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Dear Prof Adam Wentrit

Editor in Chief

TransNav Journal

We have submitted a manuscript entitled " Analysis of Inflatable Liferaft Layout Effectiveness Towards The Evacuation Process for Passenger Ships Based on IMO MSC.1/Circ. 1533" by *Imam Pujo Mulyatno, Hartono Yudo, Syanindita Adilia Prasanti, Wilma Amiruddin* for TransNav Journal in Oct 2022. Is our Manuscript, can be published in the issue in Desember 2022.

Best Regards

Analysis of Inflatable Liferaft Layout Effectiveness Towards The Evacuation Process for Passenger Ships Based on IMO MSC.1/Circ. 1533

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Abstract

The inflatable liferaft layout applied to passenger ships for the effectiveness of the evacuation process must be based on IMO MSC.1/Circ. 1533 regulations with the maximum evacuation duration is n ≤ 60 minutes. Based on the data from KNKT, in 2021, sea transportation became the biggest contributor to accidents with 342 people dying and missing. Liferaft is one of the main safety tool used during an emergency to save the people and leave the ship. This study used Thunderhead Pathfinder software which was Agent Based Evacuation Simulation combined with 3-D simulation results. The modeling was conducted with two types of layout liferaft and two scenarios of dangerous conditions, the first was a fire in the engine room and the second is the ship experiencing a 20° of heel. The results of this study indicate that there was a difference in the total evacuation duration between the existing layout and the layout that has been changed according to the writer's suggestion. In fire conditions there is a difference of 1 minute 18 seconds in case 1, 1 minute 16 seconds in case 2, 1 minute 38 seconds in case 3, and 22 seconds in case 4. In the heel condition there is a difference of 1 minute 19 seconds in case 1 and 1 minute 25 seconds in case 2.

The results of the evacuation simulation modeling with the liferaft layout on the navigation deck that have been modified according to the writer's suggestion in all cases are getting a value of n ≤ 60 minutes and also have complied with the IMO MSC.1/Circ. 1533 regulations.

Keywords: *Liferaft, Evacuation, Duration.*

1. INTRODUCTION

Until this time water transportation is still very liked by Indonesian citizen because it is more efficient and also water transportation is free from traffic jam. But the number of ship accidents that occurred caused some people became a doubt to make a ship as a man transportation in determining the preferred mode of transportation for cross-island travel.

Even based on the results of the investigation data from The National Transportation Safety Committee (*KNKT*) in 2021 water transportation mode became the biggest contributor with most of the fatalities are in accident. KNKT investigated as many as 19 cases, with a total death toll of dead and missing reaching 342 souls. From 19 cases investigated by *KNKT* there is several prominent accidents, one of them is from *KMP*. Yunicee who is passenger on Ro-ro ship Ketapang-Gilimanuk who sank in Bali strait on June 29th, 2021 at midnight.

When the ship has an emergency condition or which allows dangerous conditions, passenger evacuation became the first thing that must to do to prevent the occurrence of many casualties, both death and missing. But unfortunately, poor evacuation planning in the ship became one of the factor that can cause many victims/toll who not safe when the ship accident happened. SOLAS conferention in 1995 it has been established that all evacuation procedures on Ro-ro passenger ships must be completed in 60 minutes. Time effectivity that used during evacuation process depending on the number of passengers and the distance traveled to embarkation corridor. The attitude and reaction that passengers show when they hear the dangerous alarm will be different, these things are depend on the background experience and the knowledge of the passenger in dealing with the situation under pressure when are in the group. Human behavior and walking speed under list and dynamic condition of ships are very important factors in analysis for Ro-ro passenger and large passenger ships [1].

The Maritime Safety Committee, at its seventy-first session (19 to 28 May1999), noted that under SOLAS II-2/28-1.3, Ro-ro passenger ships constructed on or after 1 July 1999 are required to undergo an evacuation analysis at an early stage of design [2]. Regarding to SOLAS regulation II-2/13 about the provision of evacuation routes so that passenger can quickly and safely get to the meeting point, the ship must follow the following conditions:

a. Safe escape routes shall be provided;
b. Scape routes shall be maintained in a safe condition, clear of obstracles; and
c. Additional aids for escape shall be provide as necessary to ensure accessibility, clear marking, and edequate design for emergency situations [3].

In this case the evacuation route will direct passengers to a place where ship safety equipment is provided.

Liferaft is one of the man safety equipment that used to emergency situation to save themselves and leave the ship. As specified in MSC/Res. 809, all inflatable liferaft must fulfill the requirements of paragraph 4.2, namely: The lowering speed for a fully equipped fast rescue boat with its full complement of persons on board should not exceed 1 m/s. [4]. So the placement of the liferaft must be in the right position so that it can be effective when an emergency occurs.

This is because the layout of the liferaft will greatly affect the length of time it takes necessary for the evacuation of passengers. Therefore, the author will conduct further research on the effect of liferaft layout on the effectiveness of the passenger ship evacuation process. This research was conducted by simulating using Thunderhead Pathfinder software which is an Agent Based Evacuation Simulation combined with Simulation result in the form of 3-Dimensional animation.

2. METHOD

2.1 Research Object

This research acquired the data from crossing ship 600 gross tone (GT) belonging to Directorate General of Land Transportation that operate in track Singkil – Banyak Island. It was the types of Ro-Ro crossing ship with IMO 9926817 and the BKI Regulation Number 191 213 0043. It was constructed in 2019 in *PT Citra Bahari* Shipyard.

Table 1. Principal Dimensions *KMP. Aceh Hebat* 3

NO	Name	Measure	Unit
1.	Length Overall (LOA)	54.50	Meter
2.	Length of Perpendiculars (LPP)	47.25	Meter
3.	Weight (B)	13.00	Meter
4.	Heght (H)	3.45	Meter
5.	Draft (T)	2.45	Meter
6.	Speed (Trial Speed)	2.45	Meter
7.	Passenger	212	Person
8.	Crew	24	Person

With a lot of the capacity, this crossing ship could accommodate 15 trucks and 6 sedans. On this crossing ship detents 14 liferafts that were each of it could accommodate 25 people.

2.2 Regulation

International Maritime Organization (IMO) published the standard term related the ship's passenger evacuation, as referred it was provisions of Safety Of Life At Sea (SOLAS) that related with the ship's safety and the total of lifebuoy with all the characteristic.

Thereafter on 2016 International Maritime Organization (IMO) published MSC.1/Circ. 1533 that contained about "Revised Guidelines on Evacuation Analysis for New and Existing Passenger Ships". The calculation of the performance standards of the total maximum duration evacuation that must be compiled with is:

$$1{,}25\ (R+T)+\frac{2}{3}(E+L)\leq n \qquad \text{.....................................(1)}$$

$$(E+L)\leq 30\ min \qquad \text{.....................................(2)}$$

In performance standars:

For ro-ro passenger ship, n = 60 minute; and for passenger ships other than ro-ro passenger ship, n = 60 if the ship has no more than three main vertical zones; and 80, if the ship has more than three main vertical zone [5].

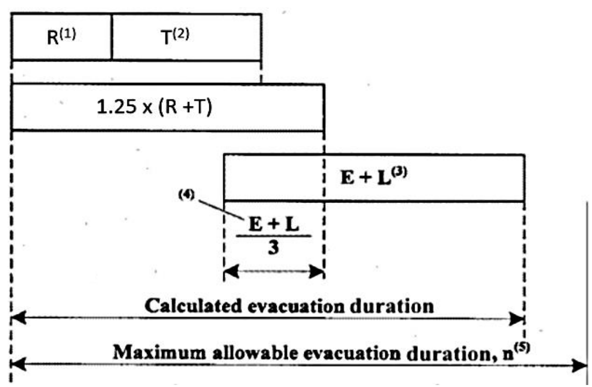

Figure 1. Performance Standards

1) Response duration (R) = 10 minutes for night case and 5 minutes for day case.
2) Total travel duration (T) = duration it takes for all persons on board to move from where they are upon notification to the assembly stations.
3) Embarkation and launching duration (E+L) = maximum 30 minutes with the regulation Safety Of Life At Sea (SOLAS) III/21.1.3.
4) Overlap duration = 1/3 (E+L).
5) n value (minutes).

