Evacuation Analysis of Ship Passenger Using Agent Based Modelling Simulation

M B Zaman¹, N Siswantoro¹, M Zulfikar¹

¹Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia

Email: druz_zaman@ne.its.ac.id

Abstract. Ship accidents that occur in Indonesian have a high frequency. The ship accidents is dominated by fires of Ro-ro or passenger ships which cause material loss, water pollution and loss of human life. In this paper, an analysis of the ship evacuation system will be carried out. The Agent Based Modelling Simulation (ABMS) was using in this study. Initial data required are in the form of ship general arrangement, passenger walking speed, as well as the composition and distribution of passengers. The distribution of ship passengers in Indonesia for the category of women aged less than 30 years is 12%, women aged 30-50 years are 21%, women aged greater than 50 years are 5%, there are no female passengers with disabilities, while for the category of males aged less than 30 years as much as 19%, males with an age range of 30-50 years as much as 31%, males over 50 years old as much as 12%, and no male passengers were found. a man with a disability. The number of ship passengers is conditioned to exceed the passenger capacity, namely 880 passengers should be conditioned to become 1527 passengers. The evacuation simulation of ship passengers using an agent based modelling simulation is run based on the IMO MSC.1 / Circ. 1533 using 4 cases during the day and night. In the case of a normal night it takes 38.24 minutes to evacuate all passengers, and in the case of a night the evacuation takes 36.45 minutes. In the normal day case it took 29.49 minutes and in the afternoon case the evacuation took 28.12 minutes.

1. INTRODUCTION

Based on data from the Central Statistics Agency (BPS), in the last 4 years the mode of sea transportation in the form of passenger ships has always experienced an increase in the number of passengers from year to year. In 2017, the number of ship passengers at the port was recorded at 22,828,900 passengers. Then there was an increase in 2018 to 25,696,900 passengers. However, the increase in the number of passengers on board was also followed by the occurrence of ship accidents in Indonesian seas [1]. According to 2019 shipping accident investigation data issued by the NTSC on December 19, 2019, there are several types of accident cases including: ship collision (29%), sinking ship (25%), fire ship (25%), ship aground (4 %) as well as other causes (17%). The number of ship accidents occurred in Indonesia in the last six years (2010-2016) as data on shipping accidents issued by the National Transportation Safety Committee (NTSC), noted that there were 54 cases of shipping accidents with 337 dead / missing victims and injured victims. injured as many as 474 victims [2]. Based on the marine ship accident phenomenon above, it is interesting to do further research. The high rate of passenger ship accidents in Indonesia shows the importance of implementing safety standards on passenger ships. The evacuation process on passenger ships is a complex process because in addition to requiring proper rescue standards, fast evacuation handling is also needed. This process aims to save all passengers from a place that contains danger to a safe place [3]. Evacuation is expected to reduce...
or eliminate casualties. The variable that is most closely related to the evacuation process is time, where the longer the evacuation process, the greater the chance for victims to occur [4][5]. The evacuation process is closely related to the characteristics of the passengers on the ship [6][7]. The evacuation time is influenced by the walking speed of passengers during the evacuation process. Each passenger has a different speed according to the gender and age group of the passenger. The proper of machinery and sistem could support the process of navigation [8][9]. This resulted in not all passengers being able to move to the assembly station during the evacuation process, causing casualties in the ship accident. In the study of evacuation of passenger ships, evacuation modeling refers to the standard IMO MSC.1533 Guidelines for evacuation analysis for new and existing ships passenger. IMO MSC.1533 has provided a standard walking speed or passenger walking speed which can be used as an assumption in conducting a study of the passenger evacuation process. Passenger walking speed is the input data required in calculating the total evacuation time [10]. Therefore, it is necessary to conduct a study regarding the evacuation time of the passengers on board so that all passengers can get off the ship safely [11]. Evacuation modeling in this study refers to MSC.1533 Guidelines for evacuation analysis for new and existing passenger ships, where modeling is carried out with advanced analysis for primary case day and primary case night. Advanced analysis modeling is simulated using the agent base model simulation (ABMS) method [12].

