Determining the effects of HKC requirements on the productivity of a ship recycling yard using discrete event simulation

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Abstract

It is economically unfeasible to operate an outdated vessel. Therefore, when the costs associated with operating such vessels exceed the potential gains, shipowners tend to stop operating these vessels. Several options are available for end-of-life vessels, but recycling is considered a sustainable and preferable solution compared to abandoning or sinking them. Generally, these ships are sent to ship recycling yards located in developing countries. However, the health, safety, and environmental conditions in these yards cause much concern for the international community. As a result, new international regulations will be implemented to regulate ship recycling globally, and ship recycling yards need to improve their effectiveness to remain competitive and profitable. This paper proposes to develop a framework for ship recycling yard to more fully understand problems relating to resource optimisation and the gap between current regulations and the existing yards. The framework employs discrete event simulation to create the evidence and optimize the efficiency activities in ship recycling. Therefore, a case study was designed and conducted to validate the framework mentioned above. This study successfully demonstrates that the framework can effectively identify problems in ship recycling yards, propose improvement measures, and conduct resource optimization. It is expected that evidence created from this framework can support yard owners when they are making investment decisions to improve their yards.

Keywords: Ship Recycling, Efficiency, Sustainability, Process Flow, Discrete Event Simulation, ARENA software

1 Introduction

Ship recycling is one of the various solutions for end-of-life-ships after completing their operational life. Ship recycling covers all activities involved in dismantling old and non-functional ships, allowing the re-use of valuable materials (Ozturkoglu, Kazancoglu, & Ozkan-Ozen, 2019). The recycling of a ship can be divided into three core phases: preparation, deconstruction and material stream management (Welaya, Naby, & Tadros, 2012). Recycling end-of-life vessels in an environmentally friendly manner is a significant challenge faced by ship owners, ship recycling yards, and government agencies worldwide (Du, Zhang, Zhou, Yuen, & Wong, 2018). Therefore, the maritime community has acted on this and, as a result, new regulation is being implemented which encourages ship recycling yards to improve their facilities in an effort to improve health & safety, and their impact on the environment. However, it is vital for shipyards to also consider how to optimize these new processes and continue to produce profit in order to sustain the business. One of the strategies which can be implemented is to improve the effectiveness of ship recycling processes. Effectiveness can be reached by different means, for example, by optimising the load of equipment and eliminating delays. It can also be achieved through minimising the idle status of equipment, using elaborated production scheduling, reducing process time, decreasing production costs, and lean manufacturing built on eliminating waste (Plinere & Aleksejeva).

Meanwhile, with its 17,500 islands, Indonesia is the world's largest archipelago and is dependent on maritime transportation (Hartanto, Victoria, & Chuasanga, 2019). In order to meet the demand of maritime transport, the Indonesian Government has implemented the Cabotage regulation (azas cabotage) and national shipping companies are given incentives to purchase used ships. Even though this policy has increased the number of ships significantly, it has also resulted in an influx of older ships moving to Indonesia (Hasbullah M., 2016). Currently, there are at least 500 ships that need to be replaced and sent to ship recycling yards every year due to reaching their end-of-life, but there is no official information regarding where and how these ships are being demolished (Siti Fariya, Suastika, & Manfaat, 2016). In addition, lacks the implementation of regulation and safety control, causes serious pollution, affecting the food chain and harming public health. Furthermore, the working conditions in ship recycling yards are extremely poor because the yards are not fit for purpose and workers are exposed to many hazards. Thus, this paper will focus on addressing the gap between the existing ship recycling yards in Indonesia and their regulation, and how ship recycling can be improved by developing an improvement framework using discrete event simulation. This paper is a significant contribution to the literature as it is the first study that focuses on the Indonesian ship recycling sector from a productivity and efficiency perspective.

