propulsi yang menggunakan *shaft generator* yaitu ada atau tidaknya pembatasan power. Selain itu, pada

Input		Engine 2
. Shaft System;	No shaft [-]	
. Power of Shaft Motor	P PTI	0
. Power of Aux. Engine	P AE	625 [kW]
. MCR Generator	MCR PTO	0 [kW]
. Power of Shaft Generator	P PTD	0 [kW]
. Limited Shaft Prop. Power		0 [kW]
. Rated Power Consumption	P SM MAX	0 [kW]
. Efficiency Motor	H MOT	1 [-]
. LNG Ship Type;	Liquefaction system	
. COP Cooling	COP COOL	LNG carriers with re-liq [-]
. BOG Reliequefy	BOG RELIQ	LNG carrier with compr [-]
. BOG Total	BOG TOTAL	LNG carrier with compr [-]
. LNG Cargo Tank Capacity	LNG Outer	[m^3]
. BOR		0 [-]
. COP Compressor	COP COMP	0 [-]
. M.E. Spec. Fuel Consumption for Gasmode	SFC ME	0 [kJ/kWh]
. Specific Fuel Consumption for Gas	SFC Gas	0 [kJ/kWh]
. Dual Fuel Mode		
. Pilot Fuel;		0 [-]
. Pilotfuel Spec. Fuel Consumption	SFC	0 [g/kWh]
. Result of Main Engine		5941117.5

Gambar 5 : LNG Carrier

gambar 5 mengilustrasikan terdapat juga opsi tambahan pada kapal *LNG carrier* yang menggunakan *reliequefaction system* atau compressor, yaitu :

- Untuk kapal yang mempunyai *re-liquefaction system*.
- Untuk kapal dengan diesel atau diesel *electric* dilengkapi dengan kompresor yang digunakan untuk menyuplai gas bertekanan tinggi yang berasal dari boil-off gas (BOG). Tipe ini umumnya terdapat pada kapal dengan mesin 2 tak.
- Untuk kapal dengan diesel atau diesel *electric* dilengkapi dengan kompresor yang digunakan untuk menyuplai gas bertekanan rendah yang berasal dari boil-off gas (BOG). Tipe ini umumnya terdapat pada kapal dengan mesin 4 tak.

#### 4.1.3. Innovative Technology

Sejalan dengan konsep utama regulasi EEDI dan SEEMP, dimana sebuah kapal harus dibangun dan dioperasikan seefisien mungkin serta diharapkan untuk dilengkapi dengan inovasi teknologi yang dapat menghemat konsumsi bahan bakar. Maka GreenPADMA juga dilengkapi dengan menu tambahan yaitu menu *innovative technology*. Beberapa contoh teknologi inovatif yang sudah terdapat dalam aplikasi adalah; *Air Lubrication System*, *Waste Heat Recovery*, dan lain sebagainya. Penerapan teknologi inovasi tersebut dihitung berdasarkan *guidelines* yang diterbitkan IMO atau *gudelines* yang setara.

#### 4.2. Fitur Aplikasi EEOI

Seperti dijelaskan sebelumnya bahwa EEOI merupakan in-

dikator dari SEEMP, maka dapat diartikan bahwa parameter yang dimasukkan dalam perhitungan merupakan parameter operasional kapal. Sesuai dengan regulasi maka GreenPADMA menampilkan parameter-peremeter berikut dalam aplikasinya:

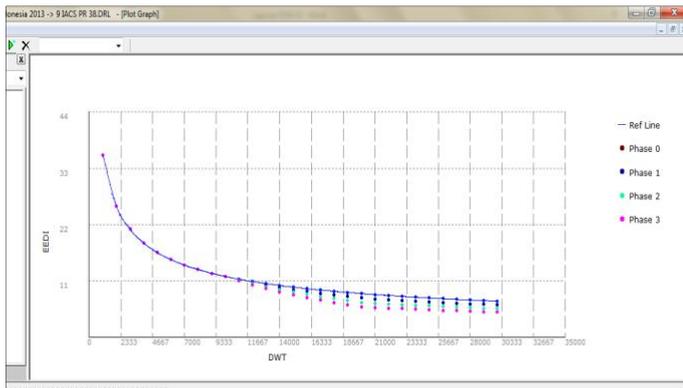
- jumlah pelayaran.
- tipe bahan bakar.
- faktor konversi CO<sub>2</sub> untuk jenis bahan bakar.
- jarak pelayaran [nm].
- Konsumsi bahan bakar untuk masing masing jenis bahan bakar pada pelayaran tertentu.
- Kargo yang diangkut kapal [tonnes] atau TEU atau penumpang.
- Karakteristik muatan kapal saat berlayar seperti : *ballast*, distribusi beban muatan, dan lain sebagainya.

#### 4.3. Output Aplikasi

Dalam regulasi yang berlaku, nilai EEDI harus dihitung sesuai dengan formulasi yang disebutkan dalam bagian 2 diatas. Nilai EEDI yang dihitung berdasarkan technical file yang diverifikasi. Dan selanjutnya, untuk mengetahui apakah nilai tersebut sudah memenuhi batas kriteria yang ditentukan, maka nilai tersebut harus dibandingkan dengan *reference line* yang telah ditentukan oleh IMO. Batasan nilai EEDI yang ditentukan oleh IMO didapatkan dari formulasi sebagai berikut:

$$\text{Required EEDI} = a \cdot b^{-c}$$

Batasan nilai EEDI tersebut, dihitung berdasarkan masing masing jenis kapal dengan koefisien a dan c dengan DWT



Gambar 6 : Reference Line

nya, b. Selain itu, batasan nilai EEDI yang dipersyaratkan juga akan semakin ketat dari tahun ke tahun. Selanjutnya, hasil grafik perhitungan dan interpolasi dari batasan atau *reference line* tersebut ditampilkan sebagai plot akhir perhitungan indeks EEDI seperti ditunjukkan dalam gambar 6 dibawah ini. Dalam tampilannya, nilai EEDI yang dihitung untuk suatu kapal akan berupa titik (dot) yang selanjutnya diplot pada grafik tersebut untuk mengetahui apakah masih dalam kriteria yang dapat diterima atau tidak.

Sedangkan untuk output EEOI akan ditunjukkan dengan grafik yang menggambarkan total emisi CO<sub>2</sub> pada pelayaran yang dilakukan. Grafik akan dapat di-generate untuk per perjalanan kapal atau dalam kurun waktu tertentu.

## 5. Kesimpulan

Regulasi terkait energi efisiensi merupakan regulasi baru yang diberlakukan oleh IMO dan dapat dipastikan akan semakin ketat di masa yang akan datang. Penerapan regulasi tersebut harus didukung oleh semua pihak terutama pemerintah, RO, maupun badan klasifikasi. Dalam perannya, badan klasifikasi diharapkan dapat senantiasa memperbaiki pelayanannya terkait perkembangan regulasi dunia. Untuk mencapai hal tersebut, BKI telah memberikan pelayanan terbarunya yaitu penerbitan *Statement of Verification* (SoV) untuk EEDI dan SEEMP yang termasuk didalamnya EEOI. Sebagai penunjang secara teknis, BKI juga telah mengembangkan perangkat yang dapat memberikan assesmen yang valid dan efisien kepada parameter kuantitatif pada regulasi tersebut. Perangkat ini berupa *software* kalkulator EEDI dan EEOI bernama GreenPADMA.

GreenPADMA merupakan perangkat penghitung yang dilengkapi dengan fitur-fitur terkini yang selalu diperbarui sesuai dengan perkembangan regulasi baik dari IMO maupun IACS. Beberapa contoh fitur yang ditawarkan yaitu; dapat mengakomodir 12 jenis kapal sesuai regulasi IMO terkini, mengakomodir jenis mesin *dual fuel* dan *diesel electric*, mengakomodir penerapan inovasi *technology* pada kapal, dan fitur-fitur lainnya. Dengan adanya pelayanan baru tersebut, maka BKI menunjukkan komitmen sebagai badan klasifikasi yang memperhatikan kebutuhan pelanggan akan perkembangan regulasi terbaru serta dapat memberikan pelayanan yang valid dan efisien.

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# ON THE USE OF THE LIFTING LINE THEORY FOR OPTIMIZING THE PROPELLER PERFORMANCE OF SHIP

Muhdar Tasrief, Faisal Mahmuddin

## Abstract

*Propeller is one of the most important and crucial part of a ship. Knowing and understanding the characteristics of a propeller may enable us to optimize its performance. Performance of a propeller in this paper is measured from its efficiency. Choosing the blade number of propeller correctly and operating it into a suitable rotation shall optimize its performance. Hence, in the present study the lifting line theory is employed to compute such performance through the Propeller Vortex Lattice (PVL) program. It is understood from this study that a propeller with less number of blades and small in diameter is recommended to be operated at middle to higher rotation and vice versa in order to acquire the highest efficiency. The effect of propeller hub increases the strength of circulation distribution, especially around the propeller hub radius.*

*Keywords : propeller performance; lifting line theory; propeller vortex lattice*

## 1. Introduction

Although the regulation of Energy Efficiency Design Index (EEDI) has been imposed for more than two years, but many researcher are still doing and trying to search an effective and efficient technique to comply with the required EEDI of that regulation. It should be noted that EEDI is an index quantifying the amount of carbon dioxide (CO<sub>2</sub>) emitted from a ship in relation to the goods transported and it is a mandatory for the new ships with 400 gross tonnages and above. The EEDI of such ships should be less than the required EEDI stipulated by the International Maritime Organization (IMO). Therefore the ships shall be designed and operated optimally in order to acquire less EEDI. In fact, the EEDI of a ship can be reduced from several point of views, for instance from the view of speed reduction, hull optimization, advanced technology devices, etc. Optimizing the propeller performance may also save fuel of a ship in operation and hence reducing the EEDI.

Propeller is one of the most important parts of a ship. Without a propeller, a ship will not be able to advance with its forward speed. Knowing the characteristics of a propeller shall allow us to understand and optimize its performance. There are a lot of benefits that can be obtained by understanding the propeller performance. For example, it

enables us to decide the number of propeller blade correctly. Another thing is that we may be able to operate the propeller at its optimum rotation and thus optimizing its performance, saving more fuel which lead to reduction of CO<sub>2</sub> pollution from ship, etc. Hence, operating the propeller at its optimum rotation may help us to comply with the EEDI regulation as mentioned before.

There are two methods commonly used to examine the performance of propeller. The first method is the conventional propeller series method based on diagrams obtained from open water experimental data. The other one is the mathematical method based on circulation theory, such as lifting line theory, vortex lattice method, boundary element method (BEM), etc. The conventional method is easy and convenient to use since the propeller performance can be obtained through diagrams as long as all necessary data such as ship speed ( $V_s$ ), diameter ( $D$ ) or radius ( $R$ ) of propeller and its rotation ( $n$ ), and number of propeller blade ( $Z$ ), etc. are known. Nevertheless, it may lead to a problem when certain necessary data, for instance, propeller rotation is not available. Another thing which may be considered as a drawback of the first method is that the accuracy of the obtained propeller performance highly depends on the precision in reading the diagrams. Such kinds of deficiency shall not be encountered in another available method.

With the assumption that the optimum propeller rotation is unknown, the conventional method may not be used, hence the mathematical method should be adopted instead. In this study, therefore, the mathematical method particularly the lifting line theory and the principles of vortex lattice solution are utilized together in the propeller vortex lattice program developed by Kerwin (2001) which are used to analyse the propeller performance of a ship. Vortex lattice method is generally robust where a lot spacing algorithms do converge to the correct answer (Kerwin, 1986). In the lifting line theory, each blade of the propeller can be considered as a lifting surface with some distribution of vortex sheet strength. It is then considered for the limiting case of vanishing chord length. The objective is to calculate the circulation distribution along propeller blade radius and hence computing force of a propeller by the vortex lattice solution. Obtaining the force may allow us to get the propeller efficiency and understand in which rotation a propeller will acquire its highest efficiency.

## 2. Theory Of Computation

It has been mentioned in the former section that the lifting line theory and the principle of vortex lattice solution are adopted in the propeller vortex lattice program in order to obtain the distribution of circulations on each propeller blades sections. These results will then be used to compute the forces in the axial and tangential directions. By integrating these forces over the radius and summing up over the number of blades as they are identical, the total propeller thrust and torque may be obtained. The following subsection will describe these problems in sufficiently detail.

### 2.1. Coordinate System and Notation

A right-handed coordinate system is adopted to define the propeller coordinate system and notation, with the x-axis coincident with the axis of propeller rotation and y-axis positive upward. The z-axis completes the right-handed coordinate system as shown in the following Figure 1.

As shown in Figure 1, the propeller is rotating with angular velocity ( $\omega$ ) in a clockwise direction when looking downstream. The axial inflow velocity ( $V_A$ ) is coming from the negative x-axis, where the origin of the coordinate is in the plane of propeller as a reference point for all axial dimensions of the surface of a propeller blade.

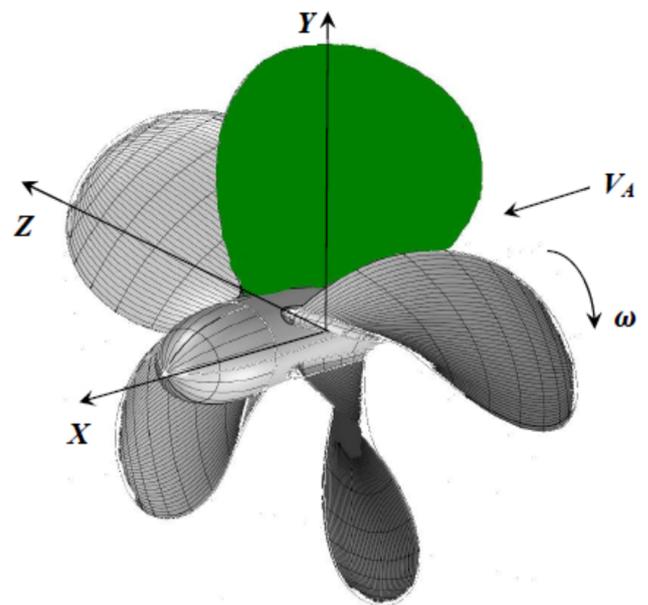


Figure 1 : Propeller Coordinate System and Notation

Since a propeller has Z number of identical blades with maximum radius R, thus only one blade is considered first for computing the distribution of circulation which is called as a key blade given as green color in Figure 1. This blade and the others are placed on a hub which is attached to a shaft. The hub and shaft may be considered as an axisymmetric body and usually idealized as a cylinder of radius  $r_h$ ,

### 2.2. Vortex Lattice Lifting Surface

In the lifting line theory, each blade of propeller may be considered as a lifting surface with some of bound and free vortex sheet strength distributed along the lifting surface. Bound vortex is the portion of the vortex lying along the span and the free vortex or so-called the trailing vortex extending downstream indefinitely (Flood, 2009). The limiting case of vanishing chord length is then considered. Therefore the bound vortex reduces to a single concentrated vortex on each blade with strength  $\Gamma(r)$  as for a planar foil. Because the propeller blades are identical, they will have the same circulation distribution in circumferentially uniform flow and thus one blade can be chosen and designated as a key blade.