Based on the MSC.1/Circ.1533 this provided the parameter to facilitate evacuation simulation, that is related the population categorize which is explained the composition of the population in term of age, gender, physical attribute, and response duration. The population consist of the following combination:

Table 2. Populations Composition

Population Group – Passengers	Percentage of Passengers (%)	Amount of Passengers
Female < 30 years	7	15
Female 30 – 50 years	7	15
Female > 50 years old	16	34
Female > 50 years, Mobility Impaired (1)	10	21
Female > 50 years,	10	21

Mobility Impaired (2)		
Male < 30 years	7	15
Male 30 – 50 years	7	15
Male > 50 years	16	34
Male > 50 years, M1	10	21
Male > 50 years, M2	10	21
Population Group - Crew	**Percentage of Crew (%)**	**Amount of Crew**
Crew Females	50	12
Crew Males	50	12
Total		**236**

For the purpose of conducting an evacuation analysis, the initial distribution of passengers and crew on board should be considered. In this study, the researcher uses IMO MSC.1/Circ. 1533 guidelines for the following case:

1. Case 1 (primary evacuation case, night)
   Passengers in cabin with maximum berthing capacity occupied; 2/3 of crew members in their cabins; of the remaining 1/3 of crew members:
   1) 50% are in their respective workplaces.
   2) 50% are spread over each deck.
2. Case 2 (primary evacuation case, day)
   Public spaces, as defined by SOLAS regulation II-2/3.39, will be occupied to 75% of maximum capacity of the spaces by passengers. Crew will distributed as follows:
   1) 1/3 of the crew are in cabin.
   2) 1/3 of the crew are in public spaces.
   3) the other 1/3 are in their respective workplaces.
3. Case 3 and 4 (secondary evacuation, night and day)
   These cases use the same population demography as the primary evacuation case with the difference that one stair on a ship that has a large capacity for passengers to pass during an evacuation is considered unusable in this case simulation.

In this study, case 3 and 4 will only be used in a fire scenario.

For each of the gender group specified in table 2, walking speed must be modeled as a statistical distribution which has minimum and maximum values, as follow:

Table 3. Walking Speed on Flat Terrain

Population Group – Passengers	Walking Speed	
	Min (m/s)	Max (m/s)
Female < 30 years	0.93	1.55
Female 30 – 50 years	0.71	1.19
Female > 50 years	0.56	0.94
Female > 50 years, M1	0.43	0.71
Female > 50 years, M2	0.37	0.61
Male < 30 years	1.11	1.85
Male 30 – 50 years	0.97	1.62
Male > 50 years	0.84	1.4
Male > 50 years, M1	0.64	1.04
Male > 50 years, M2	0.55	0.91
Population Group – Crew	**Walking Speed**	
	Min (m/s)	**Max (m/s)**

Crew Females	0.93	1.55
Crew Males	1.11	1.85

The walking speed on stairs were given by the category of gender, age, and direction of travel up which has the values as follow:

Table 4. Walking Speed on Stairs

Group of The Passenger Population	Walking Speed on Stairs	
	Min (m/s)	Max (m/s)
Female < 30 years	0.47	0.79
Female 30 – 50 years	0.44	0.74
Female > 50 years	0.37	0.61
Female > 50 years, M1	0.28	0.46
Female > 50 years, M2	0.23	0.39
Male < 30 years	0.50	0.84
Male 30 – 50 years	0.47	0.79
Male > 50 years	0.38	0.64
Male > 50 years, M1	0.29	0.49
Male > 50 years, M2	0.25	0.41
Group of The Crew Population	**Walking Speed on Stairs**	
	Min (m/s)	**Max (m/s)**
Crew Females	0.47	0.79
Crew Males	0.50	0.84

Previous research conducted by Trika Pitana et al., showed that the differenciate in total evacuaton time between walking speed data in IMO and research is not too significant, it could mean that the data is relevant IMO if applied to the case of evacuation in Indonesia [6].

2.3 Accident Scenario

This study was conducted with two dangerous conditions that triggered the evacuation. The conditions are a fire in the engine room caused by a leak in the fuel pipe and the ship experiencing a 20° heel. This scenario is defined based on primary cases and secondary cases according to IMO MSC.1/Circ.1533.

2.4 Data Processing

From the data that has been obtained, several evacuation simulations will be carried out by moving the position of the liferaft to determine the placement of the liferaft where the evacuation simulation process shows the most effective results. The following are the steps taken in processing the data:

1. Reading the General Arrangement of *KMP Aceh Hebat* 3 to find out the placement of liferaft.
2. Redrawing the General Arrangement in Thunderhead Pathfinder software.
3. Conduct an evacuation simulation using a liferaft layout according to the real design.
4. Conduct an evacuation simulation by moving the liferaft according to the researcher's suggestion.
5. Calculate the total duration of evacuation in each simulated case.
6. Determine the most optimal liferaft layout for the passenger evacuation process.

3 RESULT AND DISCUSSION

3.1 Evacuation Simulation Modeling

The simulation modeling in this research was conducted to analyze the effectiveness of the inflatable liferaft layout on the evacuation process on *KMP Aceh Hebat* 3. Where the goal is to get liferaft placement position that will produce the most effective total duration of evacuation. This research was conducted by doing simulation using Thunderhead Pathfinder which is Agent Based Evacuation combined with 3-D simulation results. Simulation will be done 2 times, namely the condition of the existing ship (real design) and when the liferaft placement has been changed according to the author's suggestion.

The model is very influential in calculating the evacuation time. This is about the characteristics of the model that can represent real conditions in the field. This simulation is used to calculate the total travel duration (T) in the evacuation process. Modeling refers to the general arrangement of *KMP Aceh Hebat* 3.

The following are the stages of modeling in the Thunderhead Pathfinder software:

1. Import file general arrangement of the ship to Pathfinder through Menu "Model" on the toolbar then click "Add a Background Image" on the dialog box that appears.
2. Redrawing every room that exist on the ship. In the accordance with the general arrangement. In the redrawing of the room, it is also equipped with the provision of door access, so that the passenger can get out of the room to a predetermined evacuation point.
3. Combining all the decks and making the stairs that later will be connecting each deck and the crew. Every deck will be arranged upwards according to the order and height corresponding to the general arrangement.
4. Adding agents representing passengers and crew as objects of the evacuation simulation process. The agents to be added have their respective characteristics according to predetermined parameters such as walking speed on flat terrain and walking speed on stairs as presented in table 3 and table 4.
5. Furthermore, after all data is entered, the distribution of the agent is adjusted according to the rules of IMO MSC.1/Circ.1533 as presented in table 2.
6. The next step is to run a simulation of the evacuation process modeling. "Run Simulation" must be pressed to be able to rn this simulation process. Then a dialog box will automatically appear regarding the evacuation simulation process.
7. After the process is running and all agents have been evacuated, the process will automatically stop and display a video about the total travel duration (T) running time.

Figure 2. Evacuation Simulation Process

Based on the picture above, it can be seen that in the video of the evacuation results will be presented some informations related to the number of passengers who reach the muster point in unit time. Each case will have a different result according to the characteristics of the simulated case. In each simulated case, the results will displayed in graphical form.