1.1 Ship Recycling General Review

Shipping is a major mode of transportation, where approximately 90–95% of international commercial goods are transported by sea due to cost efficiency (Chang, Wang, & Durak, 2010). The dismantling and recycling of end-of-life ships are primarily carried out in India, Bangladesh, Pakistan, and Turkey. Ship recycling is the procedure of dismantling an obsolete vessel for disposal or scrapping (Demaria, 2010), and is a critical step in a ship's life cycle, in which all valuable materials are recovered, reconditioned, reused, or recycled. The mean age of all types of old ship for demolition is greater than 30 years (Yin & Fan, 2018). Like any other recycling industry, ship recycling can be considered the most environmentally friendly option for end-of-life ships compared to alternative options including reefing or abandoning the vessel (Du et al., 2018; Favi, Campi, Germani, & Manieri, 2018; Sefer A. Gunbeyaz, Kurt, & Baumler, 2019). The range of materials, equipment, and machinery that can be reappraised from end-of-life ships is extensive, which has the potential to be reused, repaired, remanufactured, and recycled. This is particularly important for developing countries, such as Indonesia, as these materials can be reutilised in different industries., e.g., metal from the ship can be rerolled/melted and reused in the construction industry. Furthermore, other equipment on board ships can be utilized in ships (during refit or repair) or other industries (e.g., diesel generators are often used in factories) (McKenna, Kurt, & Turan, 2012). Therefore, the ship recycling industry benefits from the economic development of the country. On the other hand, the ship recycling process can be difficult and is accepted as one of the most hazardous working environments if not done correctly (ILO). Ship recycling involves a wide range of activities and operations, which may expose workers to hazardous situations resulting in incidents, accidents, health problems, injuries, and even fatalities (OSHA). One of the hazards was measured by Kurt, et al., (2017) showing that noise level emissions in ship recycling activities are often beyond safety limits. In the past, a public image of secrecy, stubbornness and an overwhelming reluctance to change has been felt by the international community from the ship recycling industry (R. E. Kurt, McKenna, S.A., Attila, B.D., Turan, 2013). Also, end-of-life ships contain a high amount of toxic waste on board, and the current practice in these countries adversely affects human life and the environment. Several pollutants are comprised mainly of heavy metals, petroleum hydrocarbons and other xenobiotic compounds (Patel, Munot, Shah, Shouche, & Madamwar, 2015; Patel, Patel, & Madamwar, 2013; Reddy, Basha, Joshi, &

Ramachandraiah, 2005) which are accumulated in the coastal sediment. Eventually, international regulators were forced to focus on developing international regulations and standards.

The Basel Convention on The Transboundary Movements of Hazardous Wastes and their Disposal, the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, European Union's Ship Recycling Regulation (EUSRR) are examples of these new regulations.

1.2 Improving Ship Recycling Processes

Due to more stringent regulations, ship recycling yards need to improve their health, safety, and environmental procedures. These improvements will have an impact their running costs, and they therefore need to improve their production efficiency to remain profitable. Several studies and other research suggest tools and planning to achieve this optimization in the ship recycling area. One of the tools developed to analyse and plan the ship recycling process is Material flow analysis, which allows ship recycling yards to improve the management of waste and resources, reducing their costs (K. P. Jain, Pruyn, & Hopman, 2017). Besides these additional tools, the prospect of using plasma gasification plants to improve the offer price of 'green' ships recycled yards on large-sized has been researched (Kanu Priya Jain & Pruyn, 2018), where the waste produced in a recycling yard could be utilised as a possible source of additional profits by using plasma gasification plants to turn waste into energy and other commercial products. In addition, the plants are considered a better option in terms of environmental impact in comparison to burning or landfilling. Ultimately, the additional profit can reduce the scrapping costs for ship owners. In terms of economics, studies have been carried out which builds a case for an aid-based, 'demandeur pays' approach to addressing this impasse, compared to other options, to fund the improvement of ship recycling practices in South Asia (Yujuico & Practice, 2014). In addition to these, there are also several projects that were focused on improving the ship recycling processes. SHIPDISMANTL project developed a risk framework which applicable to the optimise the ship dismantling activities (ShipDismantl, 2010). An evaluating study of the status of current occupational training in the ship recycling industry in Bangladesh has been done as a part of SENSREC project (Sefer A. Gunbeyaz et al., 2019). The current practice in Turkey was investigated and any gaps to enhance the practice towards best practice was identified through DIVEST project (Rafet Kurt, 2010).

ShipDIGEST project developed an innovative vocational education and training in order to tackle the vital issues of the low standards of health, safety and environmental awareness in the ship dismantling industry (Stuart A. McKenna, 2013). These projects have contributed towards improving the industry in recent years, specifically in Turkey, Bangladesh, and India.

In addition to the above strategies, more focused approaches on the shipyard itself exist in the literature. A simulation analysis was performed to design efficient contemporary ship recycling yards through discrete event simulation with ARENA software (Sefer Anil Gunbeyaz, Kurt, & Turan, 2018; S. A. Gunbeyaz, Kurt, & Turan, 2020). This study aims to increase the productivity of ship recycling yards and optimize their procedures for achieving cost-efficient facilities.