The span of a key blade is then divided into M number of panels extending from the hub radius,  $r = r_h$  to the maximum radius of propeller  $r = R$ . Its chord is also divided into N number of panels. A specified control point,  $r_c$  will be put in the middle of each panel of a key blade where

the induced velocity field in axial and tangential directions will be computed. These velocities are actually induced by each set of horseshoe vortex elements consisting of a bound vortex segment of strength  $\Gamma_m$  and two free vortex lines of strength  $\pm\Gamma_m$ . Hence the total induced velocity at  $r_c$  can be computed in axial and tangential directions as follow:

$$u_a^*(r_c(n)) = \sum_{m=1}^M \Gamma_m \bar{u}_a(n, m) \quad (1)$$

$$u_t^*(r_c(n)) = \sum_{m=1}^M \Gamma_m \bar{u}_t(n, m) \quad (2)$$

where  $\bar{u}_a$  and  $\bar{u}_t$  denote the horseshoe influence function of axial and tangential velocities, respectively. For a finite bladed propeller, these functions can be approximated as

$$\left. \begin{aligned} \bar{u}_a(r_c) &= \frac{Z}{4\pi r_c} (y - 2Zr_v F_1) \\ \bar{u}_t(r_c) &= \frac{Z^2}{2\pi r_c} y_0 F_1 \end{aligned} \right\} \text{for } r_c < r_v \quad (3)$$

$$\left. \begin{aligned} \bar{u}_a(r_c) &= -\frac{Z^2}{2\pi r_c} y y_0 F_2 \\ \bar{u}_t(r_c) &= \frac{Z}{4\pi r_c} (1 + 2Zy_0 F_2) \end{aligned} \right\} \text{for } r_c > r_v \quad (4)$$

where

$$\begin{aligned} F_1 &\approx -\frac{1}{2Zy_0} \left( \frac{1+y_0^2}{1+y^2} \right)^{0.25} \left\{ \frac{1}{U^{-1}-1} + \frac{1}{24Z} \right. \\ &\left. \left[ \frac{9y_0^2+2}{(1+y_0^2)^{1.5}} + \frac{3y^2-2}{(1+y^2)^{1.5}} \right] \ln \left( 1 + \frac{1}{U^{-1}-1} \right) \right\} \\ F_2 &\approx -\frac{1}{2Zy_0} \left( \frac{1+y_0^2}{1+y^2} \right)^{0.25} \left\{ \frac{1}{U^{-1}-1} - \frac{1}{24Z} \right. \\ &\left. \left[ \frac{9y_0^2+2}{(1+y_0^2)^{1.5}} + \frac{3y^2-2}{(1+y^2)^{1.5}} \right] \ln \left( 1 + \frac{1}{U^{-1}-1} \right) \right\} \end{aligned} \quad (5)$$

with

$$\begin{aligned} U &= \left\{ \frac{y_0 \sqrt{1+y^2}-1}{y \sqrt{1+y_0^2}-1} \exp \left( \sqrt{1+y^2} - \sqrt{1+y_0^2} \right) \right\}^Z \\ y &= \frac{r_c}{r_v \tan \beta}; \quad y_0 = \frac{1}{\tan \beta}; \quad \tan \beta = \frac{V_A}{J_s + V_T} \end{aligned} \quad (6)$$

$J_s$  in Eq. (6) represents the advance coefficient given as

$$J_s = \frac{V_s}{nD} \quad (7)$$

where  $n = \frac{\omega}{2\pi}$  is the number of propeller revolutions per second. It should be noted here that the cosine spacing described in Dannecker (1997) and Kerwin (2011) is adopted for the vortices and control points in above equations to compute the vortex lattice grid, which can be given as :

$$r_v(m) = r_h + h[1 - \cos(2(m-1)\delta)] \quad (8)$$

$$r_c(n) = r_h + h[1 - \cos(2n-1)\delta] \quad (9)$$

where  $h = \frac{(R-r_h)}{2}$  and  $\delta = \frac{\pi}{2M}$ . By combining the axial and tangential induced velocities with the effective inflow velocities in axial ( $V_A$ ) and tangential ( $V_T$ ) directions and the rotational speed of propeller ( $\omega r$ ), the resultant of an inflow velocity can be computed by the following equation

$$V^* = \sqrt{(V_A(r) + u_a^*(r))^2 + (\omega r + V_T(r) + u_t^*(r))^2} \quad (10)$$

Note that this velocity is oriented at a certain angle ( $\beta_i$ ) with respect to the plane of rotation.  $\beta_i$  itself can be given as follows

$$\beta_i(r) = \tan^{-1} \left[ \frac{V_A(r) + u_a^*(r)}{\omega r + V_T(r) + u_t^*(r)} \right] \quad (11)$$

Therefore the force per unit radius directed at the right angle to  $V^*$  can be obtained and given as

$$F(r) = \rho V^*(r) \Gamma(r) \quad (12)$$

The effect of viscous drag may be included by adding the viscous drag force acting in a direction parallel to  $V^*$ . Once the drag coefficient ( $C_{Dv}$ ) is determined, this force can be computed as follow

$$F_v(r) = 0.5 \rho (V^*(r))^2 c(r) C_{Dv}(r) \quad (13)$$

where  $\rho$  denotes the mass density of the water and  $c(r)$  the chord length at any radius. Integrating these forces over the radius and summing up over the number of blades will allow us to get the total propeller thrust and torque.

$$T = \rho Z \int_{r_h}^R [V^* \Gamma \cos \beta_i - 0.5 (V^*)^2 c C_{Dv} \sin \beta_i] dr \quad (14)$$

$$Q = \rho Z \int_{r_h}^R [V^* \Gamma \sin \beta_i + 0.5 (V^*)^2 c C_{Dv} \cos \beta_i] r dr \quad (15)$$

The propeller thrust and torque may be nondimensionalized with respect to the advance coefficient as follow

$$C_T = \frac{8K_T}{\pi J_s^2} \quad (16)$$

$$C_Q = \frac{16K_Q}{\pi J_s^2} \quad (17)$$

where

$$K_T = \frac{T}{\rho n^2 D^4} \quad (18)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (19)$$

Therefore, finally the efficiency of propeller can be obtained and computed as (Carlton, 1997).

$$\eta = \frac{J_s K_T}{2\pi K_Q} \quad (20)$$

The thrust and torque of propeller given in Eqs. (14) and (15) can be computed after obtaining the circulation distribution ( $\Gamma_m$ ). According to Lee (1979),  $\Gamma_m$  on the blade may be resolved into spanwise and chordwise components. It can be obtained by solving the following simultaneous equation:

$$\sum_{m=1}^M [\bar{u}_a(n, m) - \bar{u}_t(n, m) \tan \beta_i(n)] \Gamma_m = \frac{V_A(n)}{V_s} \left( \frac{\tan \beta_i(n)}{\tan \beta(n)} - 1 \right) \quad n = 1, \dots, M \quad (21)$$

### 3. Ship and Propeller Data

In order to compute the performance of propeller by employing the propeller vortex lattice (PVL) program, the following propeller data are required as for the input data.

**Table 1 : Propeller Input Data**

$r/R$	$c$	$\frac{c}{D}$
0.1848	0.735	0.199728261
0.2000	0.756	0.205434783
0.2500	0.820	0.222826087
0.3000	0.888	0.241304348
0.4000	0.986	0.267934783
0.5000	1.068	0.290217391
0.6000	1.121	0.304619565
0.7000	1.128	0.306521739
0.8000	1.065	0.289402174
0.9000	0.878	0.238586957
0.9500	0.680	0.184782609
1.0000	0.0001	0.000027174

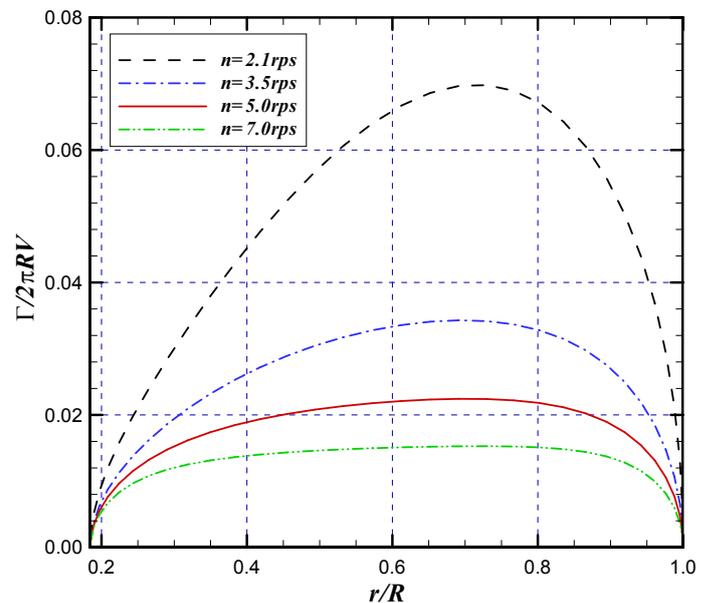
The main input data in PVL are the nondimensionalized spanwise of propeller represented by  $r/R$  and the ratio between the propeller chord length and diameter given as  $c/D$  shown in Table 1. The ship particular and other parameters used in computation are summarized in Table 2. Another important data are the drag coefficient ( $C_{Dv}$ ), ratio between axial velocity and ship velocity ( $V_A/V_s$ ) as well as ratio of tangential velocity to ship velocity ( $V_T/V_s$ ). Here  $C_{Dv}$  is defined to be 0.008 and the inflow velocity is assumed moving only in horizontal direction with  $V_A$  equals to  $V_s$ .

**Table 2 : Ship Particulars and Other Parameters**

Item	Value
Length over all ( $Loa$ )	130.29 (m)
Length between perpendicular ( $Lbp$ )	125.37 (m)
Breadth ( $B$ )	20.00 (m)
Height ( $H$ )	13.70 (m)
Height ( $H$ )	5.76 (m)
Draught ( $T$ )	19.6 (kn)
Service speed ( $V_s$ )	6700 (hp)
Delivered power ( $P_D$ )	3.68 (m)
Diameter of propeller ( $D$ )	5 (blades)
Number of propeller blade ( $Z$ )	1.00
Desired thrust coefficient ( $C_T$ )	32
Number of vortex panel ( $M$ )	12
Number of input radii	

### 4. Numerical Results And Discussions

Figure 2 shows the computation result of circulation distribution strength obtained by solving simultaneous equation given in Eq.(21) for several propeller revolutions. From this figure, we could clearly observe that the circulation distribution strength increases as the propeller revolution decreases.



**Figure 2 : Strength of Circulation Distribution along Radius of 5 Bladed Propeller without Hub Effect.**

Needless to say that in this figure the effect of the presence of propeller hub is not taken into account in computing the circulation distribution. It means that the blades are assumed to have a free tip at both ends. Consequently the circulation becomes zero at blades ends, both at the hub and the tip. By judging from Figure 2, one may envisage that a propeller with the specifications

given in Table 2, when running at slow speed, will have larger propeller forces than one running in high speed. This can be seen obviously in Figure 3 given as follows.

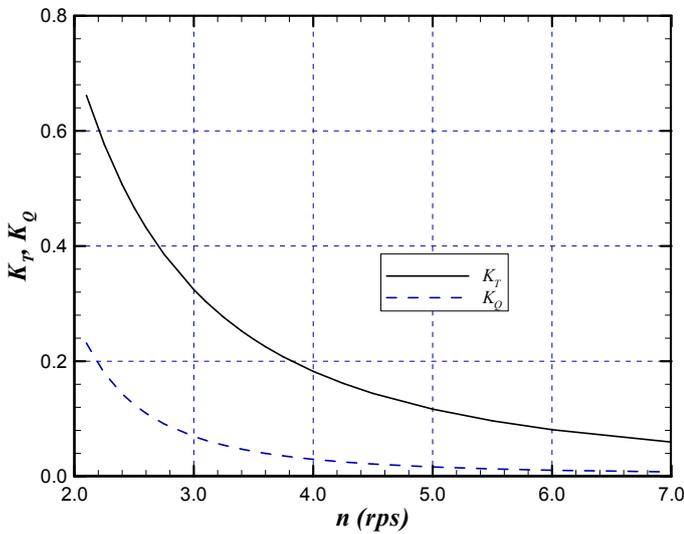


Figure 3 : Propeller Thrust and Torque

Although this propeller has a high thrust and torque at slow speed, it does not necessarily mean that it will get high efficiency at that speed. The efficiency of propeller is depicted in Figure 4 for several revolutions. It can be seen from this figure that the propeller efficiency has its highest value at certain rotation. Here we could observe that the maximum efficiency of propeller under consideration (5 blades) is obtained at  $n=3.5$  rps with  $\eta=0.6797$ , not at  $n=2.1$  rps where the propeller forces become large.

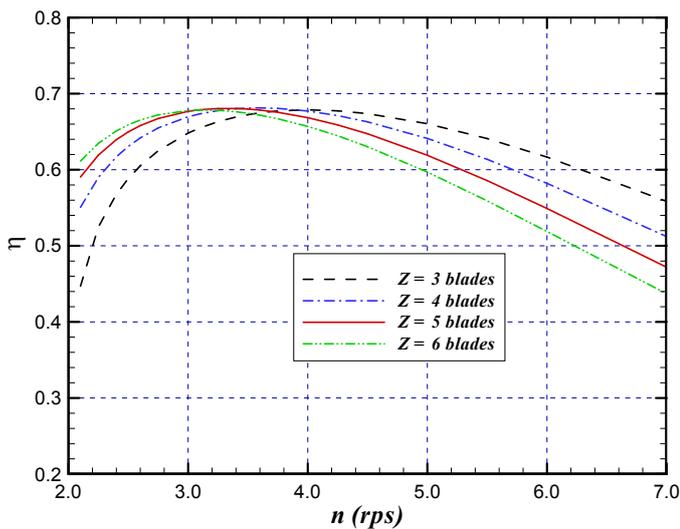


Figure 4 : Propeller Efficiency with Blade Variation at Several Propeller Rotations

It is also shown in the same figure the effect of changing the number of propeller blades to the propeller efficiency.

Propeller with blade number 3, 4 and 6 reach its maximum efficiency;  $\eta=0.6788$ ,  $\eta=0.6813$ ,  $\eta=0.6785$  at propeller rotation 4.0 rps, 3.6 rps, 3.1 rps, respectively. The maximum efficiency of all propellers is almost the same with different rotation. Based on this result, it can be said that the maximum propeller efficiency shifts to higher rotation as the number of propeller blades decreases. It means that the slow speed propellers should have more blades compared to that of the high speed propeller in order to get the optimum efficiency. Different with Figure 4, Figure 5 presents the consequence of modifying the radius of propeller to its efficiency. It is observable in Figure 5 that the efficiency of propeller with 5 blades reduces as its diameter decreases for slow rotation and vice versa for high rotation.