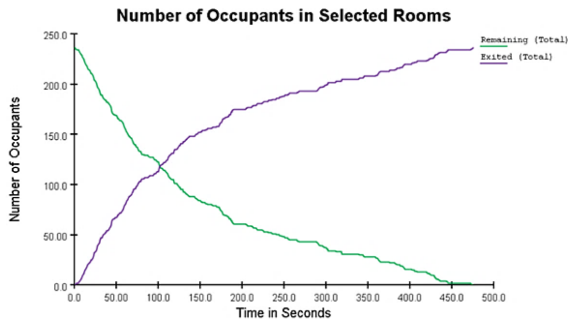

Figure 3. Evacuation Simulation Results Graph

3.2 Evacuation Simulation

As explained above, the liferaft laying scenario for this research conducted with two kinds of layout liferaft. The first layout of the entire liferaft is on the front navigation deck according to the existing conditions on the ship.

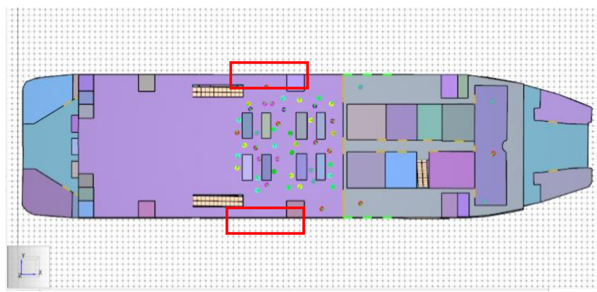
Figure 4. Layout 1 (Existing Condition)

While the second layout, liferaft is deployed on the navigation deck in order to get the right evacuation time. The transfer of the liferaft namely, 2 liferafts are moved to the back closer to the exit stairs one each on the starboard and portside, 2 liferafts moved to the center closer to the passenger area one each on the starboard and portside, then 2 liferafts remain at the front of the navigation deck one each on the skateboard and portside.

Beside aiming to get a faster evacuation time compared to the first layout, the second layout also aiming to prevent queues or accumulation of passengers at one point on master point.

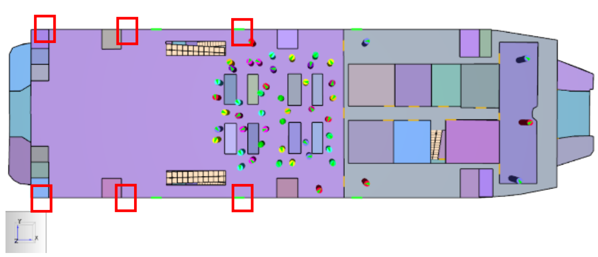
Figure 5. Layout 2 (Liferaft Layout Changes)

3.2.1 Fire Scenario

This modeling is carried out to calculate the evacuation time in the event the ship experiences a fire in the engine room. In this research the source of the fire trigger is the occurrence of leaks in the fuel pipe. Based on the research about the danger of fire that coordinated by International Maritime Organization (IMO) identified the main source of the fire trigger in the engine room. In this research also present calculation of frequency of fires caused by self-ignition of flammable liquids in fuel oil and diesel oil systems, which constitute 60% of the overall hazard [7].

Figure 6. Fire Triangle

On this case when the fuel molecules evaporate on an open surface, the steam will mix with the surrounding air and the heat from the main engine will produce a diffusion air. Then, assumed that fire will grab the pvc pipe on the main engine which then causes a fire.

The fire modeling is done by combining between software Thunderhead Pathfinder and Pyrosim software to cause smoke effect in fire simulation, with the following process:

1. Import the ship's general arrangement autocad file to the Pyrosim software. Make sure that the design in autocad has been made with a scale of 1:1 so that it can depict on a real scale with real conditions.
2. Then, the picture import result as in the form of 2 dimensions will be converted into 3 dimensions by extruding the ship design line from autocad into a wall with an adjusted thickness to approach the real conditions.

3. Then, details of the composition of the materials used on the ship are carried out. This is intended to be able to resemble the real conditions that exist in the field.

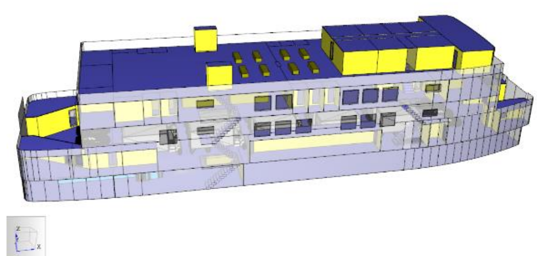
Figure 7. Modeling That Has Been Adapted to The Type of Material

4. Models are converted into customized materials, the model is added to a fire source to simulate a fire. As explained above, the fire scenario in this study is assumed that the initial material burned is pvc pipe with Heat Release Per Area (HARRPUA) value is $50\ {}^{kW}/_{m^2}$. The heat exposure are considered as the advisable value to be used in the methodology [8]. Assuming the width of the burned area is $2{,}4\ m^2$.

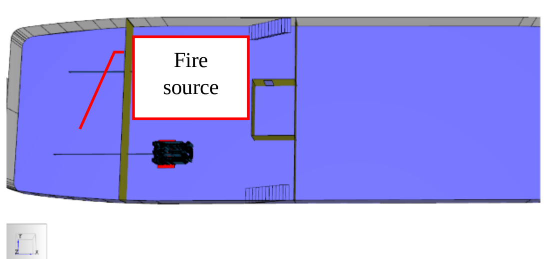

Figure 8. The Place of Fire Source

5. The next step is to determine the reaction used for the fire source during the fire simulation. The reaction used is a Polyurethane reaction using the standard "SPFE Handbook, GM 27" with the following composition details:
   1) *Carbon atoms 1,0*
   2) *Hydrogen Atoms 1,7*
   3) *Oxigen Atoms 0,7*
   4) *Nitrogen Atoms 0,08*
6. The next step was mesh making. This serves to limit the fire affected area in this model. In this study the restricted mesh was one full ship with different open ventilation on board so that the smoke produced was not trapped within the specified mesh limit.
7. The last step was simulate the modeling by pressing "Run Simulation" on the toolbar.
8. After the process was complete, then it will automatically stop and display a video of fire simulation results.

Figure 9. The Result of Fire Simulation Process

After making the model on Pyrosim software complete, then the next step was to combine the model with the previous model that was made in the Thunderhead Pathfinder software by importing the Pyrosim model into the Pathfinder file. Then both models will be adjusted to become a single unit.

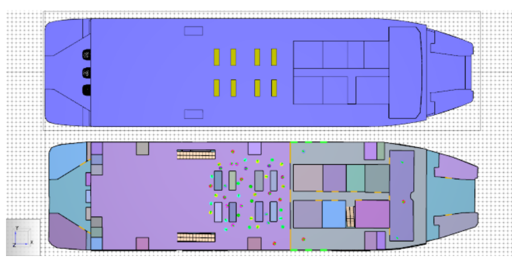
Figure 10. The Result of Import Pyrosim Model into Pathfinder

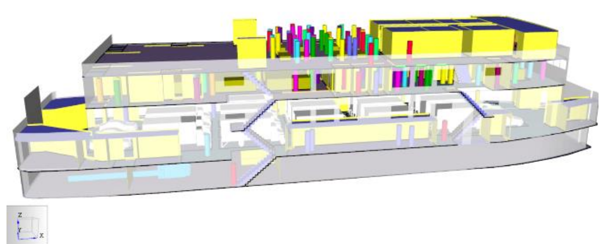
Figure 11. The Result of Merged Model

The picture above was a final picture of evacuation modeling on fire case. The model was ready to simulate and would produce total score travel duration (T) in the simulated case.