ARENA software has been applied by several researchers in various disciplines, including: the construction of a simulation of two adjacent unsignalized T-junctions during rush hours. Kamrani et al also demonstrated how ARENA software could be adopted to successfully simulate traffic problems (Kamrani, Hashemi E.A, & Rahimpour Golroudbary, 2014). ARENA has also been successfully applied to develop a simulation for improving the Hold Baggage Security Screening (AlKheder, Alomair, & Aladwani) system at Kuwait International Airport. Existing models can be optimized using various tools available in ARENA like OptQuest which can be achieved by changing the resources available (Neeraj, Nithin, Niranjhan, Sumesh, & Thenarasu, 2018). Similarly ARENA and discrete event simulation has been utilised in shipyard studies as well; from design of the yard to optimisation (Caprace, Moreira Freire, Assiss, Martin Pires, & Rigo, 2011; Chabane, 2004; Goo, Chung, & Han, 2019; Ju, Sung, Shen, Jeong, & Shin, 2020; Ozkok, 2012; Song & Woo, 2013) in order to increase the throughput, decreasing the costs or to boost the utilisation of the resources in the shipyards.

Regarding the existing research, simulation models were generally used to analyse a system. Because previous works have already shown the ARENA's capability, discrete event simulation (ARENA software) was chosen to fulfil this paper's objectives. The study case was done in traditional Indonesian ship recycling yard, where the current ship recycling activities in Indonesia can cause harm to the workers involved, the surrounding environment and to the public health through contaminating the food chain. This underdeveloped industry has the potential to develop into a major industry at a national and global scale (Siti Fariya et al., 2016)

2 Methodology

The framework of the project is an integration between discrete event simulation and gap analysis. The importance of simulation for ship recycling facility design and optimisation has been introduced previously by Gunbeyaz (2019). The research demonstrated that developed discrete-event simulation frameworks are applicable to ship recycling yards and can be used for decision making by investors or other stakeholders.

Building on the approach presented above, the methodology of this study is demonstrated in six different steps as shown in Figure 1.

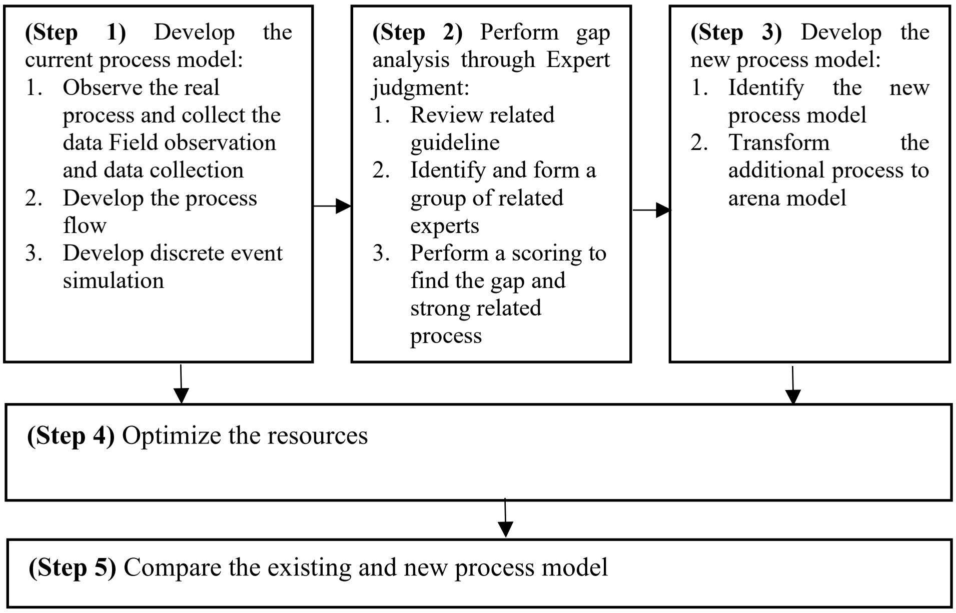


Figure 1. Methodology for improvement process model in ship recycling yard using discrete event simulation and expert judgment in terms of efficiency

The first stage of developing the current process model is to understand the actual processes of ship recycling through completed process observations for the overall process of ship recycling. The data from the observation that will be used in the ARENA simulation are:

- Number and specification of resources for each process, such as cutter, helper, cutting machine, crane, crane operator.
- Time consumed for each process.