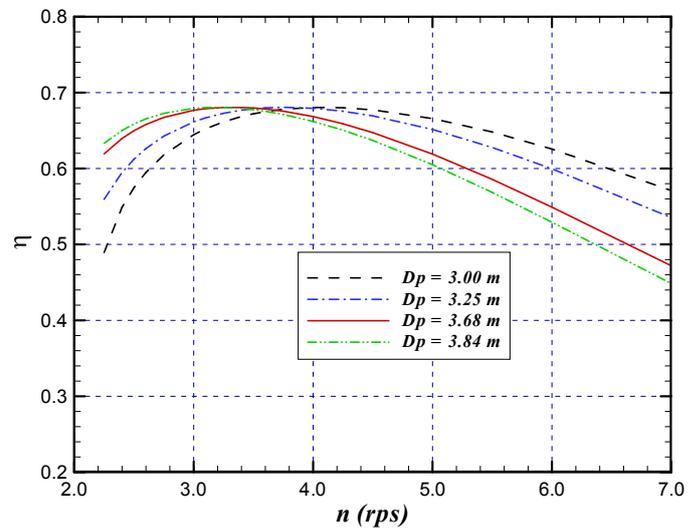


Figure 5 : Propeller Efficiency with Diameter Variation at Several Propeller Rotations

Looking to the both Figs. 4 and 5, it can be understood that a propeller with the high number of blade has higher efficiency than the low number at slow rotation and a propeller with the small diameter has higher efficiency than the large one at high rotation as already previously described. By combining these two considerations, one may get a propeller with high efficiency for a wider range of rotation. Therefore running a propeller at its optimum rotation with suitable number of blade and size of diameter would optimize its performance and hence it may reduce the fuel consumption used during voyage.

Up to this point, the effect of presence of the hub to the propeller efficiency has not been explored. Figure 6 represents the strength of circulation distribution as in Figure 2 with the effect of hub is taken into account. From this figure, it is clearly shown that the presence of the

propeller hub increases the strength of circulation, especially around the propeller hub radius. Although the circulation strength increases, the efficiency of propeller decreases as depicted in Figure 7. It is also observed that as the number of blade reduces, the discrepancy of propeller efficiency between the propeller with and without hub increases particularly for slow rotation. Nevertheless the discrepancy between them be-

comes negligible as the speed of propeller rotation increases.

### 5. Conclusions

From this study, it may be concluded that a propeller with less number of blades and small in diameter is recommended to be operated at middle to higher rotation and vice versa in order to acquire the highest efficiency. Another conclusion is that the effect of propeller hub increases the strength of circulation distribution, especially around the propeller hub radius. However, it slightly reduces the efficiency of propeller particularly at slow rotation and becomes negligible as the propeller rotation increases.

### Acknowledgement

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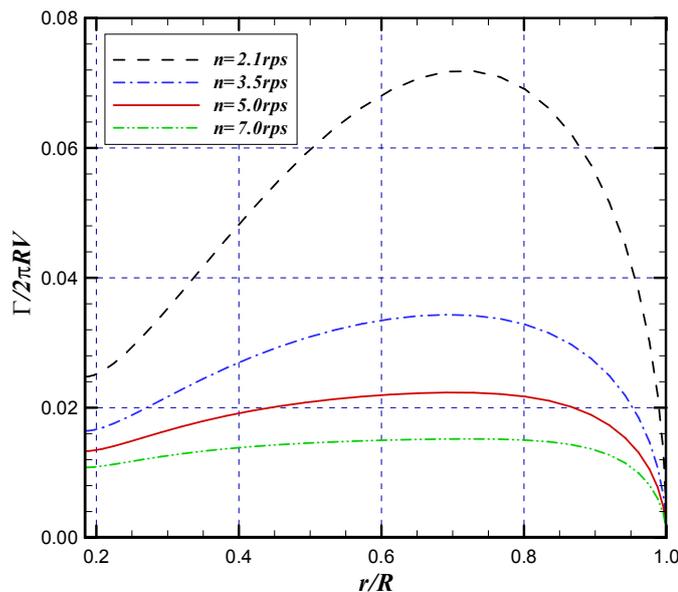


Figure 6 : Strength of Circulation Distribution along Radius of 5 Bladed Propeller with Hub Effect

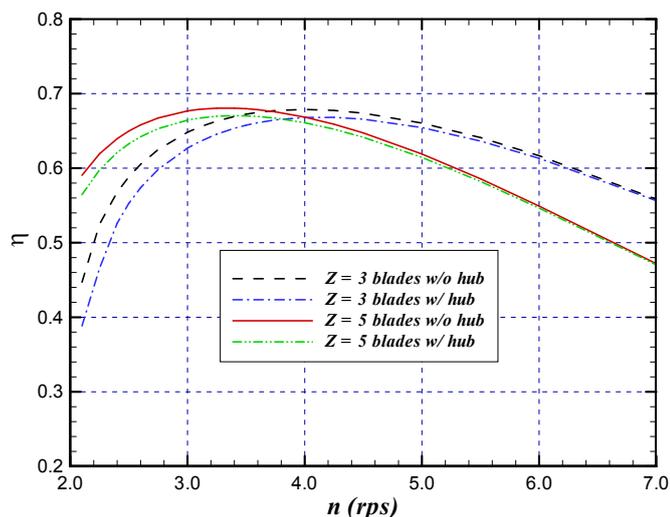


Figure 7 : Effect of The Presence of The Propeller Hub to Propeller Efficiency

**Muhdar Tasrief**, adalah personal Divisi Riset dan Pengembangan PT. Biro Klasifikasi Indonesia (Persero). Pada awal tahun 2006 penulis menyelesaikan pendidikan Sarjana Teknik di jurusan Teknik Perkapalan Universitas Hasanuddin dan bergabung dengan BKI pada akhir tahun 2006. Ta-

hun 2009, penulis berkesempatan melanjutkan pendidikan ke jenjang yang lebih tinggi.

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# NOVEL DESIGN OF HIGH LOAD CAPACITY SMART MAGNETORHEOLOGICAL ELASTOMER VIBRATION ISOLATOR IN HYBRID MODE

Hardika Ratditya Ardyanto

## Abstract

*This experimental study was a further research of Magnetorheological Elastomer (MRE) utilization in order to isolating ship structural borne vibration in semi active manner. MRE have been widely used as vibration isolator and vibration absorber since 1950, because this smart material have taken many researcher interest. Their durability and easy-to-manipulate characteristic combine with relatively low production cost have been considered as feasible material used to actively attenuate excessive or unwanted vibration from ship structure. This study aim was to design high strength novel active vibration isolator which is combined the arrangement of MRE for both squeeze (horizontal) and shear (vertical) that also known as hybrid mode. This arrangement variation will be compared with each single arrangement mode, and suitable control algorithm will be designed using Skyhook Control and implemented in order to having high isolation of vibration in single degree of freedom (SDOF).*

*Keywords : Magnetorheological Elastomer, Hybrid Mode, Skyhook control, Vibration Isolator, SDOF*

## 1. Introduction

Attenuating vibration has become major topics in the development of marine vessel technology. In marine application, the vibration source mainly come from main engine or generator. Thus problems requires a system consist of several vibration isolator or absorber which is used to reduce the vibration effects to the structure. The unwanted vibration are really hard to predict and calculate in the initial design stages, which made the selection of traditional isolation might not be always appropriate in any situation to overcome all condition that might happen along ship operation. Therefore researchers are developing means to actively control vibration which can operate automatically according to set input parameter, in order to facing wide range of possible situation. In terms of naval ship engineering, the automatic tuned isolator will work on stealth operation favor. The isolation of vibration coming from high vibrating source such as propulsion engine will also reducing the structural borne noise and eliminating underwater noise signature in results.

The ship industries nowadays are tends to utilize the system which having less energy consumables, having low

price and only occupied tiny space. Therefore the method such as active vibration which using hydraulic force will require huge amount of space and also emanates another source of noise which is coming from hydraulic fluid distribution line. With the influence of technology improvement nowadays, those needs can be satisfied with the utilization of smart material. In general, smart material are all materials that having changeable mechanical properties and/or dimensional shape, with the aid of controlled external force. Among various type of smart material which is developed recently to control mechanical vibration up until now, magnetorheological materials was chosen due to its flexibility, low energy demand and low manufacturing cost (Torre, 2009). This material can exist in form of Elastomer or Fluids. The elastomer form had several advantages compare to the fluid forms such as have no special storage requirement to prevent contamination, no need to store the material in tight compartment to avoid leakage, capable to withstand more loads, etc.

Hence, the latest research have found two ways to utilize the MRE, which is shear and squeeze mode. Both of this two methods have its own advantages. In order to have wide range of isolation frequency bandwidth, researcher tends to use MRE in shear mode but on the other hand if

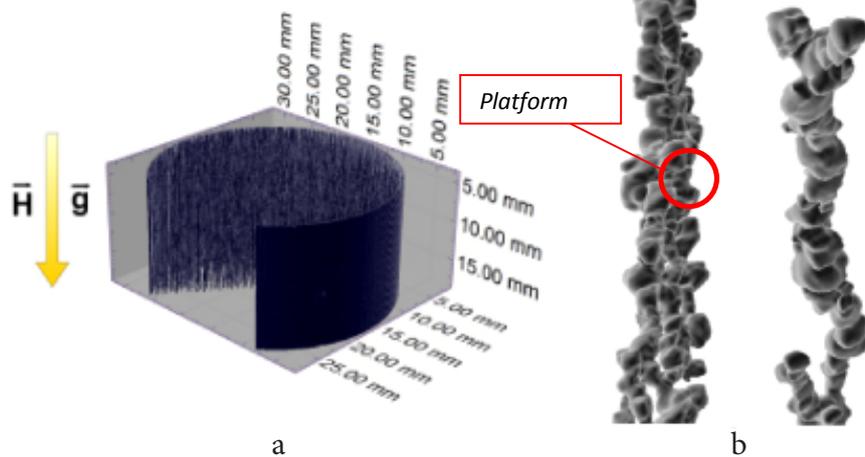


Figure 1 : Magnetorheological Materials

the strength is main objective for the system design, MRE squeeze mode will works better in that favor (Popp, 2009). Many MRE research nowadays have been conducted in order to achieve those two advantages in single system.

## 2. Research Basic Theory

### 2.1. SDOF Vibration

Regards to the actual rotating machine, the applied excitation force will not be zero. Many excitation force source could be appear, such as unbalanced rotation, dynamic forces of the bearing location due to loose component, etc. The equation of a damped SDOF with external excitation force can be given with following equation:

$$m\ddot{x} + c\dot{x} + kx = F(t) \quad (2-1)$$

While the external forces is avector it could be taken in phasor form given that

$$F(t) = F(\text{Sin}\omega t + i\text{Cos}\omega t) = Fe^{i\omega t} \quad (2-2)$$

Though for engine vibration case, the mass should translated atvertical direction only. Assuming the force is harmonic motion (i.e. uniform sine wave), then the input excitation force is the real part of F(t) that can be written as :

$$F_{ext}(t) = \text{Re}[F_0 e^{i\omega t}] = F_0 \text{Sin}\omega t \quad (2-3)$$

While the external excitation force introduced into the system, there will be a force transmitted as force received by the system foundation which is a fraction of equation such that:

$$F_T = c\dot{x} + kx \quad (2-4)$$

Therefore, the magnitude of transmitted force can be determined by following equation, viz.:

$$|F_T| = \sqrt{c^2 \dot{x}^2 + k^2 x^2} \quad (2-5)$$

The diagram of applied force and its transmitted force along SDOF forced vibration will be illustrated at Figure 2 :

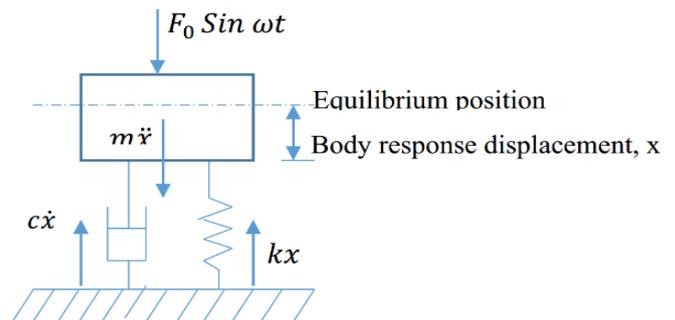


Figure 2 : Forced Vibration Diagram

The transmitted force will be distributed through ship structures and hull, and generates vibration on ship's structure which in further will become the source of structural borne noise. To avoid any damage of hull vibration that emanates from engine as a main source of vibration in concern, we should applied either one ofthe following solution that can minimize vibration effect on hull ,viz. :

1. Isolates the vibration sources
2. Applying means to 'absorb' the vibration energy
3. Repair unbalance rotating equipment

The isolation of vibration idea was chosen with consideration of application for such technique in hostile and less spacious location like the engine room. If the absorption technique is applied using vibration absorber, the risk of injury and other impact damage will raised due

to having secondary mass as part of vibration absorber moving at high frequency. It has been shown in the equation (2-2) that  $F(t) = Fe^{i\omega t}$  therefore the transmitted force should be out phase with excitation force which written as  $F_T(t) = F_T e^{i(\omega t - \phi)}$  but in the same time,  $F_T = c\dot{x} + kx$ . In an assumption that the body moves in simple harmonic motion, we can get the displacement as a function of time and also velocity and acceleration as derivation from displacement function. Put those displacement, velocity and acceleration at equation (2-1) to gain:

$$(-m\omega^2 + i\omega c + k)X = F \tag{2-6}$$

On the other hand, if we substitute derivation results into transmitted force equation (2-3) where the different phase applied, equation (2-3) will change into:

$$(i\omega c + k)X = F_T e^{-i\phi} \tag{2-7}$$

To deduce how much force transmitted to the ground from external excitation force, we can find out the ratio between transmitted force to external excitation force or well known as vibration Transmissibility. The transmissibility value for Forced Vibration system can be given as follow:

$$\left| \frac{F_T}{F} \right| = \sqrt{\frac{1 + (2\zeta \frac{\omega}{\omega_n})^2}{(1 - (\frac{\omega}{\omega_n})^2)^2 + (2\zeta \frac{\omega}{\omega_n})^2}} \tag{2-8}$$

Where  $\omega$  = oscillated frequency (in rad/s) and  $\omega_n$  = natural frequency of the system (also in rad/s).

### 2.2. Material Characteristic

To aid the isolation performance as discussed before, the research will using Magnetorheological Material (MR material) as a means to alter the stiffness of the system. MR material structure generally consists of non-magnetic polymer material (i.e. rubber or solid-like matrix in case of elastomer) as base that suspend filler magnetically

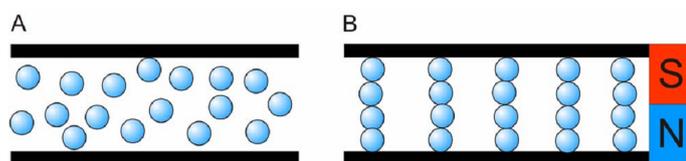


Figure 3 : (A) without magnetic field (B) with magnetic field

The changing extend of mechanical characteristic (i.e. shear modulus, stiffness, etc.) for MRE defined as magnetorheological effect (MR effect). MR effect can be calculated by

finding the percentage increment of mechanical properties (can be taken as changing value of stiffness) between zero magnetic field and maximum achieved field (Marke, 2005). It can be expressed clearly by following formula:

$$MR(\%) = \frac{K' - K}{K} \tag{2-9}$$

Where  $K'$  is the new stiffness value gained due to application of magnetic flux and  $K$  is the original stiffness without any magnetic flux.

### 2.3. MRE Configuration

There are three methods to employ MRE in vibration isolator or absorber device. The configuration method could be utilizing the change of elastic modulus of MRE that defined as compression / squeeze mode, or the one that depends on shear modulus change instead, that known as shear mode. The last method are found recently which is employing both of two configuration at the same time which known as hybrid mode.