The result total travel duration (T) that gain from the simulation above as follow:

Table 5. The Result of Total Travel Duration on Fire Case

	The total Travel Duration (T) (Second)	
	Layout 1	Layout 2
case 1	447.5	385.0
case 2	392.8	332.3
case 3	742.5	663.8
case 4	619.3	601.5

3.2.1 Heel Scenario

The evacuation simulation modeling in the case of a ship in a tilted or heeled state was not much different from previous case. Agent Basic Model Simulation (ABMS) modeling has limitation namely it can’t manipulate the speed according to the dynamic tilt angle of the ship. This is due to the modeling that can not fully represent every degree the ship will overturn, but can represent the tilt of the ship at a certain angle that was relevant to use.

This modeling was modeled with the difference in movement speed and the changing muster point. For the heel case, muster point that used was one from the starboard or the portside only. It is because when the ship is tilted, which can be used for the process of evacuating passenger and crew, the liferaft that used was on the lowest side of the ship. Because if the liferaft is launched on the higher side it is possible that the liferaft will hit the wall of the ship that is not in its normal position or evenkeel.

Evacuation simulation modeling in this case was carried out in a 20° heel conditions. For walking speed data in heel conditions was taken from previous research conducted by Refan Trisna Wijaya in 2016. The researcher did the experiments with sampling from drilling test on *KM Gunung Dempo* owned by *PT Pelni (Persero)*. From the experimental research obtained the following results:

Table 6. Walking Speed in Heel Conditions [9]

Population Group - Passengers	Walking Speed	
	Min (m/s)	Max (m/s)
Female < 30 years	0.39	1.03
Female 30 – 50 years	0.47	1.02
Female > 50 years	0.39	0.87
Male < 30 years	0.45	1.34
Male 30 – 50 years	0.56	1.13
Male > 50 years	0.37	1.07
Population Group - Crew	**Walking Speed**	
	Min (m/s)	**Max (m/s)**
Crew	0.68	1.04

Evacuation simulation is run with layout of liferaft placement as in the case of standard evacuation.. Then the results of the travel duration (T) are as follows:

Table 7. Travel Duration Results in Heel Conditions

Total Travel Duration (T)

	(second)	
	Layout 1	Layout 2
Case 1	639.3	576.3
Case 2	586.5	519.0

3.3 Evacuation Time Calculation

After all cases get their respective travel duration (T) values, then the next step is to put in the travel duration (T) values that have been obtained into the performance standards for the total maximum evacuation duration. So that each case can be searched for the total evacuation time

$$1{,}25\ (R+T)+\frac{2}{3}(E+L)\leq n$$

$$(E+L)\leq 30\ min$$

For example, the calculation of case 1 in the fire scenario where the ship is in an existing condition in the night case. In the simulation process, the total travel duration (T) in this case takes 447.5 seconds or 7.45 minutes in equivalent. The calculation of the total evacuation duration is as follows:

$$=1{,}25\ (R+T)+\frac{2}{3}(E+L)\leq n$$

$$=1{,}25\ (10+7{,}45)+\frac{2}{3}(30)$$

Total evacuation duration = 41,81 minutes

3.3.1 Fire Scenario

Here are the following results of the total evacuation duration obtained from the evacuation simulation under standard evacuation condition:

Table 8. Total Evacuation Duration in Fire Conditions

	Total Evacuation Duration (minute)	
	Layout 1	Layout 2
Case 1	41.81	40.52
Case 2	34.43	33.17
Case 3	47.97	46.33
Case 4	39.15	38.78

The table above shows the results of calculating the total required evacuation duration in fire conditions. From the calculation results obtained the differences in results in case 1 is 1,30 minutes, case 2 is 1,26 minutes, case 3 is 1,64 minutes, and case 4 is 0,37 minutes.

3.3.2 Heel Scenario

The results of the total evacuation duration obtained from the evacuation simulation in heel conditions are here as follows:

Table 9. Total Evacuation Duration in Heel Conditions

	Total Evacuation Duration (minute)	
	Layout 1	Layout 2
Case 1	45.82	44.51

Case 2	38.47	37.06

The table above shows the results of calculating the total required evacuation duration in heel conditions. From the calculation results obtained the differences in results in case 1 is 1,31 minutes and case 2 is 1,41 minutes.

3.4 Effective Evacuation Time

Based on the results from the calculation of the total evacuation duration in all cases, it was found that the difference in the results of the evacuation time was quite big between the ship in existing conditions and when the liferaft placement had been changed.

Here are the comparison graphs of the total evacuation duration obtained from the evacuation simulations that have been carried out, as follows:

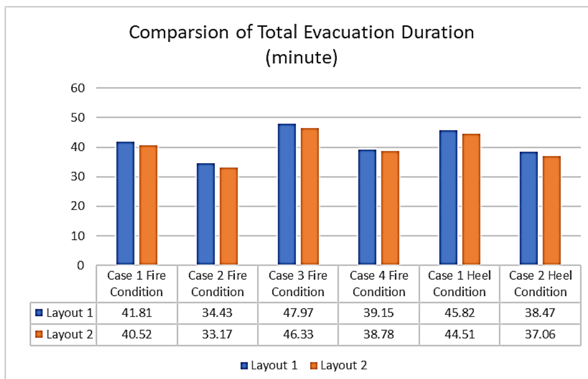

Figure 12. Comparison Chart of Total Evacuation Duration

From those results, it can be concluded that layout 2 (layout of liferaft that has been changed according to the writer's suggestion) is more optimal than layout 1 (layout of liferaft with existing conditions).

4 CONCLUSION

Based on the analysis and simulations that have been carried out with IMO MSC.1/Circ. 1533 standards regarding the evacuation process on passenger ships, along with standards and other sources with variations in evacuation of ships in fire and heel conditions, it can be concluded that each identified case will show a different total evacuation duration depending on the characteristics of each case. In this study, it was found that layout 2 (layout of liferaft that has been changed according to the writer's suggestion) is more effective than layout 1 (layout of liferaft with existing conditions). This is proved by the differences in the total duration of evacuation between layout 1 and layout 2 in all cases. In the fire conditions, there is a difference of 1 minute 18 seconds in case 1, 1 minute 16 seconds in case 2, 1 minute 38 seconds in case 3, and 22 seconds in case 4. In the heel conditions, there is difference of 1 minute 19 seconds in case 1 and 1 minute 25 seconds in case 2. Also, from the modeling results of passengers evacuation of *KMP Aceh Hebat 3*, the entire evacuation durations obtained have fulfilled the IMO MSC.1/Circ. 1533 rules with maximum evacuation time for passenger ship is n ≤ 60 minutes.

REFERENCES

[1] D. Lee, J. H. Park, and H. Kim, "A study on experiment of human behavior for evacuation simulation," Ocean Engineering, vol. 31, no. 8–9, pp. 931–941, Jun. 2004.

[2] International Maritime Organization (IMO), "MSC/Circ.909 – Interim Guidelines for A Simplified Evacuation Analysis On Ro-Ro Passengers Ship," 1999.

[3] IMO, "SOLAS-Consolidated-Edition," 2018.

[4] International Maritime Organization (IMO), "MSC/Res.809 – Recommendation for Canopied Reversible Liferaft, Automatically Self-Rghting Liferaft and Fast Rescue Boat, Including Testing, On Ro-Ro Passenger Ship," 1997.
[5] International Maritime Organization (IMO), "MSC.1-Circ.1533 – Revised Guidelines on Evacuation Analysis for New and Existing Passenger Ships (Secretariat)," 2016.
[6] T. Pitana, B. K. Artana, D. Prasetyawati and N. Siswantor, "Observation Study the Walking Speed and Distribution of Ship's Passenger as Basis for Passenger Evacuation Simulation," Applied Mechanics and Materuals, vol. 862, pp. 232-237, 2017.
[7] A. Charchalis and S. Czyz, "Analysis of fire hazard and safety requirements of a sea vessel engine room.," Journal of KONES powertrain and transport, vol. 18, no. 2, 2011.
[8] J. Hietaniemi and E. Mikkola, "Design Fires for Fire Safety Engineering," 2010.
[9] R. T. Wijaya, "Analisa Evakuasi Penumpang dan ABK Kapal PT. Pelni dalam Kondisi List dan Kebakaran," 2016.