Agent-based modeling and simulation (ABMS) is a new approach to modeling complex systems in which agents / individuals interact autonomously (self-managing their interests). Agents have behaviors that are often described by simple rules and interact with other agents which influence each other's behavior [12]. By modeling the agent individually, the nature of the diversity and behavior in the agent's system can be observed as a whole [13][14]. The patterns, structures and behaviors that emerge are not explicitly programmed into the model, but emerge through agent interaction. Emphasis on modeling of agent heterogeneity across populations and the emergence of self-organization are two features that distinguish agent-based model simulation from other simulation techniques such as discrete event simulation and system dynamics (Macal, 2010). Individuals can be simulated based on their respective characteristics with the ABMS method, so that ABMS is suitable for use in evacuation modeling that represents every passenger characteristic on the ship.

2. METHOD

2.1 Identification and formulation of the problem

The first stage is to identify and formulate existing problems. The first step taken in this final project is to information is in the form of theory, work methods, regulations, and standards. Literature studies can be obtained by reading books, journals, papers, regulations and standards related to the discussion in this final project.

2.2 Data processing

General Arrangement (GA) is a picture of the top, side and front view of a ship that shows the division of each room according to its function. Such as, engine room, accommodation room, and cargo room. At the data processing stage, information will be sought from the ship's GA in the form of passenger room design, placement of evacuation equipment and design. From this data will be used as data for the next stage, namely data analysis. At this data processing stage, the general arrangement of ships in 2D and 3D will be redesigned. The purpose of the redesign stage is to help the final project work on the simulation stage. From the walking speed data contained in IMO MSC.Circ 1533, evacuation modeling can be carried out. In modeling the evacuation using advanced analysis, Pathfinder 2019 software is used which is based on the Agent Base Model Simulation. Modeling with agent base model simulation can model like real conditions, where each agent (passenger) has the ability / behavior to make decisions when interacting with other passengers or with their environment. The scenarios used in this study are the primary evacuation case night and primary evacuation case day. Then calculate the evacuation by distributing the population of passengers and crew according to the perform data processing in the form of evaluation to receive the information needed in the data
analysis process. In this study, the problems taken were conducting observational studies and modeling of evacuation simulations, so that a comprehensive evacuation model would be obtained for ship accidents in Indonesia.

2.3 Evacuation Modeling
From the walking speed data contained in IMO MSC.Circ 1533, evacuation modeling can be carried out. In modeling the evacuation using advanced analysis, the Pathfinder 2020 software based on the Agent Base Model Simulation is used. Modeling with agent base model simulation can model like real conditions, where each agent (passenger) has the ability / behavior to make decisions when interacting with other passengers or with their environment. There are two types of goals in the simulation using the Pathfinder software, namely: idle goals and seek goals. Idle goal behavior is owned by passengers when waiting for an event to occur. An example of idle goal is when a passenger waits for a given response time for a certain time. Meanwhile, seek goal behavior is owned by passengers when the agent moves from one location to another, such as: waypoints, rooms, exits. The movements during the seek goal are as follows:
- If the seek goal is a waypoint, the passenger will try to stay within the radius of the waypoint.
- If the seek goal is room, the passenger will try to stay in the room, moving away from doors that allow other passengers to enter.
- If there is no initial destination, the passenger will move anywhere along the designed mesh.

The agent / passenger behavior during the simulation is as follows:

- **Door Selection**
  Passengers choose the exit with the following preference criteria:
  1. Current room travel time, the time the passenger chooses to reach the target at maximum speed, ignoring all other passengers.
  2. Current room queue time, if the target is the door, this is the estimated time the passenger will wait in the queue at the door based on the passenger's position in the queue and the door flow rate. If the target is not a door, the queue time is 0.
  3. Global travel time, the time a passenger travels from the current target seeking a destination thereafter at the maximum passenger speed, ignoring all other passengers.
  4. Distance traveled in room, distance of passengers to move to a certain room.