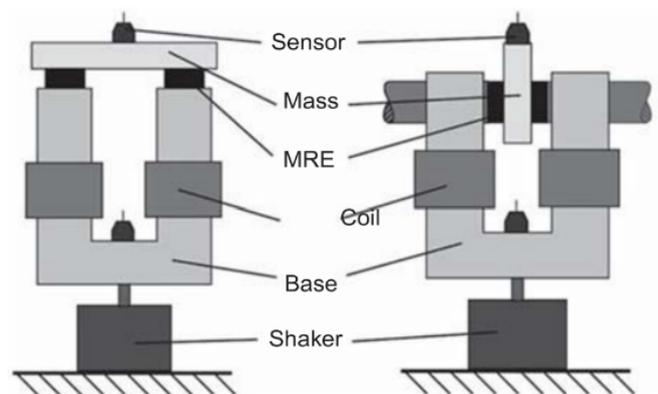


Figure 4 : MRE Configuration : Squeeze (left) and Shear Mode (right)

Naturally, MRE will get stiffer with application of magnetic field parallel to the force application. Hence in a purpose to avoid maximum transmissibility (transmissibility value = 1), we can choose either to make the natural frequency get higher (by making the MRE stiffer), or lesser in a way that transmissibility value is less than 1 by make it softer.

However, it was found in this research that the application to make the MRE softer which involving permanent magnet and control magnetic flux in the opposite direction with permanent magnet is really difficult to maintain. Hence the design configuration will focused to make the MRE stiffer.

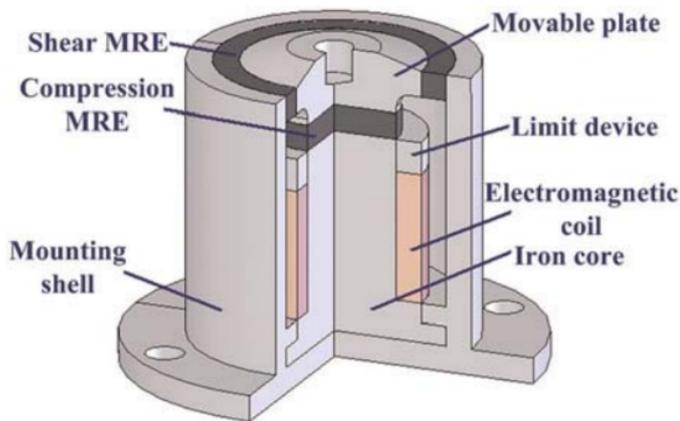


Figure 5 : MRE in Hybrid Mode Configuration

2.4. Control Theory

In order to create isolation system that can adapt in any situations, we need to create active or semi-active control rather than passive ones. Passive isolation method only isolate system from vibration response (either force or displacement) using fixed mechanical characteristics item-without any external power. With this type of isolation, the working frequenct bandwidth that the system able to attenuate is very limited. Therefore, active/semi-active control was more feasible to implement.

As have been mentioned in above paragraph, Skyhook

control was used as main algorithm to giving command into the system which will get MRE stiffer in result. This type of control system will active immediately at the control signal and de-activate soon after the signal vanish.

The force excitation input onto the system have various frequency, such as the magnitude of excitation force and the working frequency variation. The excitation force should be simplified as simple harmonic motion which is the real part of equation (2-2) in sine wave form force where the maximum amplitude of the force will be remain the same along the whole simulation duration. However, the system needs to be observed in different kind of working frequency, specifically where the working frequency is equal to the current natural frequency of the system which has the most severe impact on structure.

In order to do that objective, the excitation force will be simulated at each short period. Hence the excitation force will be in the form of Sine Wave. To activate the control signal, the detection of near natural frequency parameter will be used as the most accurate way to tell when the system needs to work. In real practice, it is a common to use frequency counter chip as shown in Figure 6, to gain the frequency magnitude of certain working system. However, this system also includes the algorithm to measure working frequency of the system.

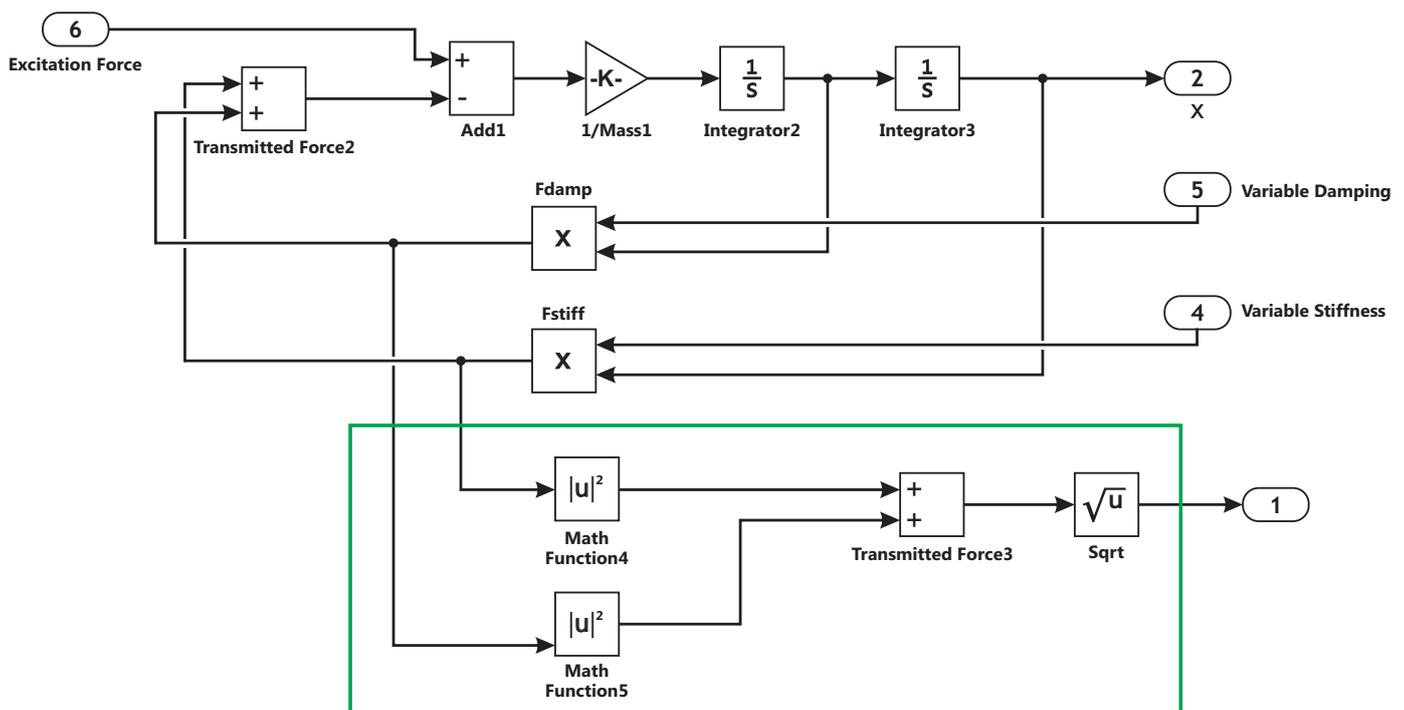


Figure 6 : System Model in Simulink

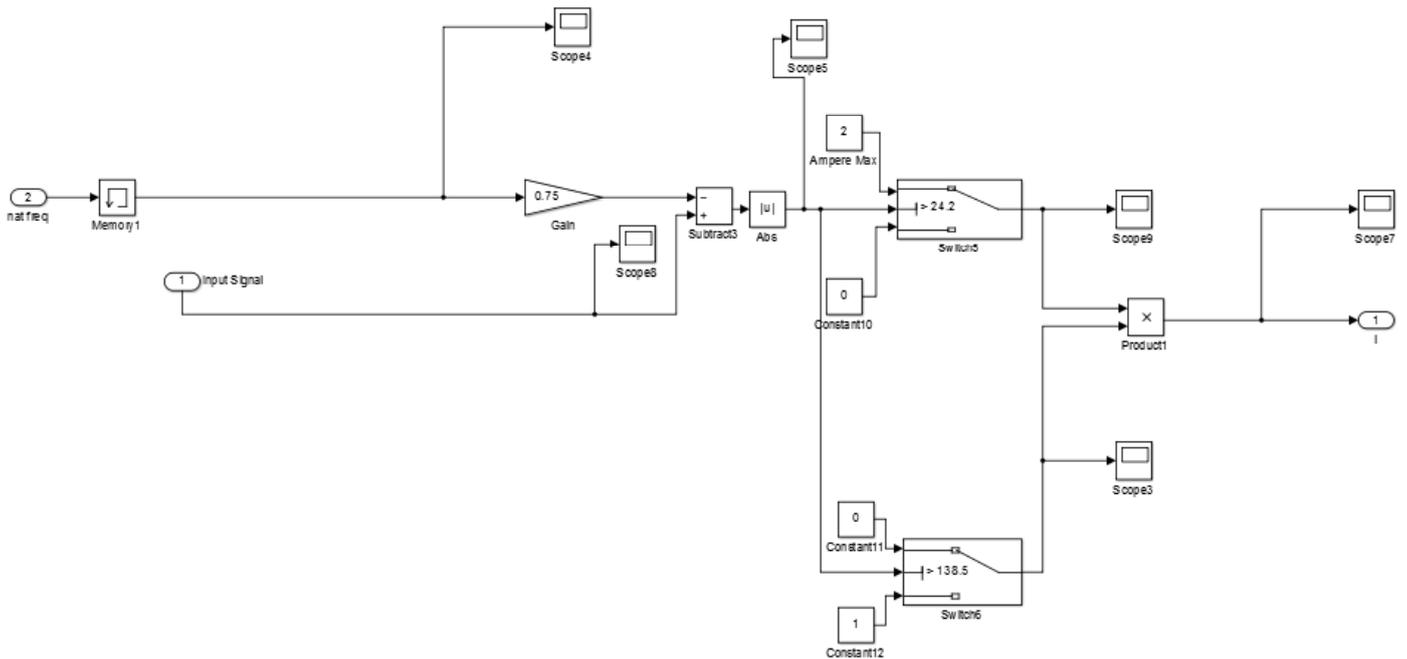


Figure 7 : Control Actuator

Using the working frequency parameter, the control actuator can be set to start trigger the control signal when the working frequency have reach 75% value of original natural frequency of the system. Likewise, the control actuator will be deactivated after detected working frequency will only remain 25% from the original natural frequency. To be able to observe the behavior of isolator system, the mechanical properties of the material also modelled, based on static and dynamic loading test on INSTRON E1000 machine.

Hence the stiffness and damping factor value were originally come to the produced MRE mechanical characteristic. The stiffness and damping value can be derived from following equation.

Therefore it can be draw form Figure 8 that stiffness is a function of liner equation  $F = kx$ .

On the other hand, the damping factor can be obtained with energy method using this formula :

$$\delta = \text{Arcsine} \left( \frac{\text{energy area}}{\pi \cdot \frac{x_0}{2} \cdot \frac{F}{2}} \right) \quad (2-10)$$

Where the energy area is the area enclosed in hysteresis loop (integral of force regards to the displacement),  $x_0$  and  $F$  is the maximum displacement and maximum load on the hysteresis loop.

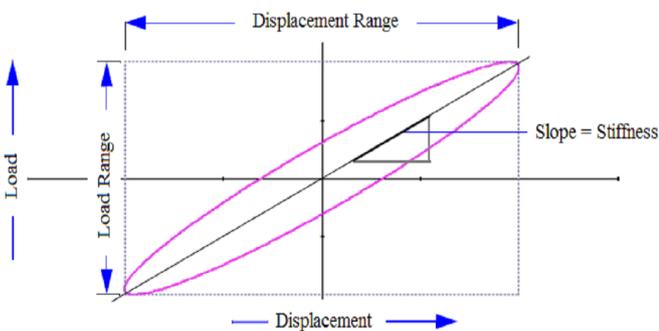


Figure 8 : Static Loading hysteresis loop

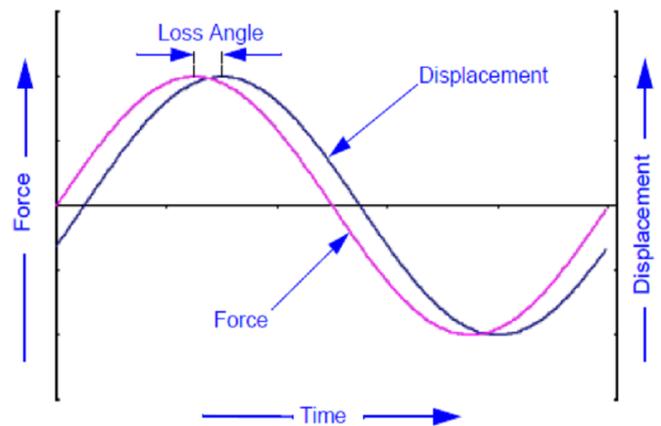


Figure 9 : Dynamic Load Diagram

### 3. Mechanical Testing

The MRE Production material consists of Small Iron powder (10nm), Silicon, which have been dried and mixed thoroughly and continued with magnetization process. This procedure have been done in order to create anisotropic MRE material which is more efficient in control actuator power.

### 4. MRE Isolator Magnetic Circuit

The magnetic circuit of the vibration isolator were configured at Figure 11. Magnetic flux density and the flow have been tested before experiment.



**Figure 10 :**  
Testing of MRE Hybrid Isolator at Instron E 1000

Numerical investigation of such magnetic configuration have been done using Software MagNet 7.5. which can be shown in Figure 12.

### 5. TESTING RESULT

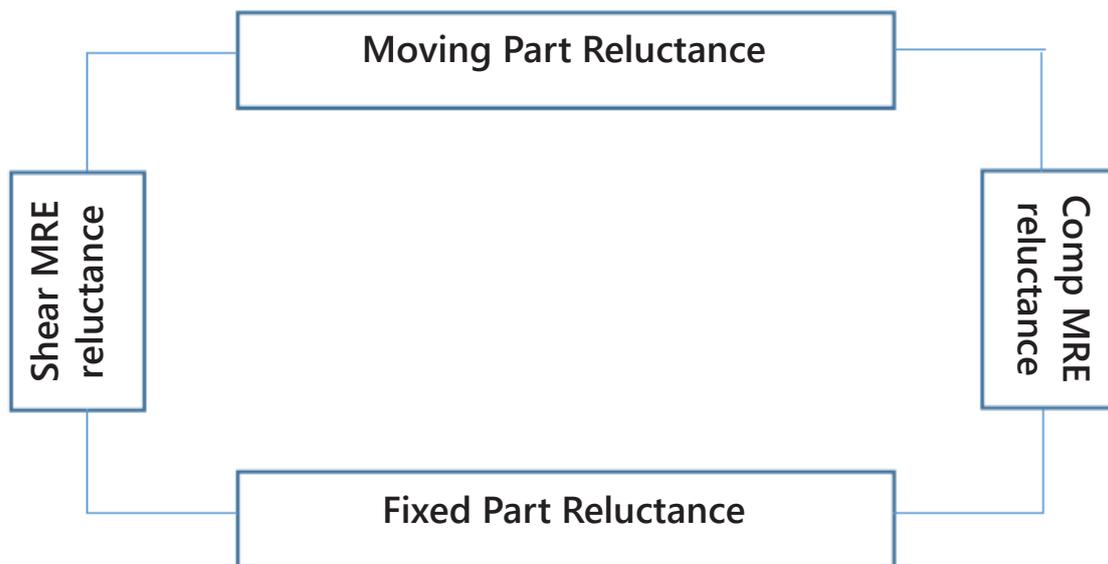
Testing for static and dynamic load have been carried out while the coil around isolator have been flowed by electrical current in variation of 0.5 – 2.5 A with 0.5 Ampere increment. The test result can be seen in Figure 13 & 14.