The second stage is the development of a discrete event simulation with ARENA software. This model aims to show the existing situation as a benchmark. The primary data for cutting time was taken from observation. Because several data points are missing, estimation was used to complete the data. From the ship's general arrangement, the ship's construction can be visualised, which will lead to the estimation of cutting time. Each block consists of two main parts: vertical (side hull, bottom transverse) and horizontal plates (bottom hull, longitudinal bottom). The thickness for each plate is acquired through calculations regarding the ship building rules from class. Dimensions for each plate (length and height) can be found in the general arrangement plan. This estimation includes penetration for each girder, preheat, and reposition time with the observation and previous studies' estimation number. Table 1 shows the various times for each thickness derived from observation, previous studies, and cutting machine specifications (S Fariya, Gunbeyaz, Kurt, Sunaryo, & Djatmiko, 2019).

Table 1**.** The cutting speed of different metal thickness

Metal thickness in mm **(Yujuico & Practice)**	Cutting speed (mm/min)
5	750
5 till 10	680-750
10 till 15	600-680
15 till 30	500-600
30 till 40	450-500
40 till 50	400-450

Furthermore, the second stage is to perform gap analysis through expert judgment, which have been done as follows.

1. Define ideal ship recycling in relation to the IMO guideline MEPC.210(63) Guidelines for Safe and Environmentally Sound Ship Recycling
   - Define the criteria for Safe and Environmentally Sound Ship Recycling
   - Requirement needed to fulfil the criteria.
   - Proposed additional process.
2. Gather multiple experts based on their occupation, level of education, and years of education
3. Experts rank the criteria from: Strongly related to the process to strongly not related to the process.
4. Each expert receives a total score from their occupation, years of experience, and education. Each criterion has a score based on their rank. So, rank score multiplied by expert score will provide the total score for each criterion. The highest score will be chosen as the strongest related to the process.

Then, the existing and proposed model were compared. The proposed additional process from the strongest related to each criterion's process will be added to the new model.

Next, resources were optimized by OptQuest, which is an optimization tool built into the ARENA software, which facilitates the enhancement of analysis capabilities to obtain the simulation models' optimal solution (Bradley, 2009). It helps to define various system inputs based on the required output and simulate various scenarios for each set of inputs to achieve the desired output. There are three main features in OptQuest utilised in this simulation process:

1. **Control**: Cutter, cutting tool, helper, foreman, crane, crane operator, foreman
2. **Objective:** Minimize the queue
3. **Constrain:** Output steel >95%

Both existing and new models are analysed with OptQuest to find the most efficient resources. Finally, the comparison between the two models will be made by calculating the total process time which will be benefitting the company.

3 Study Case

To design the process model, the first step of the methodology is to understand the entire process of ship recycling through field observation and data collection. Observation was performed with time-motion observation for the overall process of ship recycling. The data from observation will be utilised in the ARENA simulation. For this stage, a full ship recycling process was investigated. In this study, the ship recycling process was observed for a 48-meter cargo ship recycled in a traditional Indonesian Ship Recycling Yard. The yard in this study case was divided into five zones as shown in figure 2. Primary cutting is located in the intertidal zone (Zone A), and Zone B is used for secondary cutting. Segregation and material reprocessing is mixed in the shore (Zone C&D), and Zone E is used for office space.

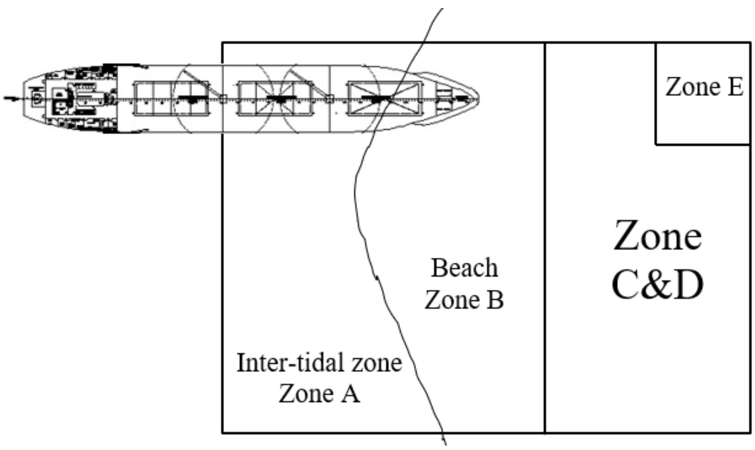


Figure 2. Current layout of Case Study Ship Recycling Yard

Furthermore, based on observations, there are five steps of the recycling process: 1. Ship arrival and administration, 2. Preparation for recycling with the beaching method, 3. Cleaning and primary cutting at the same time, as shown in Figure 3, 4. Secondary cutting, plates to be cut further into smaller pieces, generally 100cm x 50cm as seen in Figure 4 5. Segregation for reusable materials, equipment, and waste. The observation study shows that solid waste, liquid waste and hazardous materials were mixed without any separation at this stage.