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We have submitted a manuscript entitled " Analysis of Inflatable Liferaft Layout Effectiveness Towards The Evacuation Process for Passenger Ships Based on IMO MSC.1/Circ. 1533" by *Imam Pujo Mulyatno, Hartono Yudo, Syanindita Adilia Prasanti, Wilma Amiruddin* for TransNav Journal in Oct 2022. Is our Manuscript, can be published in the issue in Desember 2022.

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Analysis of Inflatable Liferaft Layout Effectiveness Towards The Evacuation Process for Passenger Ships Based on IMO MSC.1/Circ. 1533

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ABSTRACT: The inflatable liferaft layout applied to passenger ships for the effectiveness of the evacuation process must be based on IMO MSC.1/Circ. 1533 regulations with the maximum evacuation duration is n ≤ 60 minutes. Based on the data from KNKT, in 2021, sea transportation became the biggest contributor to accidents with 342 people dying and missing. Liferaft is one of the main safety tool used during an emergency to save the people and leave the ship. This study used Thunderhead Pathfinder software which was Agent Based Evacuation Simulation combined with 3-D simulation results. The modeling was conducted with two types of layout liferaft and two scenarios of dangerous conditions, the first was a fire in the engine room and the second is the ship experiencing a 20° of heel. The results of this study indicate that there was a difference in the total evacuation duration between the existing layout and the layout that has been changed according to the writer's suggestion. In fire conditions there is a difference of 1 minute 18 seconds in case 1, 1 minute 16 seconds in case 2, 1 minute 38 seconds in case 3, and 22 seconds in case 4. In the heel condition there is a difference of 1 minute 19 seconds in case 1 and 1 minute 25 seconds in case 2.
The results of the evacuation simulation modeling with the liferaft layout on the navigation deck that have been modified according to the writer’s suggestion in all cases are getting a value of n ≤ 60 minutes and also have complied with the IMO MSC.1/Circ. 1533 regulations.

1 INTRODUCTION

Until this time water transportation is still very liked by Indonesian citizen because it is more efficient and also water transportation is free from traffic jam. But the number of ship accidents that occurred caused some people became a doubt to make a ship as a man transportation in determining the preferred mode of transportation for cross-island travel.

Even based on the results of the investigation data from The National Transportation Safety Committee (KNKT) in 2021 water transportation mode became the biggest contributor with most of the fatalities are in accident. KNKT investigated as many as 19 cases, with a total death toll of dead and missing reaching 342 souls. From 19 cases investigated by KNKT there is several prominent accidents, one of them is from KMP. Yunicee who is passenger on Ro-ro ship Ketapang-Gilimanuk who sank in Bali strait on June 29th, 2021 at midnight.

When the ship has an emergency condition or which allows dangerous conditions, passenger evacuation became the first thing that must to do to prevent the occurrence of many casualties, both death and missing. But unfortunately, poor evacuation planning in the ship became one of the factor that can cause many victims/toll who not safe when the ship accident happened.

SOLAS conference in 1995 it has been established that all evacuation procedures on Ro-ro passenger ships must be completed in 60 minutes. Time effectivity that used during evacuation process depending on the number of passengers and the distance traveled to embarkation corridor. The attitude and reaction that passengers show when they hear the dangerous alarm will be different, these things are depend on the background experience and the knowledge of the passenger in dealing with the situation under pressure when are in the group. Human behavior and walking speed under list and dynamic condition of ships are very important factors in analysis for Ro-ro passenger and large passenger ships [1].

The Maritime Safety Committee, at its seventy-first session (19 to 28 May1999), noted that under SOLAS II-2/28-1.3, Ro-ro passenger ships constructed on or after 1 July 1999 are required to undergo an evacuation analysis at an early stage of design [2]. Regarding to SOLAS regulation II-2/13 about the provision of evacuation routes so that passenger can quickly and safely get to the meeting point, the ship must follow the following conditions:

- Safe escape routes shall be provided;
- Scape routes shall be maintained in a safe condition, clear of obstacles; and
- Additional aids for escape shall be provide as necessary to ensure accessibility, clear marking, and adequate design for emergency situations [3].

In this case the evacuation route will direct passengers to a place where ship safety equipment is provided.

Liferaft is one of the man safety equipment that used to emergency situation to save themselves and leave the ship. As specified in MSC/Res. 809, all inflatable liferaft must fulfill the requirements of paragraph 4.2, namely: The lowering speed for a fully equipped fast rescue boat with its full complement of persons on board should not exceed 1 m/s. [4]. So the placement of the liferaft must be in the right position so that it can be effective when an emergency occurs.

This is because the layout of the liferaft will greatly affect the length of time it takes necessary for the evacuation of passengers. Therefore, the author will conduct further research on the effect of liferaft layout on the effectiveness of the passenger ship evacuation process. This research was conducted by simulating using Thunderhead Pathfinder software which is an Agent Based Evacuation Simulation combined with Simulation result in the form of 3-Dimensional animation.

2 METHOD

2.1 *Research Object*

This research acquired the data from crossing ship 600 gross tone (GT) belonging to Directorate General of Land Transportation that operate in track Singkil – Banyak Island. It was the types of Ro-Ro crossing ship with IMO 9926817 and the BKI Regulation Number 191 213 0043. It was constructed in 2019 in PT Citra Bahari Shipyard.

Table 1. Principal Dimensions KMP. Aceh Hebat 3

NO	Name	Measure	Unit
1.	Length Overall (LOA)	54.50	Meter
2.	Length of Perpendiculars (LPP)	47.25	Meter
3.	Weight (B)	13.00	Meter
4.	Heght (H)	3.45	Meter
5.	Draft (T)	2.45	Meter
6.	Speed (Trial Speed)	2.45	Meter
7.	Passenger	212	Person
8.	Crew	24	Person

With a lot of the capacity, this crossing ship could accommodate 15 trucks and 6 sedans. On this crossing ship detents 14 liferafts that were each of it could accommodate 25 people.

2.2 *Regulation*

International Maritime Organization (IMO) published the standard term related the ship's passenger evacuation, as referred it was provisions of Safety Of Life At Sea (SOLAS) that related with the ship's safety and the total of lifebuoy with all the characteristic.

Thereafter on 2016 International Maritime Organization (IMO) published MSC.1/Circ. 1533 that contained about "Revised Guidelines on Evacuation Analysis for New and Existing Passenger Ships". The calculation of the performance standards of the total maximum duration evacuation that must be compiled with is:

$$1,25(R+T)+\frac{2}{3}(E+L)\leq n \quad (1)$$

$$(E+L)\leq 30\,min \quad (2)$$

In performance standars:

For ro-ro passenger ship, n = 60 minute; and for passenger ships other than ro-ro passenger ship, n = 60 if the ship has no more than three main vertical zones; and 80, if the ship has more than three main vertical zone [5].