- **Backtrack prevention**
  Passengers are only aware of the size of the queue and door discharge in their room at this time. When a passenger enters a new room, knowledge of the last room is replaced with knowledge of the current room. Large queues can cause passengers to walk back and forth between the two rooms. Without reversal prevention, this will potentially result in a long period of time (until the previous room is cleared). In Pathfinder, passengers can make it out of the room using certain exits, passengers have the initiative for routing decisions using the following rules:
  1. The next local door designated by the passenger may not lead back to the previous room. If this rule eliminates all options (for example: the passenger went through the door unplanned), then
  2. Prevention of selecting a reverse path is disabled, passengers can choose from one of the local doors.

- **Avoid Walls**
  Passengers have the behavior of avoiding, detecting walls and directing themselves to avoid collisions with walls. The displacement vector between the passenger and the wall is based on the distance the passenger can walk comfortably. Availability of escape routes, unless otherwise stated;

- **Avoid Collisions**
Between Passengers Behavior of passengers to avoid collisions with other passengers. This collision behavior is controlled by the speed of the passenger while walking. Resolve conflicts to move due to geometry. There are several scenarios where passenger's motion conflicts with another passenger's motion due to geometric limitations. In this situation the passengers have to negotiate how to resolve this conflict so that they can keep moving. Pathfinder provides special handling to resolve this movement conflict and prevent passengers from experiencing trapped / unable to leave the room. Here's how to solve it if there is such a scenario:

1. A passenger has the ability to determine the lowest vector direction, which is to stay or move in the opposite direction to other passengers.
2. This occupant does a "free pass". If the occupants get a free pass, they continue with the next step.
3. Passengers recalculate with increasing local priority. Increasing local priority is one that makes passengers appear to have a higher priority.
4. Passengers maintain priority lift and enter a state where they can immediately pass other passengers in their way.

In carrying out an advanced evacuation (advanced analysis) the things that need to be considered are as follows:

a. Describing the System
   1. Identify assembly stations
   2. Identify escape routes

b. Assumptions
   The advanced analysis evacuation method estimates the evacuation time, therefore the assumptions of the evacuation analysis must be made as follows:
   1. The passengers and crew are represented as unique individuals, determined by the ability and response time of the individual.
   2. Passengers and crew will evacuate via the main exit, as referred to in SOLAS regulation II-13/2;
   3. Initial passenger and distribution loads are assumed to be in accordance with article 13 of the FSS Code;
   4. The safety factor can be 1.25 used in calculations to take into account the negligence of the model, assumptions, and the limited number and nature of scenarios, such as:
      a. The crew will immediately be at the post on duty to evacuate and ready to assist passengers;
      b. Passengers follow the system and crew instructions (i.e. route selection not predicted by analysis);
      c. Smoke, heat, and toxic fire products in fire waste are not considered to affect passenger / crew performance;
      d. Boat movements, heels and trim are not considered.

2.4 Scenario Considerations
The scenarios used in this study are the primary evacuation case night and primary evacuation case day.

2.5 Passenger Evacuation Simulation
The passenger evacuation simulation stage will be carried out in accordance with the actual conditions, which is adjusted to the guideline's IMO MSC.1 / Circ. 1533 with a model that has been adapted to. Where the simulation will be carried out based on four cases based on day and night conditions. This simulation will be applied to a condition where the number of passengers exceeds the load capacity, namely the number of passengers in the night conditions of 1527 passengers and in the conditions of the
day 1527 passengers with a predetermined composition and distribution of passengers. The simulation stages use Pathfinder software with agent based modeling simulation where the agent is an independent variable with a continuous uniform running speed. Agents behave in accordance with conditions and cannot be controlled for their response to a stimulus. In this software, the range of values for passenger walking speed based on gender and age range will be determined with the initial delay value determined based on day and night conditions. The final goal of the passenger ship evacuation simulation stage is to find out the value of the duration of an agent's trip to the assembly station. Therefore, the assembly station location of the model will be determined according to its actual location. The case used in the passenger evacuation simulation stage is in addition to referring to the guideline's IMO MSC.1 / Circ. 1533 also refers to the results of a fire simulation where the area experiencing a fire event will be avoided by the agent on the way to the assembly station.