Figure 3. Cutting and cleaning activities in primary zone

Figure 4. Cutting a block into small pieces

Furthermore, data observation and previous research (S Fariya et al., 2019) have produced a simplified representation of the ship recycling processes, shown in Figure 5 below.

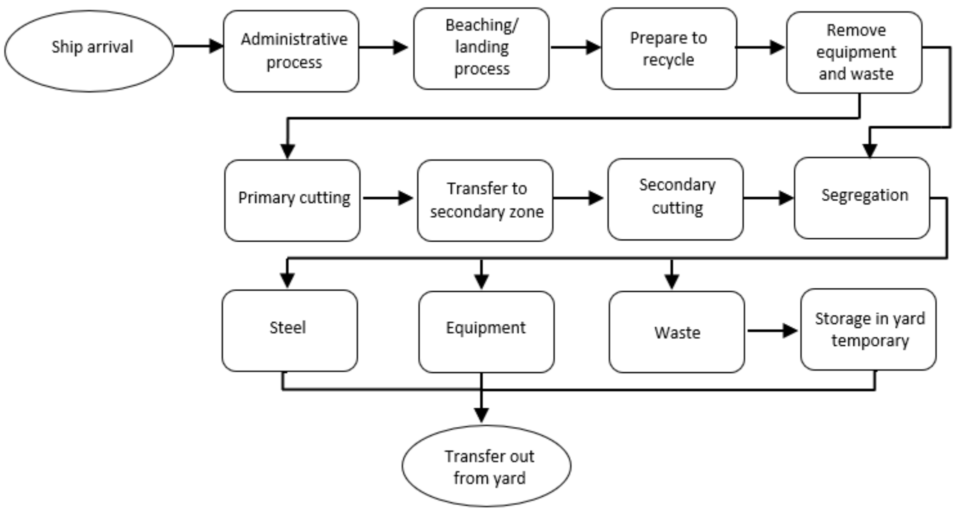


Figure 5. Simplified ship recycling process flow for observed yard in Indonesia

During the data collection and observation phase, a full cutting process map was produced from the real situation in primary cutting and is shown in Figure 6. The purpose of this observation is to understand the detailed and sequence of primary cutting block as well as the number block created which will be used to build primary cutting model in ARENA.