The result from mechanical test will become an alogarithm input in order to simulate isolator system behavior.

After the mechanical properties were put into the system, the performa can be reviewed according to previous control algorithm in figure 15. The transmitted force into the structure can also be minimized as shown in Figure 16.

### 6. Conclusion

As the purpose of this research, the aim and objectives is to make design of smart vibration isolator using MRE in hybrid mode, with consideration of compact design and capable to carry on engine weight load within 10% limit of strain. The design shows smart hybrid isolator with 49% MR effect which capable to carry the intended load in 3% limit strain, the system have been simulated using SIMULINK and the performance was proven quite well SDOF forced vibration isolation. Compare to the shear / squeeze



**Figure 11 :** Magnetic Circuit Configuration

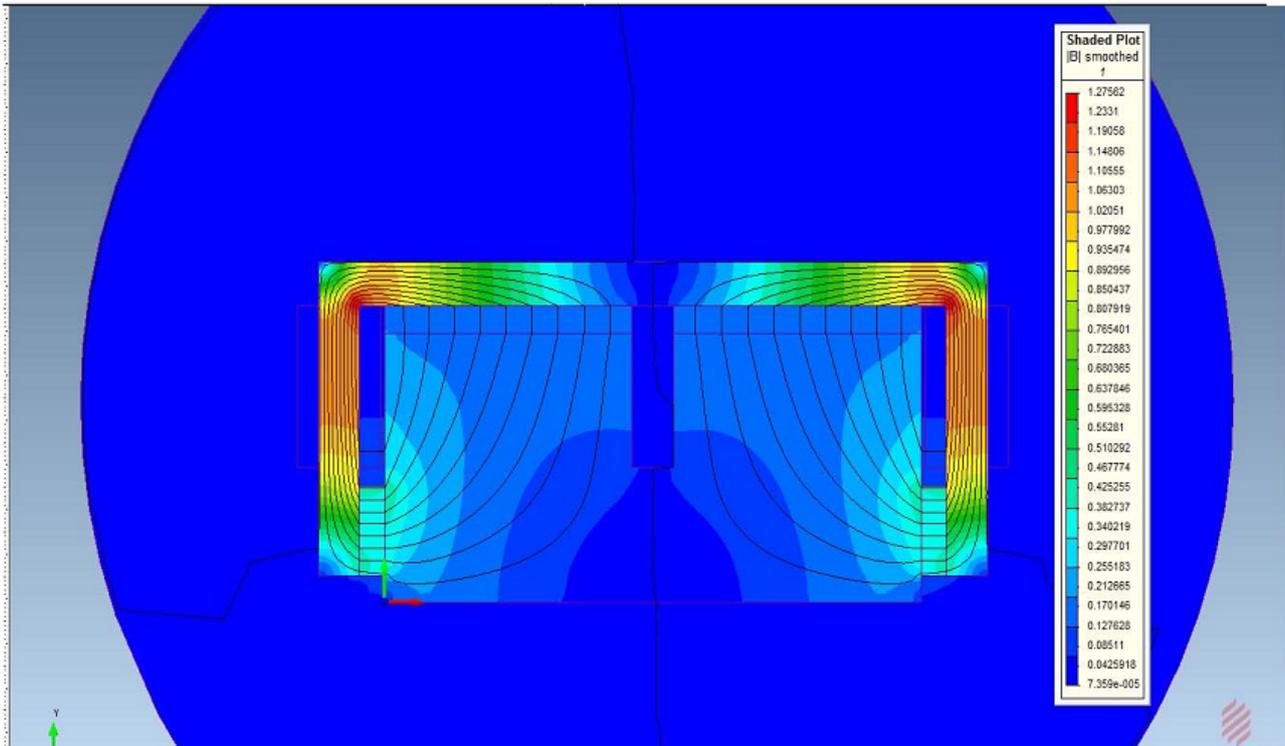


Figure 12 : Magnetic flux density simulation

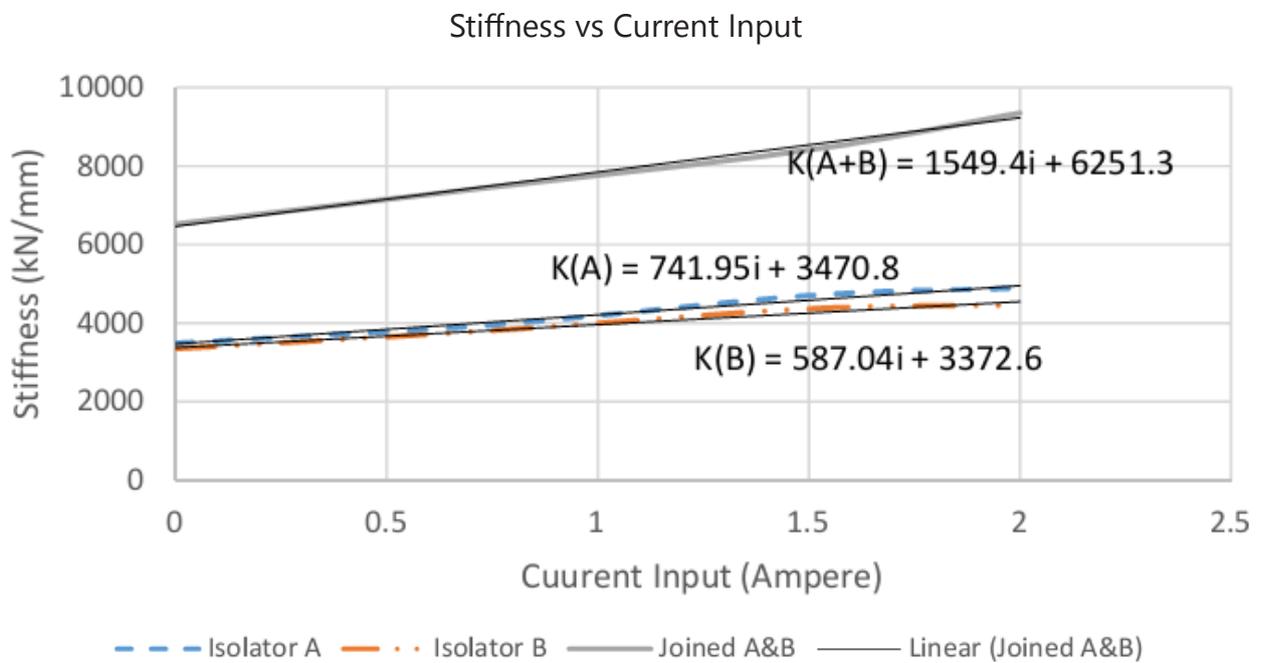


Figure 13 : Current vs Stiffness

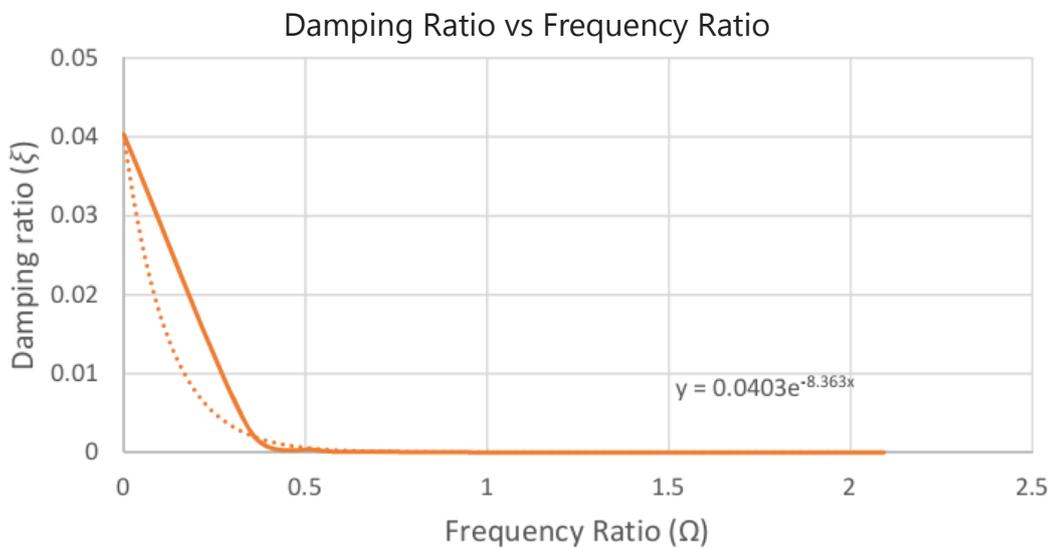
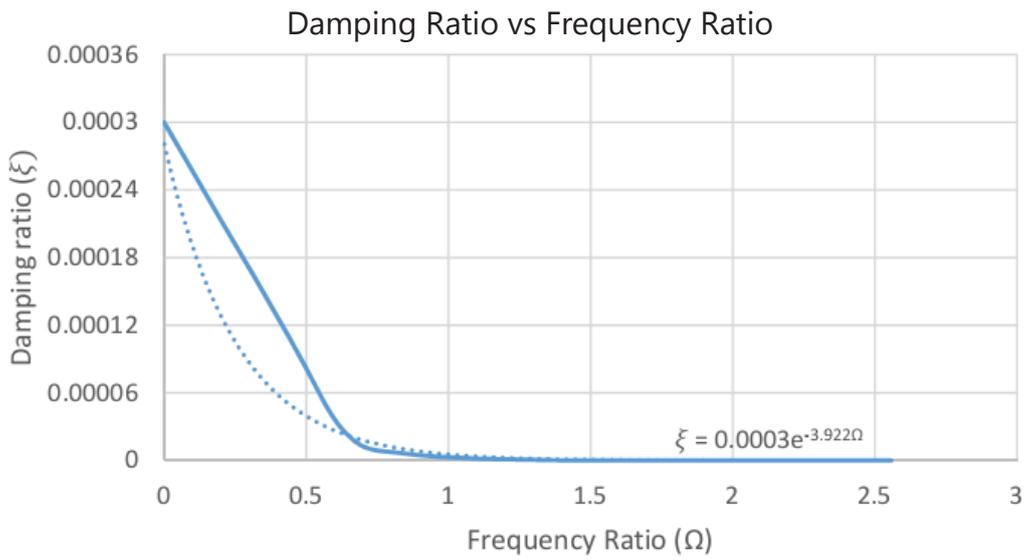


Figure 14 : Damping factor for Current 0 – 2 Ampere

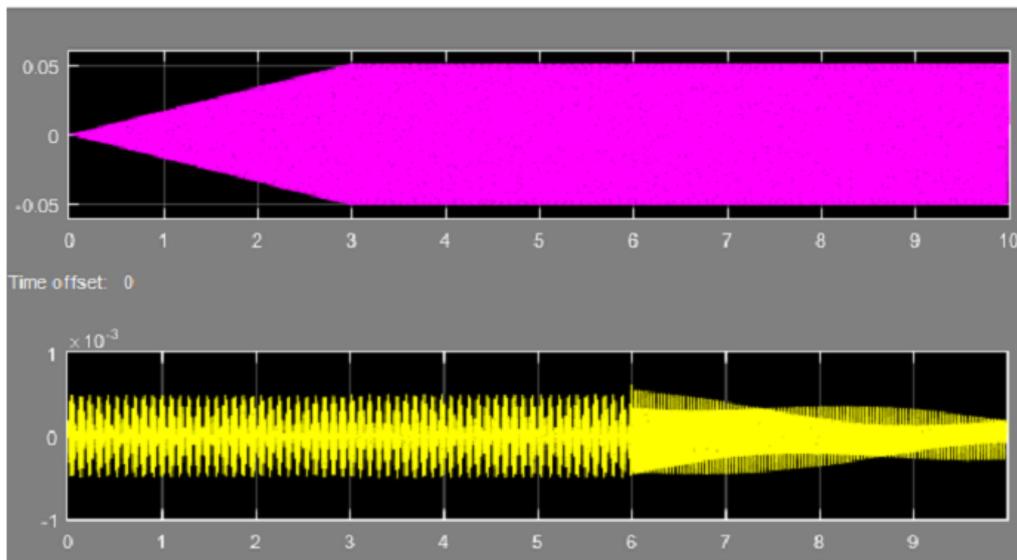
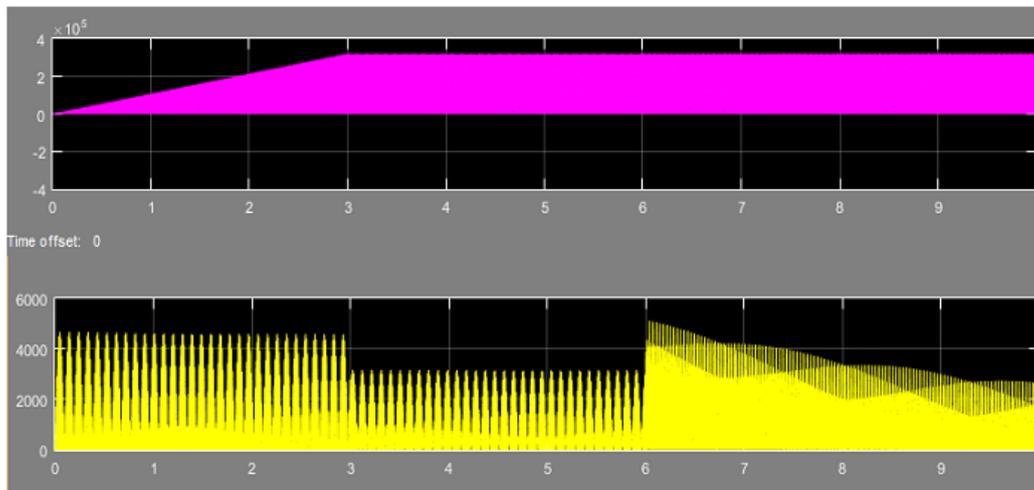


Figure 15 : Comparison of response displacement at : Without control (up) & With Control (down)



**Figure 16 :** Comparison of transmitted force at : Without control (up) & With Control (down)

only mode, the hybridmode was showing both advantage from each mode. Compare to the shear / squeeze only mode, the hybridmode was showing both advantage from each mode.

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# RANCANG BANGUN SISTEM PENGINJEKSIAN GAS PADA MODIFIKASI *DUAL FUEL DIESEL ENGINE*

Puji Dhian Wijaya, I Made Ariana, Semin Sanuri

## Abstract

Cadangan minyak bumi semakin lama semakin berkurang, sehingga banyak penelitian yang dilakukan untuk menyelesaikan permasalahan ini, seperti memodifikasi diesel menjadi dual fuel. Sistem kerja dari dual fuel adalah memasukkan CNG kedalam ruang bakar bersamaan dengan udara pada saat langkah hisap di intake manifold dan akan ikut terbakar dengan solar sebagai pematiknya. Untuk mengkonversi solar ke CNG, perlu dihitung nilai kalor dari masing – masing bahan bakar tersebut. Metode yang dapat digunakan adalah berdasarkan GPA Standard dan komposisi atom penyusun CNG. Setelah didapatkan nilai kalor, perlu dianalisa nilai dari Low Explosive Limit dan High Explosion Limit dari CNG untuk mengetahui apakah bahan bakar gas dan oksigen cukup untuk melakukan pembakaran. Spesifikasi dari komponen – komponen yang diperlukan dalam konverter kit ini disesuaikan dengan standar spesifikasi untuk dioperasikan dengan CNG. Pengujian alat ini dapat dilakukan tanpa mengurangi bahan bakar solar dan kemudian ditambahkan dengan CNG. Berdasarkan hasil pengujian, CNG mampu mensubstitusi kebutuhan solar sampai 75% .