2.6 Making a Passenger Evacuation Simulation Model

1. Depiction of roars, doors and stairs

The first stage in the passenger evacuation simulation is the creation of a simulation model that describes the actual object. Making a simulation model based on the general arrangement of the Ro-ro 1309 DWT ship. In making the model, there are several steps that must be fulfilled so that it can describe the actual condition of the object. Starting from the drawing of the room, the drawing of the walls, the drawing of the assembly station, and the drawing of the access in the form of doors and stairs. At this stage the software used is a pathfinder which can assist in the process of drawing the model. This software has several tools that support the depiction of movement space, such as floors, rooms, obstruction / holes, doors, and stairs. In Figure 4.38. is the result and the display window depiction of the room where the value of the geometry and occupants capacity that can be accommodated in each room is adjusted to the ship.

![Figure 1. Display window on the passenger room manufacturing process.](image)

Each room will be connected by an access in the form of a door whose manufacturing process is shown above. In the door making process, the door layout will be considered according to the general arrangement of passenger ships. This process also determines the dimensions of the door and the flow rate which is adjusted to the density value of the room which is obtained from the ratio between the number of passengers divided by the dimensions of the room occupied provided that the value is less than 1.33 person / meter.
Meanwhile, access in the form of a ladder will be a link between the decks, whose manufacturing process is shown above in the process of making a ladder, the layout of the stairs will be considered adjusted to the general arrangement of passenger ships. In this process the dimensions of the steps are also considered by determining the values of the riser, tread, and length and width. One of the stairs was made with a riser value of 17.78 cm, a tread value of 27.94 cm, with a ladder length of 4.960091 meters and a width of 75 cm. Next, the function of the ladder will be determined whether it can be accessed by determining the status of the top door and bottom door as shown in the following figure. Along with the results of the depiction.

And after all the stages have been carried out, as shown, the final result in the picture above shows the depiction of the room on deck 4 such as a cabin, a prayer room, and a kitchen. On deck 4 there is also an assembly station which is an evacuation place in the simulation process. Walls and some furniture are depicted with holes so that they cannot be used as access by occupants.

2.7 Description of the Occupants
The next stage is the delineation of occupants to fill each room previously drawn. Occupants will describe the agent who is the passenger of the ship. In making an agent, there are several considerations that must be met, starting from the composition of passengers based on sex and age range that the results obtained during the direct field survey. The second is the consideration in the form of the percentage of passenger distribution to determine the number of passengers in the cabin and distributed passengers.
Next will be determined the value of the walking speed of each passenger and also the behavior of the passenger.

Figure 5. The process window displays the depiction of female passenger occupants.

Figure 5 shows the process of describing a passenger with a female category between 30-50 years old whose position and walking speed of the passenger has been determined with a value of 0.90001 m / s. The passenger's behavior has also been determined to go to the assembly station which is described with the description "Goto Any Exit".

Figure 6. Display window of the process of determining parameter profiles on the ship evacuation simulation

Figure 6 shows the process of determining the parameters from characteristics, movement, door choice, output, and advance. In this process, the value of passenger walking speed is determined from the results of a field survey and the value will be distributed using a uniform distribution so that the
minimum and maximum speed values can be determined. In the category of women under 30 years of age have a walking speed ranging from 0.899 m/s to 1,011 m/s. At this stage, the value of the initial delay is also determined which describes the response characteristics of the passenger to the assembly station. These stages are shown on with an initial delay value of 400 to 700 seconds. And shows the value of the distribution of passengers categorized by gender and age range with the total distribution must be 100%.