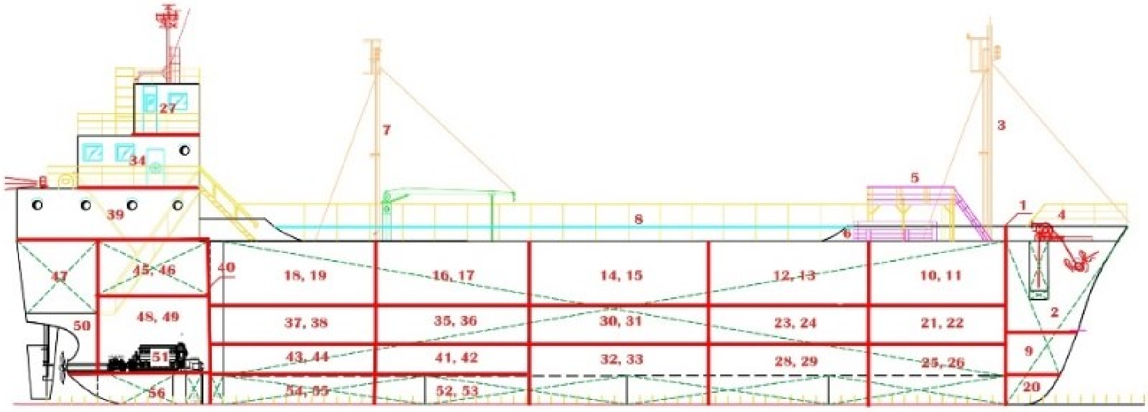


Figure 6. Primary Cutting Process Map

After understanding the process flow, the next step was the development of the current ship recycling discrete event simulation model in the ARENA discrete event simulation software. Arena has been applied to evaluate different options in the case studies, such as performance of different layout alternatives, resource combinations (worker, cranes, transporters, polygrabs etc.), technology 262 solutions, alternative cutting technologies, different plate sizes, have been implemented through simulation approach (Gunbeyaz, 2019). The process flow above in Figure 5 will be utilised to develop the models in simulation environment. The data needs to be collected to successfully run this model are the process time, resources and tool needed. The input data was taken from observation study and previous research. The time data was inputted in input analyser tool in ARENA and was used in each process model. The simulation output that used in this research is the total time process for each model and the number of optimize resource in further analysis with optQuest tool in ARENA.

The current process model aimed to present the existing situation as a benchmark. The ship recycling process simulation model was split into five main parts; Ship arrival and administration, preparation, cleaning and primary cutting, secondary cutting, and segregation. The input needed for this model included various resources such as process time and the number of resources from the real condition.

The next section will describe each process represented by the module in the ARENA simulation. Started from ship arrival, the model was defined as shown in Figure 7. The created module defined the ship's arrival model. The record module was used to create statistical data for the arrival time. The new value of the variable was calculated by assigning properties and continued to the securing activity by process module, which was fulfilled with the real number of resources needed. A rare occurrence found in the Indonesian ship recycling process was a whole day of cultural ceremony which caused a delay of the process. Later, the setting of access to the ship was also stimulated by the processing module. The station module represents zone A for primary cutting.

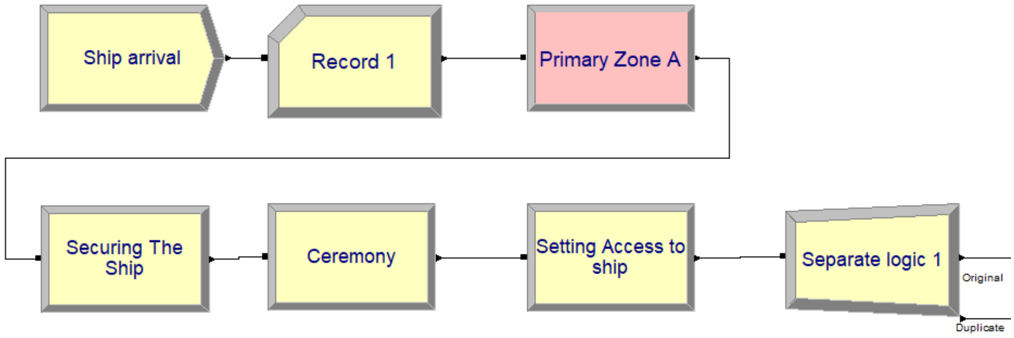


Figure 7. Ship Arrival model in ARENA simulation

A separate module was created for temporary logical separation in cleaning work as can be seen from Figure 8. Segregation model in ARENA simulation

. There are two activities: initial cleaning and fuel discharging. The assign module calculated both the value of fuel and lost items. The rest of the fuel was transported to Zone D (temporary storage area) with a route module. As a real condition, liquid waste was discharged into the sea without any process treatment. In the end, the batch module was generated to combine the separated entity.