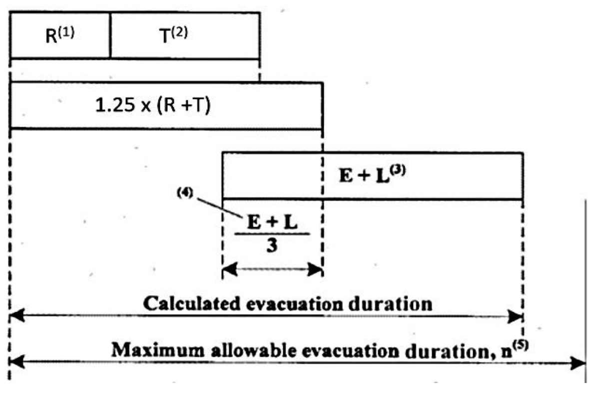

Figure 1. Performance Standards

1. Response duration (R) = 10 minutes for night case and 5 minutes for day case.
2. Total travel duration (T) = duration it takes for all persons on board to move from where they are upon notification to the assembly stations.
3. Embarkation and launching duration (E+L) = maximum 30 minutes with the regulation Safety Of Life At Sea (SOLAS) III/21.1.3.

4. Overlap duration = 1/3 (E+L).
5. n value (minutes).

Based on the MSC.1/Circ.1533 this provided the parameter to facilitate evacuation simulation, that is related the population categorize which is explained the composition of the population in term of age, gender, physical attribute, and response duration. The population consist of the following combination:

Table 2. Populations Composition

Population Group Passengers	Percentage of Passengers (%)	Amount of Passengers
Female < 30 years	7	15
Female 30 – 50 years	7	15
Female > 50 years old	16	34
Female > 50 years, Mobility Impaired (1)	10	21
Female > 50 years, Mobility Impaired (2)	10	21
Male < 30 years	7	15
Male 30 – 50 years	7	15
Male > 50 years	16	34
Male > 50 years, M1	10	21
Male > 50 years, M2	10	21
Population Group Crew	**Percentage of Crew (%)**	**Amount of Crew**
Crew Females	50	12
Crew Males	50	12
Total		236

For the purpose of conducting an evacuation analysis, the initial distribution of passengers and crew on board should be considered. In this study, the researcher uses IMO MSC.1/Circ. 1533 guidelines for the following case:

1. Case 1 (primary evacuation case, night)
   Passengers in cabin with maximum berthing capacity occupied; 2/3 of crew members in their cabins; of the remaining 1/3 of crew members:
   1) 50% are in their respective workplaces.
   2) 50% are spread over each deck.
2. Case 2 (primary evacuation case, day)
   Public spaces, as defined by SOLAS regulation II-2/3.39, will be occupied to 75% of maximum capacity of the spaces by passengers. Crew will distributed as follows:
   1) 1/3 of the crew are in cabin.
   2) 1/3 of the crew are in public spaces.
   3) the other 1/3 are in their respective workplaces.
3. Case 3 and 4 (secondary evacuation, night and day)
   These cases use the same population demography as the primary evacuation case with the difference that one stair on a ship that has a large capacity for passengers to pass during an evacuation is considered unusable in this case simulation.

In this study, case 3 and 4 will only be used in a fire scenario.

For each of the gender group specified in table 2, walking speed must be modeled as a statistical distribution which has minimum and maximum values, as follow:

Table 3. Walking Speed on Flat Terrain

Population Group Passengers	Walking Speed Min (m/s)	Max (m/s)
Female < 30 years	0.93	1.55
Female 30 – 50 years	0.71	1.19
Female > 50 years	0.56	0.94
Female > 50 years, M1	0.43	0.71
Female > 50 years, M2	0.37	0.61
Male < 30 years	1.11	1.85
Male 30 – 50 years	0.97	1.62
Male > 50 years	0.84	1.4
Male > 50 years, M1	0.64	1.04
Male > 50 years, M2	0.55	0.91
Population Group Crew	**Walking Speed Min (m/s)**	**Max (m/s)**
Crew Females	0.93	1.55
Crew Males	1.11	1.85

The walking speed on stairs were given by the category of gender, age, and direction of travel up which has the values as follow:

Table 4. Walking Speed on Stairs

Group of The Passenger Population	Walking Speed on Stairs Min (m/s)	Max (m/s)
Female < 30 years	0.47	0.79
Female 30 – 50 years	0.44	0.74
Female > 50 years	0.37	0.61
Female > 50 years, M1	0.28	0.46
Female > 50 years, M2	0.23	0.39
Male < 30 years	0.50	0.84
Male 30 – 50 years	0.47	0.79
Male > 50 years	0.38	0.64
Male > 50 years, M1	0.29	0.49
Male > 50 years, M2	0.25	0.41
Group of The Crew Population	**Walking Speed on Stairs Min (m/s)**	**Max (m/s)**
Crew Females	0.47	0.79
Crew Males	0.50	0.84

Previous research conducted by Trika Pitana et al., showed that the differenciate in total evacuaton time between walking speed data in IMO and research is not too significant, it could mean that the data is relevant IMO if applied to the case of evacuation in Indonesia [6].

2.3 *Accident Scenario*

This study was conducted with two dangerous conditions that triggered the evacuation. The conditions are a fire in the engine room caused by a leak in the fuel pipe and the ship experiencing a 20◎ heel. This scenario is defined based on primary cases and secondary cases according to IMO MSC.1/Circ.1533.

2.4 *Data Processing*

From the data that has been obtained, several evacuation simulations will be carried out by moving the position of the liferaft to determine the placement of the liferaft where the evacuation simulation process shows the most effective results. The following are the steps taken in processing the data:

1. Reading the General Arrangement of KMP Aceh Hebat 3 to find out the placement of liferaft.

2. Redrawing the General Arrangement in Thunderhead Pathfinder software.
3. Conduct an evacuation simulation using a liferaft layout according to the real design.
4. Conduct an evacuation simulation by moving the liferaft according to the researcher's suggestion.
5. Calculate the total duration of evacuation in each simulated case.
6. Determine the most optimal liferaft layout for the passenger evacuation process.

3 RESULT AND DISCUSSION

3.1 *Evacuation Simulation Modeling*

The simulation modeling in this research was conducted to analyze the effectiveness of the inflatable liferaft layout on the evacuation process on KMP Aceh Hebat 3. Where the goal is to get liferaft placement position that will produce the most effective total duration of evacuation. This research was conducted by doing simulation using Thunderhead Pathfinder which is Agent Based Evacuation combined with 3-D simulation results. Simulation will be done 2 times, namely the condition of the existing ship (real design) and when the liferaft placement has been changed according to the author's suggestion.

The model is very influential in calculating the evacuation time. This is about the characteristics of the model that can represent real conditions in the field. This simulation is used to calculate the total travel duration (T) in the evacuation process. Modeling refers to the general arrangement of KMP Aceh Hebat 3.

The following are the stages of modeling in the Thunderhead Pathfinder software:

1. Import file general arrangement of the ship to Pathfinder through Menu "Model" on the toolbar then click "Add a Background Image" on the dialog box that appears.
2. Redrawing every room that exist on the ship. In the accordance with the general arrangement. In the redrawing of the room, it is also equipped with the provision of door access, so that the passenger can get out of the room to a predetermined evacuation point.
3. Combining all the decks and making the stairs that later will be connecting each deck and the crew. Every deck will be arranged upwards according to the order and height corresponding to the general arrangement.
4. Adding agents representing passengers and crew as objects of the evacuation simulation process. The agents to be added have their respective characteristics according to predetermined parameters such as walking speed on flat terrain and walking speed on stairs as presented in table 3 and table 4.
5. Furthermore, after all data is entered, the distribution of the agent is adjusted according to the rules of IMO MSC.1/Circ.1533 as presented in table 2.
6. The next step is to run a simulation of the evacuation process modeling. "Run Simulation" must be pressed to be able to rn this simulation process. Then a dialog box will automatically appear regarding the evacuation simulation process.
7. After the process is running and all agents have been evacuated, the process will automatically stop and display a video about the total travel duration (T) running time.