Figure 7. The window displays the process of determining the initial delay value at night.

Figure 8. The window displays the percentage of passengers.

The window displays the process of determining the initial delay value at night can be seen in figure 7. In the figure 8, information is given in the form of an initial delay value with a value range of 400 to 700 seconds, which means that an agent will respond to an event with that value range. Because the agent is an independent variable where its behavior cannot be controlled, it cannot be determined with certainty that each agent will respond to an event.

2.8 Determination of Simulation Parameters and Running Stages
The stage of determining simulation parameters is the last stage in a series of simulated processes for the evacuation of ship passengers. There are several simulation parameters that must be determined before the running stage is carried out. The first is the time parameter where the maximum simulation time limit will be determined which is greater than the time the last agent went to the assembly station. The second parameter is the expected output from the simulation results. Where in the evacuation simulation the output is the time to go to the assembly station and the behavior of each agent. Image below shows the time limit value of the evacuation simulation adjusted to the provisions of IMO MSC.1 / Circ. 1533 which explains that the maximum value of evacuation of Ro-ro passengers is 60 minutes. The figure above shows the time limit value for 3600 seconds which defines that the running stage has a maximum value for 3600 seconds. If the time for the last agent to go to the assembly station is more than 3600 seconds, the simulation will not run. The image below is a simulated running stage for the
evacuation of passengers on passenger ships at night with a total of 1527 passengers.

Passenger Evacuation Simulation Results
The result of the passenger evacuation simulation is the output of the simulation according to IMO MSC.1/Circ. 1533 with predefined parameters. The output of the evacuation simulation will provide information regarding the total duration needed by all passengers to go to the assembly station and get the travel time value.

3. Result

A. Night case normal condition
The simulation results for the normal night case presented in figure 9.

![Number of Occupants in Selected Rooms](image)

Figure 9 Travel time results for night cases (normal conditions)

Based on figure 9, it can be seen that the travel time (T) value for night cases in normal conditions is 856.53 seconds (14.28 minutes) to evacuate 720 passengers. So that the total time to evacuate cases at night (normal conditions) is equal to:

\[ t = 1.25T + 23 (E + L) \]

\[ = 1.25 (14.28) + 23 (30) \]

\[ = 38.24 \text{ minutes}. \]

B. Case night evacuation conditions
The simulation results for the night case evacuation conditions can be seen in Figure 10.

![Number of Occupants in Selected Rooms](image)

Figure 10 Travel time results of night cases (evacuation conditions)
Based on figure 10, it can be seen that the value of travel time (T) for the night case in the evacuation condition is 790 seconds (13.16 minutes) to evacuate 840 passengers. So that we get the total evacuation time of the night case (evacuation conditions) is equal to

\[ = 1.25T + 23 (E + L) \]

\[ = 1.25 (13.16) + 23 (30) \]

\[ = 36.45 \text{ minutes} \]

Day case normal conditions
The simulation results for the normal daytime case can be seen in Figure 11.

**Figure 11** Travel time results for daytime cases (normal conditions)

Based on figure 11, it can be seen that the travel time (T) value for normal daytime cases is 455.28 seconds (7.59 minutes) to evacuate 840 passengers. So that the total time for evacuation cases during the day (normal conditions) is obtained

\[ = 1.25T + 23 (E + L) \]

\[ = 1.25 (7.59) + 23 (30) \]

\[ = 29.49 \text{ minutes} \]

**C. A daytime case evacuation conditions**
The simulation results for the case during the evacuation conditions presented in figure 12.