Keywords : CNG, Dual Fuel, Nilai Kalor, Solar.

## 1. Pendahuluan

Dalam industri perkapalan, mesin penggerak yang paling banyak digunakan adalah mesin diesel. Namun dengan adanya kenaikan harga minyak mentah dan pasokannya yang semakin berkurang, pemakaian mesin diesel akan semakin tidak efisien dikemudian hari. Jika diamati dengan lebih seksama, kerugian yang dihasilkan karena pemakaian bahan bakar minyak mencakup segi ekonomis dan juga lingkungan. Oleh karena itu pengembangan bahan bakar alternatif semakin gencar dilakukan oleh berbagai pihak sebagai bentuk solusi dari dampak penggunaan bahan bakar minyak. Bahan bakar alternatif lain adalah menggunakan sistem baru pada bahan bakar kendaraan, yaitu sistem bahan bakar ganda, atau lebih dikenal dengan *Dual Fuel System*.

Sistem bahan bakar ganda ini lebih ramah lingkungan jika dibandingkan dengan sistem bahan bakar tunggal (solar). *Dual Fuel System* ini juga dinilai jauh lebih ekonomis. *Dual fuel system* atau sistem berbahan bakar ganda memiliki hasil pembakaran yang jauh lebih bersih, (Ehsan, 2009). Kombinasi bahan bakar yang dipakai dalam sistem ini adalah solar dan gas alam. Potensi peman-

faatan gas alam sebagai pengganti bahan bakar minyak seperti solar, sangat besar jika diterapkan di Indonesia. Hal ini terkait dengan sumber gas di Indonesia masih relatif banyak dan belum dimanfaatkan secara maksimal. Jenis gas alam yang dipakai adalah *Compressed Natural Gas* (CNG) dimana gas alam terkompresi ini mengandung lebih dari 90% metana. Dari segi harga, CNG jauh lebih murah dibandingkan dengan bahan bakar gas lain karena tidak melalui proses pencairan dan lainnya (Clarke, 2012). Oleh karena itu, penerapan sistem berbahan bakar ganda diharapkan mampu menghemat pengeluaran konsumsi bahan bakar serta mengurangi emisi gas buang yang dihasilkan oleh mesin dengan sistem berbahan bakar tunggal.

## 2. Tinjauan Pustaka

Bahan bakar alternatif yang banyak diaplikasikan dalam modifikasi *Dual Fuel Diesel Engine* adalah bahan bakar gas, dimana gas (CNG) tersebut dicampurkan dengan udara segar di *intake manifold* (atau disuntikkan ke dalam silinder) dan dimasukkan ke dalam silinder dan dinyalakan oleh sejumlah kecil bahan bakar diesel ketika piston mendekati akhir langkah kompresi (TMA kompresi). Partikel-partikel bahan bakar halus bercampur dengan

udara untuk membentuk campuran yang mudah terbakar yang kemudian menyatu karena suhu tinggi. Ledakan yang menghasilkan pembakaran dari kompresi tersebut kemudian ikut membakar gas secara langsung karena sudah bercampur dengan udara dan solar, (Ehsan, 2012).

Pada modifikasi motor diesel normal menjadi *dual fuel*, udara murni yang dihisap akan dicampurkan dengan gas, sehingga hanya sedikit volume solar yang dibutuhkan supaya terjadi ledakan. Motor diesel bahan bakar campuran gas kebanyakan menggunakan *intake valve* untuk memasukan gas bersamaan dengan udara murni. Pengoperasian dengan mode *dual fuel* ini dapat mengurangi emisi-emisi oksida nitrogen (NOx) mendekati 85%. Selain itu, pada saat beroperasi dengan gas alam dan bahan bakar berkadar belerang rendah, motor-motor diesel berbahan bakar ganda menghasilkan level-level kandungan SOx dan arang-para nyaris nol, (ABS, 2012).

Jika terjadi gangguan pasokan gas, motor diesel *dual fuel* akan mengganti pengoperasiannya dari gas menjadi pengoperasian bahan bakar minyak (solar) pada beban berapapun secara otomatis. Selama pengoperasian bahan bakar minyak, motor *dual fuel* menggunakan proses diesel konvensional. Karena pada dasarnya sistem *dual fuel* ini adalah motor diesel biasa, maka apabila terjadi gangguan, sistem akan secara otomatis pindah ke diesel konvensional walau motor sedang beroperasi.

**Tabel 1 : Spesifikasi CNG**

(Sumber : PT. Lapindo Brantas Indonesia, 2014)

No.	Komponen (i)	Komposisi (Mol %)
1	N <sub>2</sub>	1.720
2	CO <sub>2</sub>	1.353
3	CH <sub>4</sub>	94.034
4	C <sub>2</sub> H <sub>6</sub>	1.650
5	C <sub>3</sub> H <sub>8</sub>	0.818
6	i-C <sub>4</sub> H <sub>10</sub>	0.194
7	n-C <sub>4</sub> H <sub>10</sub>	0.060
8	i-C <sub>5</sub> H <sub>12</sub>	0.075
9	n-C <sub>5</sub> H <sub>12</sub>	0.040
10	C <sub>6</sub> +	0.056

## 2.1. Karakteristik CNG

CNG (*Compressed Natural Gas*) atau biasa disebut dengan gas alam terkompresi adalah bahan bakar alternatif yang bersih. CNG terbentuk dari suatu campuran gas-gas yang dihasilkan dari proses fermentasi bahan organik oleh

bakteri dalam keadaan tanpa oksigen. CNG adalah gas bumi yang dipampatkan pada tekanan tinggi sehingga volumenya menjadi sekitar 1/250 dari volume gas bumi pada keadaan standar. Tekanan pemampatan CNG bisa mencapai 250 bar pada suhu atmosferik. Spesifikasi CNG secara rinci disampaikan pada Tabel 2.

**Tabel 2 : Spesifikasi Diesel Yanmar TF85 MH**

Engine (four stroke cycle)	TF85 MH
Number of cylinders	1
Combustion system	Direct Injection
Bore	85 mm
Stroke	87 mm
Displacement	493 cc
Compression Ratio	18
Max. Engine speed at full load	2200 RPM
Continous Power Output	7.5 kW
Specific Fuel Consumption	171 gr/HP.h
Volume per Injection	0.07 mL

### 2.1.1. Nilai Kalor (*Heating Value*)

Nilai kalor merupakan jumlah energi kalor yang dilepaskan bahan bakar pada waktu terjadinya oksidasi unsur – unsur kimia yang ada pada bahan bakar tersebut. Harga nilai kalor solar diambil dari penelitian yang sudah dilakukan sebelumnya. Sedangkan untuk nilai kalor CNG dalam penelitian ini ditentukan dengan membandingkan data dari penelitian sebelumnya dengan hasil dari metode perhitungan berdasarkan GPA Standard 2172 – 86 : *Calculation of Gross heating Value, Relative Density and Compressibility Factor of Natural Gas Mixture from Compositional Analysis* dan GPA Standard 2261 – 89 : *Analysis for Natural Gas and Similar Gaseous Mixture by Gas Chromatograph* serta dengan perhitungan nilai kalor berdasarkan komposisi atom dari komponen penyusun CNG (C, H, O, N)

#### a. Nilai kalor berdasarkan GPA Standard 2172 – 86 dan GPA Standard 2261 – 89.

Formula yang digunakan untuk menentukan nilai dari *heating value* gas dapat diambil dari formula standar yang ditetapkan oleh suatu asosiasi atau badan internasional, seperti GPA (*Gas Processors Association*)

- Compressibility factor ideal Gas at 60°F and 14.696 psia (Z)  
 $Z = 1 - \{Hi.Vbi\}^2.14,696$

- Compressibility factor gas at 60°F and 14.7 psia (Zb)  
 $Zb = 1 - \{Hi.Vbi\}^2.Pb$
- Specific Gravity Gas Ideal  
 $SG_{ideal} = E\{Hi.Gi\}$
- Real Specific Gravity  
 $SGReal = \{Hi.Gi\}.\{Pb/14.73\}.\{0.99949/Zb\}$
- Ideal Gross Heating Value  
 $GHVIdeal = E\{Hid.Hi\}$
- Real Gross Heating Value  
 $GHVReal = \{Hid.Hi\}.\{Pb/14.696\}/Zb$

**b. Nilai kalor berdasarkan komposisi atom dari komponen penyusun CNG (C, H, O, N).**

Perhitungan nilai kalor berdasarkan komposisi atom penyusun CNG sama halnya dengan mencari berapa nilai untuk panas reaksi akibat terjadinya oksidasi pada setiap unsur atau senyawa yang ada pada CNG. Ketika sudah didapatkan nilai panas untuk masing – masing senyawa/unsur, panas pembakaran dapat dihitung dengan menjumlahkan nilai – nilai tersebut. (Morris, 2012)

- $\Delta H^\circ comb = a\Delta H^\circ fCO_2 + y\Delta H^\circ fH_2O - y\Delta H^\circ fO_2$
- $\Delta H^\circ comb \text{ comp.} = \text{vol\% comp.} \times \Delta H^\circ reax \text{ comp.}$
- Mol. mass of comp. = mol mass x vol%
- Mass% of comp. = vol%/mol mass of comp.
- Mol. mass of NG =  $\sum(\text{mol mass} \times \text{vol\%})$
- Mass% of NG =  $\text{vol\%} / \text{mol mass of NG}$
- $\Delta H^\circ comb \text{ of NG} = \sum(\Delta H^\circ comb \text{ of comp.})$
- Low Heating Value  
 $LHV = -(\Delta H^\circ comb \text{ of NG})$
- Low Heating Value  
 $HHV = LHV - \sum \text{mol. H} \times \Delta H^\circ reax \text{ of } H_2O$

**2.1.2. Explosive Limit**

*Explosive limit* juga dikenal dengan istilah *Flammable Range* yaitu batas antara maksimum dan minimum konsentrasi campuran uap bahan bakar dan udara normal, yang dapat menyala / meledak setiap saat bila diberi sumber panas. Di luar batas ini tidak akan terjadi kebakaran, (Coward, 1952).

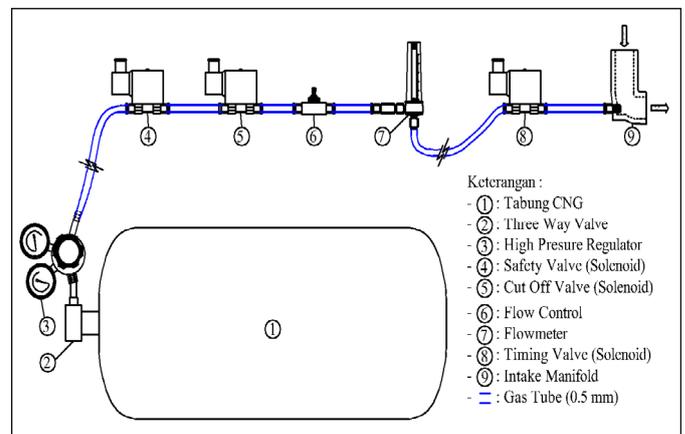
Setiap gas memiliki dua macam explosive limit, yaitu LEL (*Low Explosive Limit*) dan HEL (*High Explosive Limit*). Jika konsentrasi gas tersebut berada dibawah LEL, maka ledakan tidak akan terjadi karena kurangnya bahan bakar. Dan jika konsentrasi berada di atas HEL, maka tidak tersedia cukup

oksigen untuk memulai reaksi. Formula yang digunakan untuk menentukan nilai dari LEL (*Low Explosive Limit*) dan HEL (*High Explosive Limit*) secara teoritis adalah :

- $Cst = 21/(0.21 + n)$
- LEL of component =  $0.55 \times (Cst \text{ of comp.})$
- HEL of component =  $3.5 \times (Cst \text{ of comp.})$
- $\sum LEL = 100 / \sum(Ci/LELi)$
- $\sum HEL = 100 / \sum(Ci/HELi)$

**3. Proses Penelitian**

Pada tahap awal pengerjaan penelitian ini dimulai dengan membuat desain perancangan komponen – komponen yang diperlukan untuk membuat sistem ini. Sistem penginjeksian gas ini terdiri dari tabung gas CNG, *regulator high pressure*, katup pneumatic (solenoid), *flow control*, *flowmeter*, *gas tubing* dan *fitting*. Komponen – komponen tersebut berfungsi sebagai satu sistem yang saling terintegrasi untuk menginjeksikan bahan bakar gas dari tabung CNG yang bertekanan tinggi sampai ke *intake manifold* dengan tekanan yang jauh lebih rendah. Selain itu perlu dipersiapkan motor diesel yang akan dikonversi menjadi *dual fuel*.



**Gambar 1 : Desain Rancangan Sistem Penginjeksian Bahan Bakar CNG**

Sebelum mendapatkan jumlah gas yang mampu menggantikan *energy* panas yang dihasilkan oleh solar, perlu diketahui nilai dari *heating value* (nilai kalor) masing – masing bahan bakar. Kemudian dari nilai kalor tersebut akan diperoleh besarnya CNG yang mampu menggantikan kebutuhan solar di motor diesel. Setelah dilakukan analisa dan perhitungan serta mendapatkan desain yang direncanakan, maka dilanjutkan dengan pembuatan

prototipe *converter kit* ini.

Pada tahap selanjutnya, akan dilakukan uji kerja eksperimen dengan pengujian beberapa variasi pembebanan. Pengujian ini akan membandingkan besar konsumsi bahan bakar solar dan gas serta selisih nilai kalor yang dihasilkan sebelum dan sesudah diterapkannya aplikasi *dual fuel* ini di motor diesel.

#### 4. Analisa Data dan Pembahasan

##### 4.1. Nilai CNG dan Solar Kalor

Nilai kalor dari CNG menurut publikasi ilmiah John W Bartok dan data dari lembaga internasional seperti *National Institute of Standards and Technology (NIST)* adalah 1030 BTU/ft<sup>3</sup>. Sedangkan hasil dari perhitungan nilai kalor (*heating value*) dari CNG berdasarkan formula – formula yang ada di GPA Standard 2172 – 86 dan GPA Standard 2261 – 89 dapat dilihat pada Tabel 3.

**Tabel 3 : Nilai Kalor CNG**

No	Formula	Value	Units
1	Z	0.99779	-
2	Zb	0.9978	-
3	SG <sub>Ideal</sub>	0.59739	-
4	SG <sub>Real</sub>	0.596606	-
5	GHV <sub>Ideal</sub>	1015.2351	[BTU/ft <sup>3</sup> ]
6	GHV <sub>Real</sub>	1017,7504	[BTU/ft <sup>3</sup> ]

Detail perhitungan besarnya nilai kalor (*heating value*) berdasarkan komposisi atom penyusunnya disajikan pada Tabel 4.