Figure 2. Evacuation Simulation Process

Based on the picture above, it can be seen that in the video of the evacuation results will be presented some information related to the number of passengers who reach the muster point in unit time. Each case will have a different result according to the characteristics of the simulated case. In each simulated case, the results will displayed in graphical form.

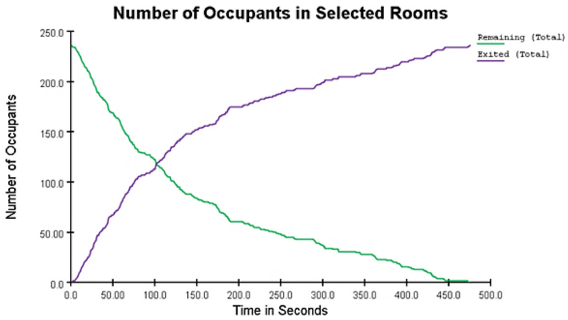

Figure 3. Evacuation Simulation Results Graph

3.2 *Evacuation Simulation*

As explained above, the liferaft laying scenario for this research conducted with two kinds of layout liferaft. The first layout of the entire liferaft is on the front navigation deck according to the existing conditions on the ship.

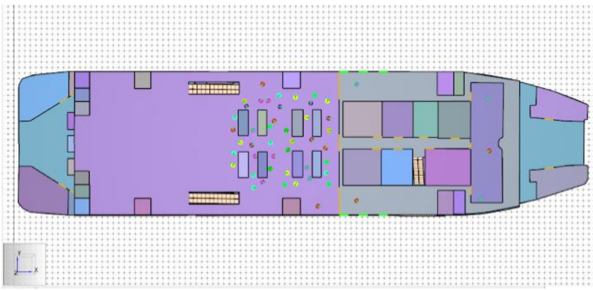

Figure 4. Layout 1 (Existing Condition)

While the second layout, liferaft is deployed on the navigation deck in order to get the right evacuation time. The transfer of the liferaft namely, 2 liferafts are moved to the back closer to the exit stairs one each on the starboard and portside, 2 liferafts moved to the center closer to the passenger area one each on the starboard and portside, then 2 liferafts remain at the front of the navigation deck one each on the skateboard and portside.

Beside aiming to get a faster evacuation time compared to the first layout, the second layout also aiming to prevent queues or accumulation of passengers at one point on master point.

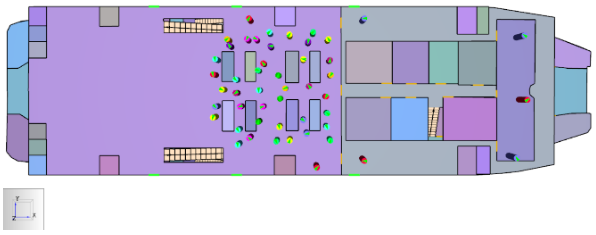

Figure 5. Layout 2 (Liferaft Layout Changes)

3.2.1 *Fire Scenario*

This modeling is carried out to calculate the evacuation time in the event the ship experiences a fire in the engine room. In this research the source of the fire trigger is the occurrence of leaks in the fuel pipe. Based on the research about the danger of fire that coordinated by International Maritime Organization (IMO) identified the main source of the fire trigger in the engine room. In this research also present calculation of frequency of fires caused by self-ignition of flammable liquids in fuel oil and diesel oil systems, which constitute 60% of the overall hazard [7].

Figure 6. Fire Triangle

On this case when the fuel molecules evaporate on an open surface, the steam will mix with the surrounding air and the heat from the main engine will produce a diffusion air. Then, assumed that fire will grab the pvc pipe on the main engine which then causes a fire.

The fire modeling is done by combining between software Thunderhead Pathfinder and Pyrosim software to cause smoke effect in fire simulation, with the following process:

1. Import the ship's general arrangement autocad file to the Pyrosim software. Make sure that the design in autocad has been made with a scale of 1:1 so that it can depict on a real scale with real conditions.
2. Then, the picture import result as in the form of 2 dimensions will be converted into 3 dimensions by extruding the ship design line from autocad into a wall with an adjusted thickness to approach the real conditions.
3. Then, details of the composition of the materials used on the ship are carried out. This is intended to be able to resemble the real conditions that exist in the field.
4. Models are converted into customized materials, the model is added to a fire source to simulate a fire. As explained above, the fire scenario in this study is assumed that the initial material burned is pvc pipe with Heat Release Per Area (HARRPUA) value is50 kW/m^2. The heat exposure are considered as the advisable value to be used in the methodology [8]. Assuming the width of the burned area is 2,4 m^2.
5. The next step is to determine the reaction used for the fire source during the fire simulation. The reaction used is a Polyurethane reaction using the standard "SPFE Handbook, GM 27" with the following composition details:
   1) Carbon atoms 1,0
   2) Hydrogen Atoms 1,7
   3) Oxigen Atoms 0,7
   4) Nitrogen Atoms 0,08
6. The next step was mesh making. This serves to limit the fire affected area in this model. In this study the restricted mesh was one full ship with different open ventilation on board so that the smoke produced was not trapped within the specified mesh limit.
7. The last step was simulate the modeling by pressing "Run Simulation" on the toolbar.
8. After the process was complete, then it will automatically stop and display a video of fire simulation results.

Figure 7. Modeling That Has Been Adapted to The Type of Material

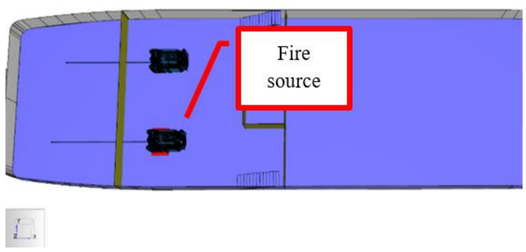

Figure 8. The Place of Fire Source

Figure 9. The Result of Fire Simulation Process

After making the model on Pyrosim software complete, then the next step was to combine the model with the previous model that was made in the Thunderhead Pathfinder software by importing the

Pyrosim model into the Pathfinder file. Then both models will be adjusted to become a single unit.

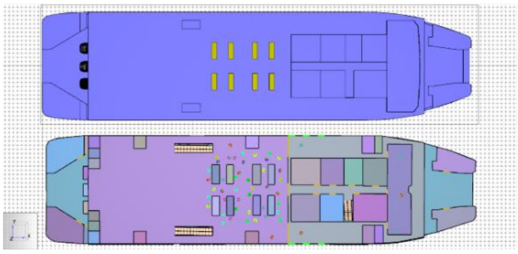

Figure 10. The Result of Import Pyrosim Model into Pathfinder

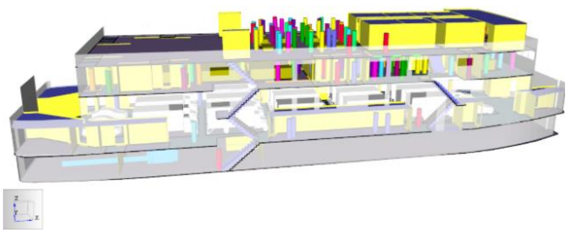

Figure 11. The Result of Merged Model

The picture above was a final picture of evacuation modeling on fire case. The model was ready to simulate and would produce total score travel duration (T) in the simulated case.

The result total travel duration (T) that gain from the simulation above as follow:

Table 5. The Result of Total Travel Duration on Fire Case

	The total Travel Duration (T) (Second)	
	Layout 1	Layout 2
case 1	447.5	385.0
case 2	392.8	332.3
case 3	742.5	663.8
case 4	619.3	601.5

3.2.2 *Heel Scenario*

The evacuation simulation modeling in the case of a ship in a tilted or heeled state was not much different from previous case. Agent Basic Model Simulation (ABMS) modeling has limitation namely it can't manipulate the speed according to the dynamic tilt angle of the ship. This is due to the modeling that cannot fully represent every degree the ship will overturn, but can represent the tilt of the ship at a certain angle that was relevant to use.