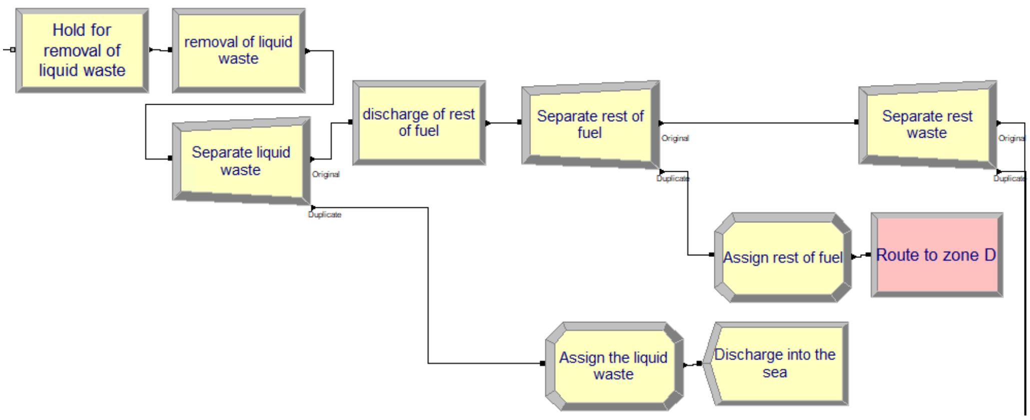


Figure 8. Segregation model in ARENA simulation

Reusable loose items were transferred to temporary storage (Zone D). Then, the module designated as detailed in Figure 8 where they were going to be placed. Reusable loose items and the rest of the fuel were picked up by customers, represented by the delay module. The rest of the materials, such as hazardous materials, and solid & liquid waste were placed in unprofessional disposal which, in essence, means burning and discharging these materials into the sea.

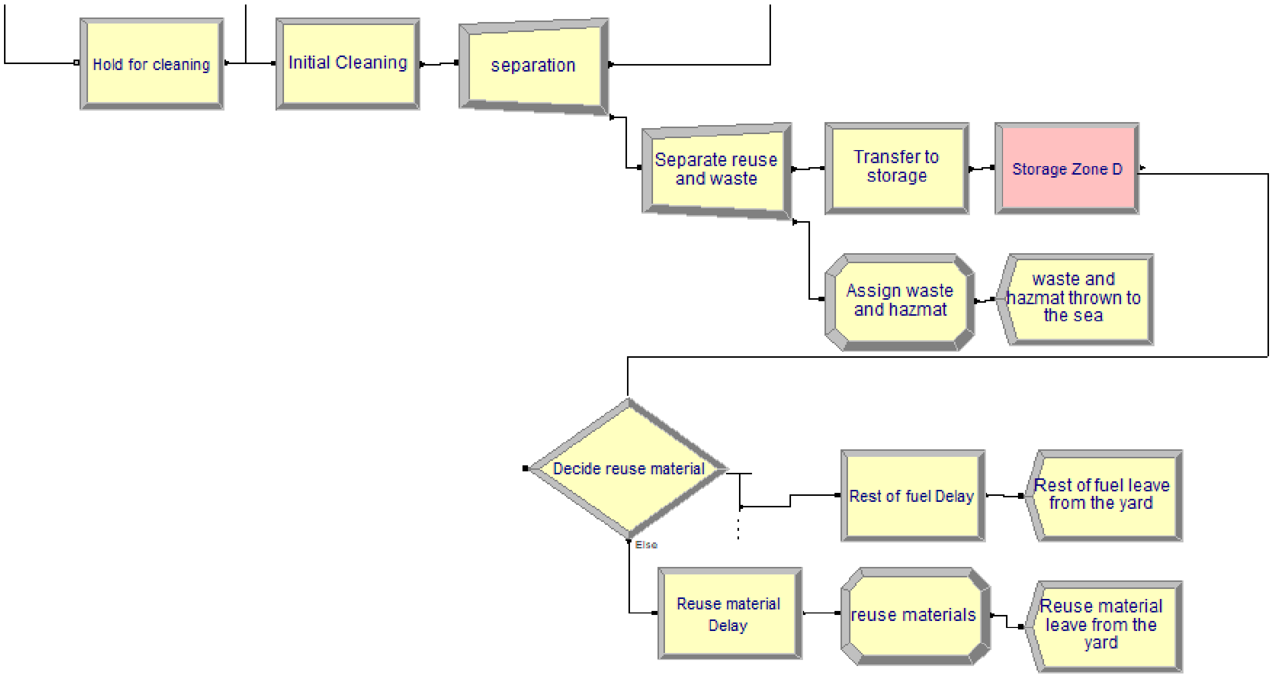
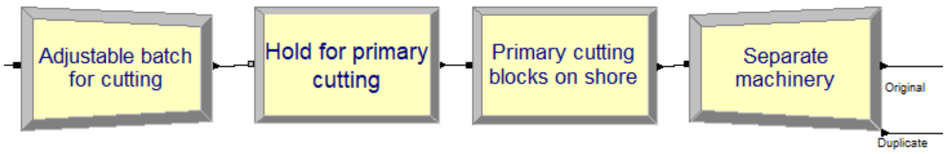


Figure 9. Cleaning and preparation model in ARENA simulation

Shown in Figure 10, primary cutting occurred in two different zones: the tidal zone and the ground, so the model is built with logical separation for primary cutting. Another separate model was used for logical separation of the number of blocks being cut. All the blocks were transferred to secondary zone B, which is represented by the station module.