**Figure 12** Travel time results for the day case (evacuation conditions)
Based on figure 12, it can be seen that the value of travel time (T) for the case of daytime evacuation conditions is 390 seconds (6.5 minutes) to evacuate 840 passengers. So that the total time for evacuation cases during the day (evacuation conditions) is obtained:

\[ 1.25T + 23 (E + L) \]
\[ = 1.25 (6.5) +23 (30) \]
\[ = 28.12 \text{ minutes} \]

4. CONCLUSION

From the simulation of passenger ship evacuation based on literature data, the results are:

a. The total evacuation time for daytime cases (normal conditions) was 29.49 minutes
b. The total evacuation time of daytime cases (evacuation conditions) is 28.12 minutes
c. The total time for evacuation of cases at night (normal conditions) was 38.24 minutes
d. The total evacuation time of night cases (evacuation conditions) is 36.45 minutes

Passenger ships could be loaded with up to 1527 passengers from a passenger capacity of 880 passengers by maximizing public spaces such as lesehan areas and stage space. Therefore all the results of the simulation meet the standards set by the IMO MSC 1533 guidelines, which is no more than 3600 seconds or 60 minutes.

REFERENCES

[1] Priohutomo, K., 2017. Analisa Waktu Evakuasi Dengan Metode Advance Pada Kapal Perintis 1200 GT. Jurnal Ilmu Pengetahuan & Teknologi Kelautan.
[2] Mufikri, M. I., 2019. Analisis Evakuasi Penumpang Kapal Ro-ro 1309 DWT Dengan Agent Based Modeling Simulation, Surabaya: s.n.
[3] Afrianza, I., 2016. Analisis Sistem Evakuasi Kapal Penumpang 1200 GT Dalam Kondisi Kebakaran Dengan Pendekatan Agent Based Modeling. Surabaya: s.n.
[4] T Pitana, KB Artana, D Prasetyawati, N Siswantoro Observation Study the Walking Speed and Distribution of Ship’s Passengers as Basis for Passenger Evacuation Simulation Applied mechanics and materials 862, 232-237
[5] Yoneda S, Kobayashi E, Koshimura S, Nanba S, Shimanooue M. 2007 A basic study of ship evacuation from tsunami attack (in Japanese). J Jpn Soc Nav Archit Ocean Eng 5:1–7
[6] Kobayashi E, Koshimura S, Yoneda S (2008) Guideline for ship evacuation from a tsunami attack. In: Proc 18th Int Offshore and Polar Engineering Conf, vol 3, Vancouver, Canada, 6–11 July 2008, pp 536–542
[7] Pitana T, Kobayashi E. 2007 Implementation of dynamic system simulation and geographic information system for large passenger vessel evacuation. In: JASNAOE (ed) Proceedings of the Japan Society of Naval Architects and Ocean Engineers conference. JASNAOE, Tokyo, 5K:33–34
[8] Siswantoro N, Priyanta D, Zaman M B, Semin 2020 Failure Mode and Effect Critically Analysis (FMECA) Fuzzy to Evaluate Critical Level on Main Engine Suporting System 557(1), 01036
[9] Siswantoro N, Semin, Zaman M B 2020 Criticality assesment fo marine diesel engine using failure mode and effect criticity analysis (Fmeca) approach: Case study on lubricating oil system 2020 14 4 pp 258 – 263
[10] International Maitime Organization (IMO), "Guidelines For Evacuation Analysis For New And Existing Passenger Ships," in MSC.1/Circ.1238, 2016.
[11] Zaman M B, Santoso A, Hasamudin, Busse W 2020 Risk Evaluation of Ferry in Bali Straits Using FMEA Method 557(1) 01045
[12] C. M. Macal and M. J. North, 2009. Agent-Based Modeling and Simulation, pp. 86-98.
[13] Law AM. 2007. Simulation modelling and analysis, 4th edn. McGraw-Hill, Boston
[14] Yoneda S, 2007. Research on ship evacuation scenario and anchored ship due to tsunami attack (Masters thesis; in Japanese). Faculty of Maritime Sciences, Kobe University, Kobe