**Tabel 4 : Molar ΔH<sup>o</sup>f Pada Temperatur 250C**

N	Details	ΔH <sup>o</sup> f	
1	Natural Gas Constituen s	CH <sub>4</sub>	-74.81
		C <sub>2</sub> H <sub>6</sub>	-84.68
		C <sub>3</sub> H <sub>8</sub>	-
			103.85
			-
2	Combustion Products	C <sub>4</sub> H <sub>10</sub>	126.15
		CO <sub>2</sub>	-
			393.51
		H <sub>2</sub> O(g)	-
			241.81
		-	
		285.83	

Sumber : FREED database, 2012)

**Tabel 5 :**

Molar dari ΔH<sup>o</sup>reax pada temperature 25°C (KJ/g-mol)

Reaction to form H <sub>2</sub> O(g)	
2O <sub>2</sub> + CH <sub>4</sub> → CO <sub>2</sub> + 2H <sub>2</sub> O(g)	-802.33
3½O <sub>2</sub> + C <sub>2</sub> H <sub>6</sub> → 2CO <sub>2</sub> + 3H <sub>2</sub> O(g)	-1427.8
5O <sub>2</sub> + C <sub>3</sub> H <sub>8</sub> → 3CO <sub>2</sub> + 4H <sub>2</sub> O(g)	-2043.9
6½O <sub>2</sub> + C <sub>4</sub> H <sub>10</sub> → 4CO <sub>2</sub> + 5H <sub>2</sub> O(g)	-2657.0
Reaction to form condense water vapor	
H <sub>2</sub> O(g) → H <sub>2</sub> O(liq)	-44.02

Sumber : FREED database, 2012)

**Tabel 6 : ΔH<sup>o</sup>comb of components**

	Vol %	Mol mass	mass %	ΔH <sup>o</sup> comb
N <sub>2</sub>	1.72	28.01	0.027906	0
CO <sub>2</sub>	1.353	44.01	0.034491	0
CH <sub>4</sub>	94.034	16.04	0.873662	-754.46
C <sub>2</sub> H <sub>6</sub>	1.65	30.07	0.028739	-23.5583
C <sub>3</sub> H <sub>8</sub>	0.818	44.097	0.020894	-16.7194
C <sub>4</sub> H <sub>10</sub> +	0.425	58.124	0.014309	-11.2921

**Tabel 7 : Perhitungan Nilai Kalor CNG Berdasarkan Komposisi Atom Penyusunnya**

No	Formula	Value	Units
1	Mol. mass of NG	17.264	-
2	ΔH <sup>o</sup> comb of NG	-806.029	kJ/g-mol
3	LHV	913.784	BTU/ft <sup>3</sup>
4	HHV	1111.821	BTU/ft <sup>3</sup>

Dari beberapa referensi yang ada dan juga hasil perhitungan dengan menggunakan dua metode yang berbeda, maka diperoleh 4 variasi nilai kalor berdasarkan metode – metode yang berbeda, yaitu 1030 BTU/ft<sup>3</sup> ; 1017,7504 BTU/ft<sup>3</sup> ; 913.784 BTU/ft<sup>3</sup> dan 1111.821 BTU/ft<sup>3</sup>.

Selain data nilai kalor *Compressed Natural Gas (CNG)*, diperlukan pula data spesifikasi Solar (*Diesel Fuel*) untuk menentukan besarnya energi yang terjadi dalam proses pembakaran mesin. Berdasarkan tabel 3.5. (Lampiran Keputusan Dirjen Migas 3675 K/24/DJM/2006 tanggal 17 Maret 2006) dan data dari *Alternative Fuels Data Center (AFDC)*, nilai kalor dari Solar adalah 960.79 BTU/ft<sup>3</sup>.

##### 4.2. Explosive Limit CNG

Hasil dari perhitungan *explosive limit* dari CNG berdasarkan formula – formula dari H.F.Coward dan G.W. Jones adalah sebagai berikut :

**Tabel 8 :** Nilai *Low Explosive Limit* dan *High Explosive Limit* dari komponen penyusun CNG (vol%)

		LEL	HEL
<b>Methane</b>	CH <sub>4</sub>	5	15
<b>Ethane</b>	C <sub>2</sub> H <sub>6</sub>	3	15
<b>Propane</b>	C <sub>3</sub> H <sub>8</sub>	2.2	9.5
<b>Butanes,dll</b>	C <sub>4</sub> H <sub>10</sub> +	1.9	8.5
<b>Carbone Dioxide</b>	CO <sub>2</sub>	5.22	33.25
<b>Nitrogen</b>	N <sub>2</sub>	2.87	60.74

**Tabel 9 :** Hasil Perhitungan Nilai *Low Explosive Limit* dan *High Explosive Limit* CNG Total (vol%)

No	Formula	Value	Units
1	∑LEL	4.8950	[vol%]
2	∑HEL	14.728	[vol%]

Dari hasil yang didapatkan dapat disimpulkan bahwa dengan LEL (*Low Explosive Limit*) dan HEL (*High Explosive Limit*) dari CNG sebesar 4.8950 [vol%] dan 14.7288 [vol%], maka ledakan (*explosion*) bisa terjadi karena tersedia cukup oksigen (HEL<15) dan memiliki kemungkinan untuk tidak terjadi karena adanya kekurangan bahan bakar (LEL<5).

#### 4.3. Kebutuhan Bahan Bakar

Diketahui bahwa nilai kalor (*heating value*) dari bahan bakar solar adalah 960.79 BTU/ft<sup>3</sup> (35.837 MJ/L) dalam satuan volume dan bernilai 44.3886 MJ/kg dalam satuan massa. Konsumsi solar untuk satu kali penginjeksian berdasarkan perhitungan diatas adalah 0.05831 gr (0.07 mL). Maka energi yang dihasilkan oleh pembakaran dari motor diesel pada putaran maksimal (2200 RPM) berdasarkan nilai kalornya sama dengan mengalikan nilai kalor dari solar dengan besarnya konsumsi bahan bakar solar per injeksi adalah 0.002588 MJ.

Berdasarkan nilai kalor diatas dan dari beberapa referensi, diketahui bahwa hasil pengkonversian bahan bakar solar dan CNG dengan acuan *energy content* atau *low heating value* dari masing – masing bahan bakar adalah dalam 1 m<sup>3</sup> CNG atau 0.78 kg CNG memiliki nilai energi yang sama dengan 1.14 L solar. Jadi dalam 1 kali penginjeksian bahan bakar solar sebesar 0.07 mL setara dengan memasukkan 57 mL CNG kedalam ruang bakar.

#### 4.4. Sistem Penginjeksian Gas

Sebelum pengoperasian alat atau menginjeksikan bahan

bakar gas, motor diesel tersebut dijalankan terlebih dahulu selama kurun waktu tertentu dengan bahan bakar solar. Beban diberikan dan dipertahankan sampai motor mencapai kondisi operasi normal (*idle*). Dengan tanpa mengurangi kuantitas bahan bakar diesel (solar) dan sekaligus membuka katup kontrol CNG, motor bisa dioperasikan untuk kecepatan dan beban yang diinginkan.

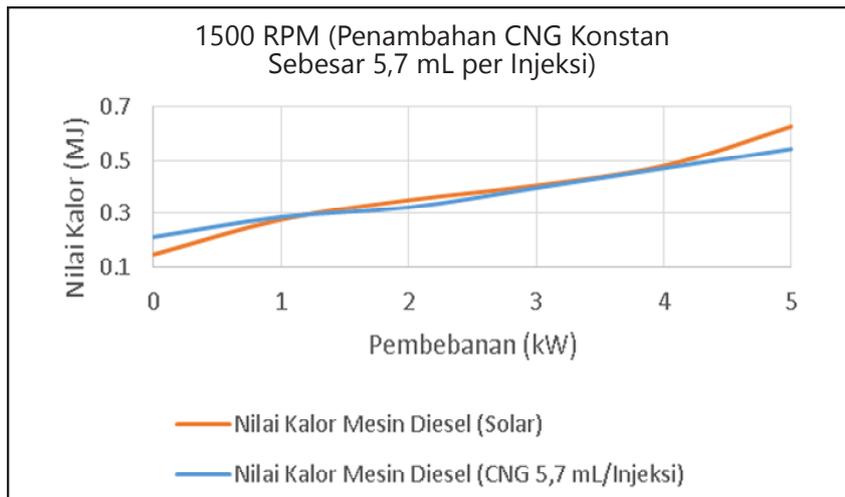
Langkah berikutnya adalah bahan bakar gas (CNG) yang berada dalam tabung bertekanan tinggi (kurang lebih 200 bar) dikeluarkan dengan menurunkan terlebih dahulu tekanannya dengan menggunakan *Pressure Regulator* sampai tekanannya sesuai dengan kebutuhan konsumsi bahan bakar. Setelah dilakukan penurunan tekanan, CNG akan dilewatkan ke *safety valve* dengan tujuan jika terjadi *over pressure*, maka gas akan dikeluarkan dari sistem dan sistem secara otomatis berhenti beroperasi (*off*). *Safety valve* juga dapat difungsikan sebagai *emergency stop*.

Katup kedua yang dilewati oleh CNG adalah *cut off valve*. Fungsi utama dari katup ini adalah sebagai katup *on* dan *off* dari sistem ini. Jadi ada 2 katup yang berfungsi sebagai *safety system* dari konverter kit ini. Komponen berikutnya yang dilewati oleh CNG adalah *flow control*. Pada sistem ini, *flow control* berfungsi sebagai pengatur atau pengendali besar kecilnya aliran fluida (debit). Untuk mengkalibrasi jumlah debit dari CNG, dapat dilihat dengan menggunakan flowmeter yang diletakan setelah *flow control* ini.

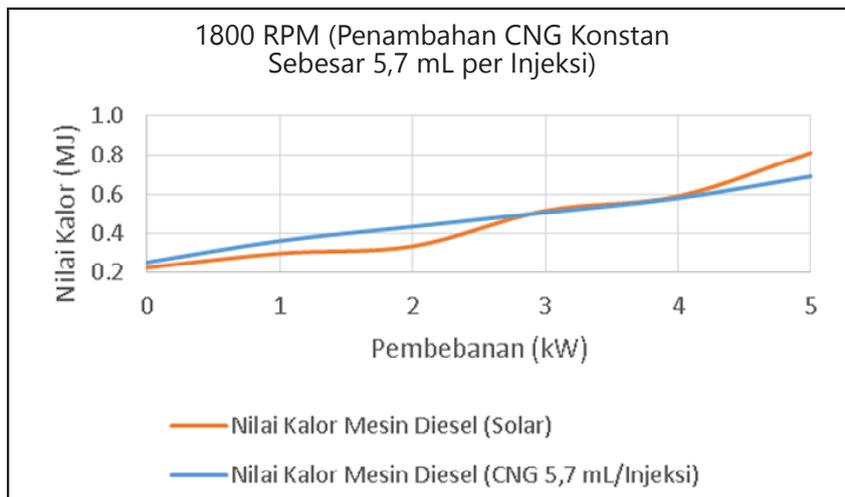
Untuk menginjeksikan bahan bakar gas (CNG) ke *intake manifold*, dibutuhkan waktu (*timing*) yang tepat. Waktu penginjeksian gas ini diatur oleh katup *timing* yang letaknya berada didekat *intake manifold*. Setiap kali sensor membaca tanda yang sudah dibuat di *gear, timing valve* ini secara otomatis akan membuka. Dan ketika sudah tidak ada inputan dari sensor, katup *timing* ini akan menutup. Durasi membukanya katup *intake* adalah selama 0,035 detik.

#### 4.5. Perbandingan Nilai Kalor Solar dan CNG-Solar

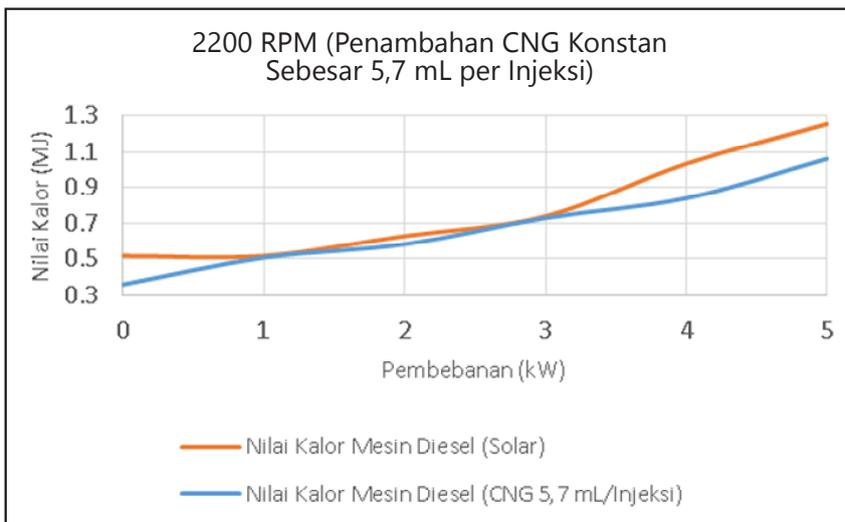
Saat pengujian, *variable* tetap yang digunakan adalah pembebanan 1 – 5 kW pada 3 variasi RPM (1500 RPM, 1800 RPM, 2200 RPM). Sedangkan untuk bahan bakar yang diuji adalah pada kondisi solar normal, dan dengan penambahan CNG secara konstan sebesar 5,7 mL per injeksi dan 11,4 mL per injeksi.