This modeling was modeled with the difference in movement speed and the changing muster point. For the heel case, muster point that used was one from the starboard or the portside only. It is because when the ship is tilted, which can be used for the process of evacuating passenger and crew, the liferaft that used was on the lowest side of the ship. Because if the liferaft is launched on the higher side it is possible that the liferaft will hit the wall of the ship that is not in its normal position or even keel.

Evacuation simulation modeling in this case was carried out in a 20° heel conditions. For walking speed data in heel conditions was taken from previous research conducted by Refan Trisna Wijaya in 2016. The researcher did the experiments with sampling from drilling test on KM Gunung Dempo owned by PT Pelni (Persero). From the experimental research obtained the following results:

Table 6. Walking Speed in Heel Conditions [9]

Population Group	Walking Speed	
Passengers	Min (m/s)	Max (m/s)
Female < 30 years	0.39	1.03
Female 30 – 50 years	0.47	1.02
Female > 50 years	0.39	0.87
Male < 30 years	0.45	1.34
Male 30 – 50 years	0.56	1.13
Male > 50 years	0.37	1.07
Population Group	Walking Speed	
Crew	Min (m/s)	Max (m/s)
Crew	0.68	1.04

Evacuation simulation is run with layout of liferaft placement as in the case of standard evacuation.. Then the results of the travel duration (T) are as follows:

Table 7. Travel Duration Results in Heel Conditions

	Total Travel Duration (T) (second)	
	Layout 1	Layout 2
Case 1	639.3	576.3
Case 2	586.5	519.0

3.3 *Evacuation Time Calculation*

After all cases get their respective travel duration (T) values, then the next step is to put in the travel duration (T) values that have been obtained into the performance standards for the total maximum evacuation duration. So that each case can be searched for the total evacuation time

$$1,25(R+T)+\frac{2}{3}(E+L)\leq n$$

$$(E+L)\leq 30\,min$$

For example, the calculation of case 1 in the fire scenario where the ship is in an existing condition in the night case. In the simulation process, the total travel duration (T) in this case takes 447.5 seconds or 7.45 minutes in equivalent. The calculation of the total evacuation duration is as follows:

$$=1,25(R+T)+\frac{2}{3}(E+L)\leq n$$

$$=1,25(10+7,45)+\frac{2}{3}(30)$$

Total evacuation duration = 41,81 minutes

3.3.1 *Fire Scenario*

Here are the following results of the total evacuation duration obtained from the evacuation simulation under standard evacuation condition:

Table 8. Total Evacuation Duration in Fire Conditions

	Total Evacuation Duration (minute)	
	Layout 1	Layout 2
Case 1	41.81	40.52
Case 2	34.43	33.17
Case 3	47.97	46.33
Case 4	39.15	38.78

The table above shows the results of calculating the total required evacuation duration in fire conditions. From the calculation results obtained the differences in results in case 1 is 1,30 minutes, case 2 is 1,26 minutes, case 3 is 1,64 minutes, and case 4 is 0,37 minutes.

3.3.2 *Heel Scenario*

The results of the total evacuation duration obtained from the evacuation simulation in heel conditions are here as follows:

Table 9. Total Evacuation Duration in Heel Conditions

	Total Evacuation Duration (minute)	
	Layout 1	Layout 2
Case 1	45.82	44.51
Case 2	38.47	37.06

The table above shows the results of calculating the total required evacuation duration in heel conditions. From the calculation results obtained the differences in results in case 1 is 1,31 minutes and case 2 is 1,41 minutes.

3.4 *Effective Evacuation Time*

Based on the results from the calculation of the total evacuation duration in all cases, it was found that the difference in the results of the evacuation time was quite big between the ship in existing conditions and when the liferaft placement had been changed.

Here are the comparison graphs of the total evacuation duration obtained from the evacuation simulations that have been carried out, as follows:

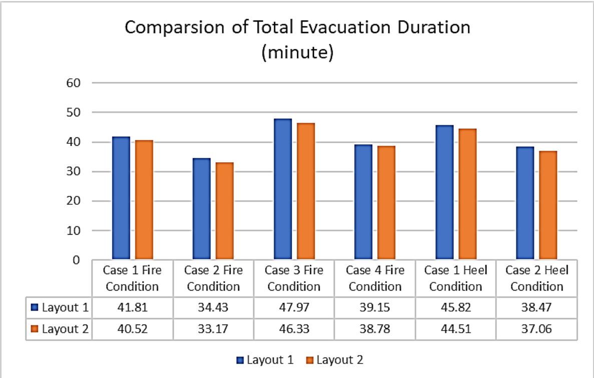

Figure 12. Comparison Chart of Total Evacuation Duration

From those results, it can be concluded that layout 2 (layout of liferaft that has been changed according to the writer's suggestion) is more optimal than layout 1 (layout of liferaft with existing conditions).

4 CONCLUSION

Based on the analysis and simulations that have been carried out with IMO MSC.1/Circ. 1533 standards regarding the evacuation process on passenger ships, along with standards and other sources with variations in evacuation of ships in fire and heel conditions, it can be concluded that each identified case will show a different total evacuation duration depending on the characteristics of each case. In this study, it was found that layout 2 (layout of liferaft that has been changed according to the writer's suggestion) is more effective than layout 1 (layout of liferaft with existing conditions). This is proved by the differences in the total duration of evacuation between layout 1 and layout 2 in all cases. In the fire conditions, there is a difference of 1 minute 18 seconds in case 1, 1 minute 16 seconds in case 2, 1 minute 38 seconds in case 3, and 22 seconds in case 4. In the heel conditions, there is difference of 1 minute 19 seconds in case 1 and 1 minute 25 seconds in case 2. Also, from the modeling results of passengers evacuation of KMP Aceh Hebat 3, the entire evacuation durations obtained have fulfilled the IMO MSC.1/Circ. 1533 rules with maximum evacuation time for passenger ship is n $\leqslant$ 60 minutes.

REFERENCES

[1] D. Lee, J. H. Park, and H. Kim, "A study on experiment of human behavior for evacuation simulation," Ocean Engineering, vol. 31, no. 8–9, pp. 931–941, Jun. 2004.

[2] International Maritime Organization (IMO), "MSC/Circ.909 – Interim Guidelines for A Simplified Evacuation Analysis On Ro-Ro Passengers Ship," 1999.

[3] IMO, "SOLAS-Consolidated-Edition," 2018.

[4] International Maritime Organization (IMO), "MSC/Res.809 – Recommendation for Canopied Reversible Liferaft, Automatically Self-Rghting Liferaft and Fast Rescue Boat, Including Testing, On Ro-Ro Passenger Ship," 1997.

[5] International Maritime Organization (IMO), "MSC.1-Circ.1533 – Revised Guidelines on Evacuation Analysis for New and Existing Passenger Ships (Secretariat)," 2016.

[6] T. Pitana, B. K. Artana, D. Prasetyawati and N. Siswantor, "Observation Study the Walking Speed and Distribution of Ship's Passenger as Basis for Passenger Evacuation Simulation," Applied Mechanics and Materuals, vol. 862, pp. 232-237, 2017.

[7] A. Charchalis and S. Czyz, "Analysis of fire hazard and safety requirements of a sea vessel engine room.," Journal of KONES powertrain and transport, vol. 18, no. 2, 2011.

[8] J. Hietaniemi and E. Mikkola, "Design Fires for Fire Safety Engineering," 2010.

[9] R. T. Wijaya, "Analisa Evakuasi Penumpang dan ABK Kapal PT. Pelni dalam Kondisi List dan Kebakaran," 2016.