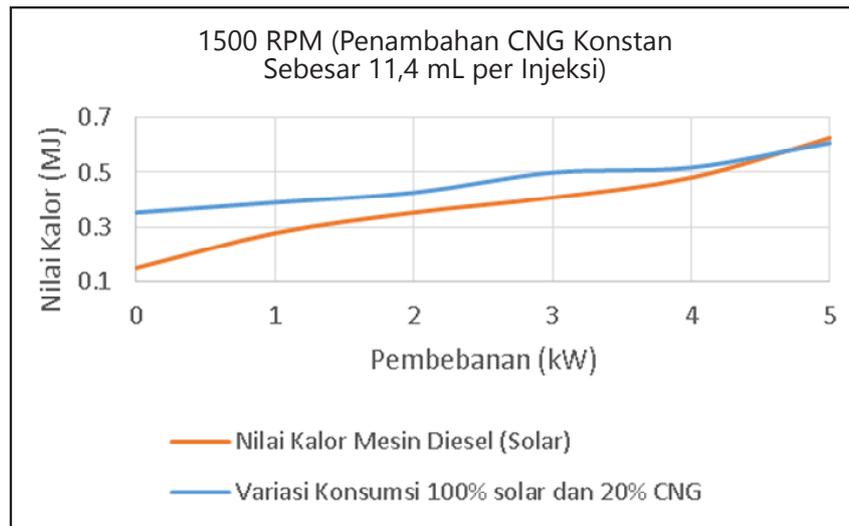
Gambar 2 : Grafik Nilai Kalor Vs Pembebanan Pada 1500 RPM (5,7 mL)



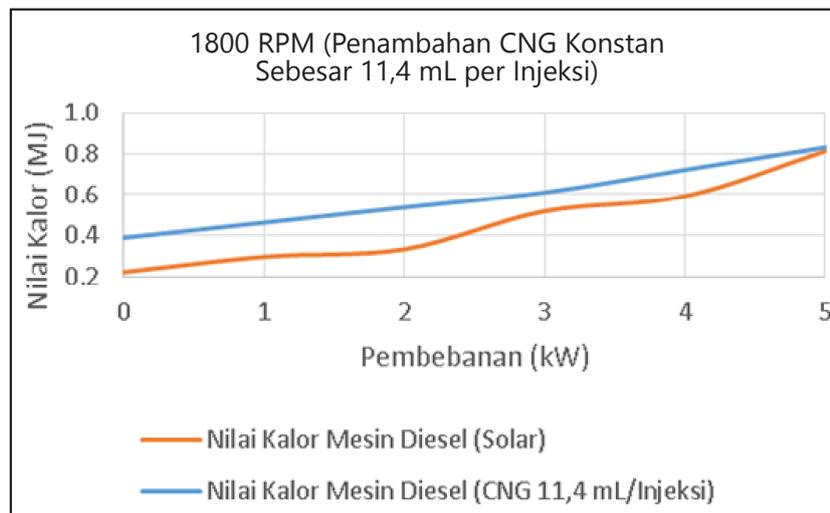
Gambar 3 : Grafik Nilai Kalor Vs Pembebanan Pada 1800 RPM (5,7 mL)



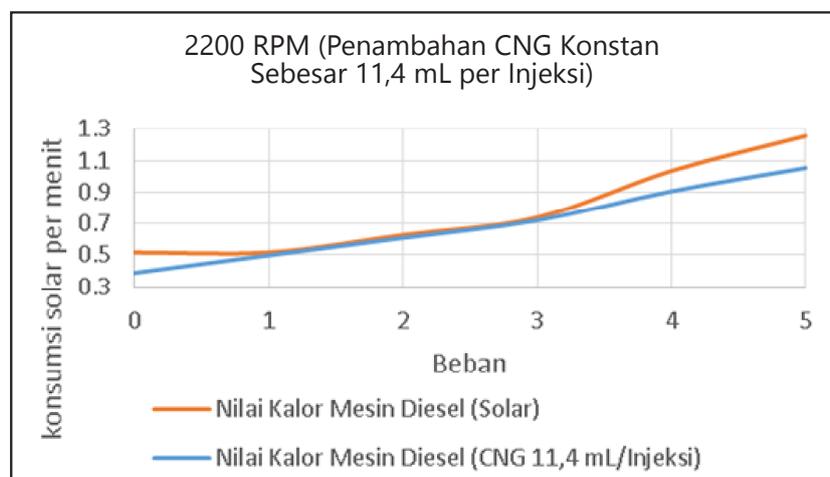
Gambar 4 : Grafik Nilai Kalor Vs Pembebanan Pada 2200 RPM (5,7 mL)



Gambar 5 : Grafik Nilai Kalor Vs Pembebanan Pada 1500 RPM (11,4 mL)



Gambar 6 : Grafik Nilai Kalor Vs Pembebanan Pada 1800 RPM (11,4 mL)



Gambar 7 : Grafik Nilai Kalor Vs Pembebanan Pada 2200 RPM (11,4 mL)

**Tabel 10 :** Hasil Pengujian Diesel Dengan Penambahan CNG Konstan Sebesar 5,7 mL per Injeksi

Putaran	Waktu	Beban	Vol Solar I	Vol Solar II	% Vol. Solar I	%HV I
[RPM]	[s]	[kW]	[mL]	[mL]	[%]	[%]
<b>1500</b>	60	0	4	2	50.0%	43.8%
	60	1	7.5	4	46.7%	3.4%
	60	2	9.5	5	47.4%	-7.9%
	60	3	11	7	36.4%	-2.3%
	60	4	13	9	30.8%	-1.9%
	60	5	17	11	35.3%	-13.3%
<b>1800</b>	60	0	6	3	50.0%	12.5%
	60	1	8	6	25.0%	21.9%
	60	2	9	8	11.1%	30.6%
	60	3	14	10	28.6%	-1.8%
	60	4	16	12	25.0%	-1.6%
	60	5	22	15	31.8%	-14%
<b>2200</b>	60	0	14	6	57.1%	-30%
	60	1	14	10	28.6%	-1.8%
	60	2	17	12	29.4%	-7.3%
	60	3	20	16	20.0%	-1.2%
	60	4	28	19	32.1%	-18%
	60	5	34	25	26.5%	-15%

**Tabel 11 :** Hasil Pengujian Diesel Dengan Penambahan CNG Konstan Sebesar 11,4 mL per Injeksi

Putaran	Waktu	Beban	Vol Solar I	Vol Solar III	% Vol. Solar II	%HV II
[RPM]	[s]	[kW]	[mL]	[mL]	[%]	[%]
<b>1500</b>	60	0	4	2	50.00%	137.6%
	60	1	7.5	3	40.00%	40.03%
	60	2	9.5	4	42.11%	21.08%
	60	3	11	6	54.55%	22.75%
	60	4	13	6.5	50.00%	7.71%
	60	5	17	9	52.94%	-2.93%
<b>1800</b>	60	0	6	3	50.00%	75.04%
	60	1	8	5	62.50%	56.28%
	60	2	9	7	77.78%	61.14%
	60	3	14	9	64.29%	17.88%
	60	4	16	12	75.00%	21.89%
	60	5	22	15	68.18%	2.28%
<b>2200</b>	60	0	14	3	21.43%	-24.9%
	60	1	14	6	42.86%	-3.55%
	60	2	17	9	52.94%	-2.93%
	60	3	20	12	60.00%	-2.49%
	60	4	28	17	60.71%	-12.4%
	60	5	34	21	61.76%	-16.1%

Berdasarkan hasil pengujian, pada penambahan CNG sebesar 5,7 mL per injeksi, cenderung terjadi penurunan nilai kalor sampai 30% dan mampu mensubsitisi kebutuhan solar hingga 50%. Untuk penambahan CNG sebesar 11,4 mL per injeksi, cenderung terjadi peningkatan nilai kalor lebih dari 100% dan mampu mensubsitisi kebutuhan solar antara 40 – 75%.

## 5. Kesimpulan

Dari serangkaian tahapan yang telah dilakukan pada penelitian ini didapatkan kesimpulan bahwa waktu penginjeksian bahan bakar gas (CNG) adalah selama 0,035 detik pada saat langkah hisap, dimana untuk satu kali penginjeksian CNG adalah sebesar 5,7 mL dan 11,4 mL. Pada sistem yang dirancang ini, CNG mampu mensubsitisi kebutuhan solar sampai 75%.

## 6. Ucapan Terima Kasih

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Rules, guidelines dan guidance dibawah ini dapat diunduh melalui <http://www.bki.co.id/ajax/Login.php> dengan terlebih dahulu membuat akun unduh rules dan guidelines.

Part/Vol.	Rules/Guidelines/Guidance	Edition
<b>Part 0 - General</b>		
<b>Guidance</b>		
A	Petunjuk Masuk Ruang Tertutup	2014
<b>Part 1- Seagoing Ships (Rules/Guidelines/Guidance for The Classification and Construction)</b>		
<b>RULES</b>		
I	Rules for Classification and Surveys	2016
II	Rules for Hull	2014
III	Rules for Machinery Installations	2016
IV	Rules for Electrical Installations	2016
V	Rules for Materials	2014
VI	Rules for Welding	2015
VII	Rules for Automation	2014
VIII	Rules for Refrigerating Installation	2014
IX	Rules for Ships Carrying Liquefied Gasses in Bulk	2014
X	Rules for Ships Carrying Dangerous Chemicals in Bulk	2014
XI	Rules for Approval of Manufacturers and Service Suppliers	2014
XII	Rules for Fishing Vessel	2003
XIII	Regulation (Rules) for The Redundant Propulsion and Steering Systems	2002
XIV	Rules for Non Metallic Material	2014
XV	Rules Common Structural Rules for Bulk Carrier	2014
XVI	Rules Common Structural Rules for Oil Tanker	2014
<b>Guidelines</b>		
1	Guidelines for the Use of Gas as Fuel for Ship	2015
2	Guidelines for Ocean Towage	2001
3	Guidelines for Machinery Conditioning Monitoring	2011
4	Guidelines for the Explosion Protection of Electrical Equipment	2001
5	Guidelines for the Carriage of Refrigerated Containers on Board Ships	2004
6	Guidelines for Analysis Techniques Strength	2005
8	Guidelines for Determination of the Energy Efficiency Design Index	2014
11	Guidelines for Condition Assessment Program	2015
<b>Guidance</b>		
A	Guidance for Ventilation System on Board Seagoing Ships	2004
B	Petunjuk Percobaan Berlayar Kapal Motor (Guidance for Sea Trials of Motor Vessels)	2002
C	Guidance / Petunjuk Pemakaian Ultrasonic Thickness Measurement Report	2006

D	Guidance for the Inspection of Anchor Chain Cables	2002
E	Guidance for The Construction And Testing Towing Gears	2000
G	Guidance for the Corrosion Protection and Coating Systems	2004
H	Guidance for Assessment and Repair of Defects on Propellers	2000
I	Guidance / Petunjuk Klasifikasi dan Survey Kapal Notasi A90 dan A80	2015
K	Guidance for Mass Produces Engines	2016
<b>Part 2-Inland Waterway</b>		
<b>RULES</b>		
I	Rules for Inland Waterways - Classification and Survey	2015
II	Rules for Inland Waterway - Hull Construction	2015
III	Rules for Inland Waterway - Machinery Installation	2015
IV	Rules for Inland Waterways - Electrical Installations	2015
V	Rules for Inland Waterways - Additional Requirements of Notation	2015
<b>Part 3-Special Ships</b>		
<b>RULES</b>		
I	Rules for Oil Recovery Vessel	2005
II	Rules for Floating Dock	2002
III	Rules for High Speed Craft	2002
IV	Rules for High Speed Vessels	1996
V	Rules for Fibreglass Reinforced Plastics Ships	2016
VI	Peraturan Kapal Kayu	1996
VII	Rules for Small Vessel Up to 24 M	2013
VIII	Rules for Classification and Construction of Wing-in-Ground Craft (WIG CRAFT)	2006
<b>Guidance</b>		
A	Guidance for FRP and Wooden Fishing Vessel up to 24 m	2015
<b>Part 4-Special Equipment And Systems</b>		
<b>Rules</b>		
I	Rules for Stowage and Lashing of Containers	2012
II	Rules for Dynamics Positioning Systems	2011
III	Regulation (Rules) for the Bridge Design on Seagoing Ships One Man Console	2004
<b>Guidelines</b>		
1	Guidelines for Certification Loading Computer Systems	2015
1-Ina	Pedoman untuk Sertifikasi Sistem Komputer Pemuatan	2015
<b>Guidance</b>		
A	Guide (Guidance) for Risk Evaluation for the Classification of Marine Related Facilities	2012
<b>Reference</b>		
	Reference Notes on Risk Assessment for the Marine and Offshore Oil and Gas Industries	2012
<b>Part 5-Offshore Technology</b>		
<b>Rules</b>		
I	Rules for Classification and Surveys	2016
II	Rules for Structures	2011
IV	Rules for Machinery Installations	2011

V	Rules for Electrical Installations	2011
VII	Rules for Fixed Offshore Installation	2011
VIII	Rules for Offshore Mooring Chains	2000
IX	Rules for Single Point Mooring	2013
X	Rules for Mobile Offshore Drilling Units and Special Purpose Units	1999
XII	Rules for Facilities on Offshore Installation	2013
<b>Guidelines</b>		
2	Guidelines for Classification and Construction Floating Offshore Liquefied Gas Terminals	2013
3	Guidelines for Classification and Construction Floating Production Installation	2016
<b>Guidance</b>		
A	Guidance for Survey Using Risk Based Inspection for the Offshore Industry	2012
B	Guidance for Fatigue Assessment of Offshore Structures	2015
C	Guidance for Buckling and Ultimate Strength Assessment of Offshore Structures	2015
<b>Part 6-Statutory</b>		
I	Regulation for the Audit and Registration of Safety Management Systems (Bilingual)	2012
II	(Regulation) Rules for the Verification and Registration of Ship Security Management System (Bilingual)	2004
<b>Guidelines</b>		
1	Guidelines for The Preparation Damage Stability Calculations and Damage Control Documentation on Board	2005
3	Guidelines on Intact Stability	2014
4	Guidelines on Crew Accommodation	2016
<b>Guidance</b>		
A	Guidance for the Audit and Registration of Safety Management Systems (Bilingual)	2012
B	Guidance for the Verification and Registration of Ship Security Management Systems (Bilingual)	2004
C	Guidance for Inclining Test	2015
C-Ina	Petunjuk Pengujian Kemiringan dan Periode Olenng Kapal	2015
G	Guidance on Intact Stability	2014
<b>Part 7-Class Notation</b>		
<b>Guidelines</b>		
1	Guidelines for Certification of Lifting Appliances (LA)	2013
2	Guidelines for Dynamic Loading Approach	2013
3	Guidelines for Spectral-Based Fatigue Analysis	2013
4	Guidelines for Livestock Carriers	2015
<b>Guidance</b>		
A	Guidance for the Class Notation Helicopter Deck and Facilities (HELIL & HELIL(SRF))	2013
B	Guidance for Crew Habitability on Ship	2014
C	Guidance for Crew Habitability on Offshore Installation	2014
D	Guidance for Hull Inspection and Maintenance Program	2013
E	Guidance for Planned Maintenance Program	2013
F	Guidance for the Environmental Service Systems for Ships and Offshore Units, Floating Installations and Liftboats	2013

G	Guidance for Coating Performance Standards	2013
H	Guidance for the Class Notation Emergency Response Service (ERS)	2013
I	Guidance for Survey Based on Reliability Centered-maintenance	2012
Part 8-Kapal Domestik		
<b>Guidelines</b>		
1	Pedoman Lambung	2016

## Pedoman Penulisan Jurnal Teknik BKI

1. **Naskah tulisan**, dalam bahasa Indonesia atau bahasa Inggris.
2. **Format penulisan**, maksimal 10 halaman dalam 1 kolom ukuran kertas A4 dengan font Times New Roman ukuran 12, spasi 1,5. Batas atas dan bawah 2,5 cm, tepi kiri 3 cm dan tepi kanan 2,5 cm.
3. **Judul**, menggunakan huruf capital tebal (bold) ukuran font 14 posisi di tengah
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  - Bila 3 orang (Joko, et al., 2014)
10. **Daftar pustaka**, disusun berdasarkan alphabet, dengan ketentuan sbb:
  - a. Buku: Penulis (Tahun). Judul Buku. Penerbit.
  - b. Jurnal: Penulis (Tahun). Judul Tulisan. Nama Jurnal (cetak miring). Volume (Nomor). Halaman.
  - c. Paper dalam prosiding: Penulis (tahun). Judul Tulisan. Nama Seminar (cetak miring). Tanggal Seminar. Halaman.
  - d. Tesis/TA: Penulis (Tahun). Judul. Tesis/TA. Universitas.
  - e. Engineering Standard: Penulis (Tahun). Judul Buku. Penerbit.
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  - g. Manual Laboratorium: Judul Manual (Tahun). Nama Buku Manual. Penerbit.
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12. Naskah tulisan dikirim dalam bentuk soft copy ke alamat email [propulsi@bki.co.id](mailto:propulsi@bki.co.id).
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