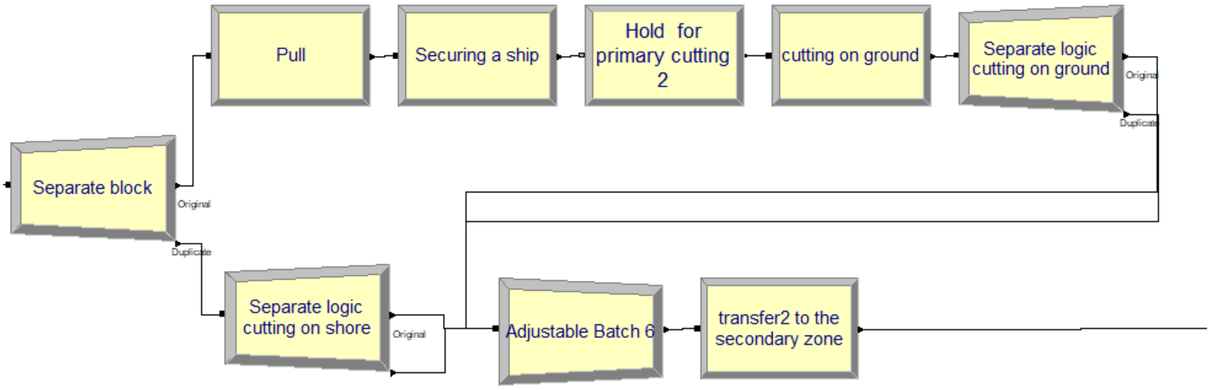


Figure 10. Primary cutting model in ARENA simulation

The machinery removal is shown as a process module (Figure 11) detailed into the sub-model, as shown in Figure 12.

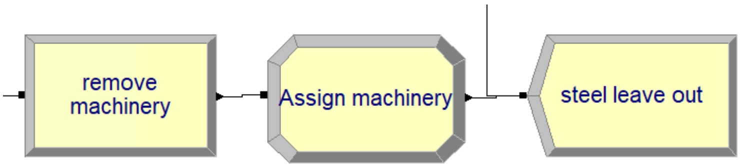


Figure 11. Machinery removal model in ARENA simulation

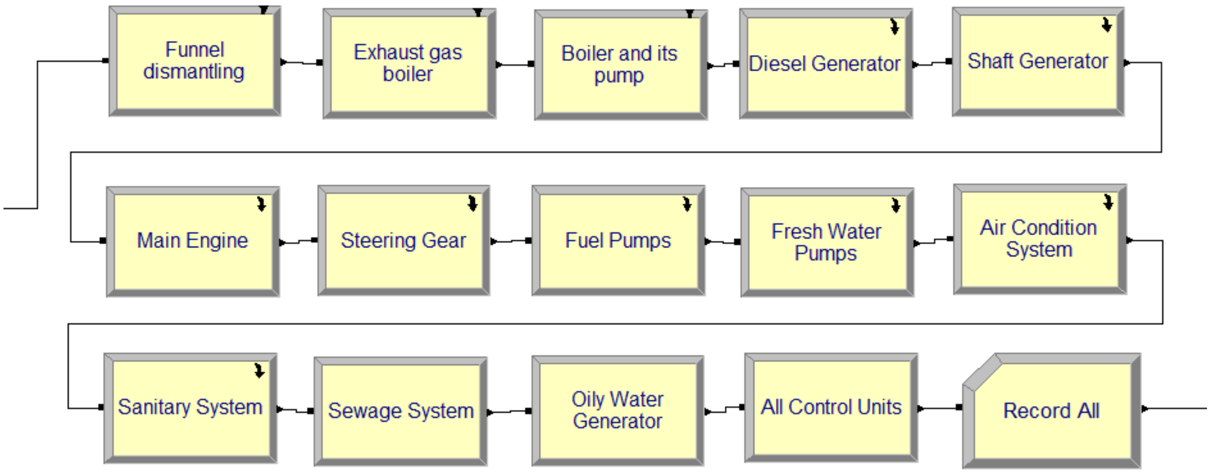


Figure 12. Sub model of machinery removal model in ARENA simulation

A process module represents secondary cutting. After the cutting process, the helpers loaded the scraps to the truck by crane. For one-time handling, the crane can load five steel pieces, represented by a separate and batch module (Figure 13) and process module represents the truck's loading, and the outstation module means the steel has left the yard.

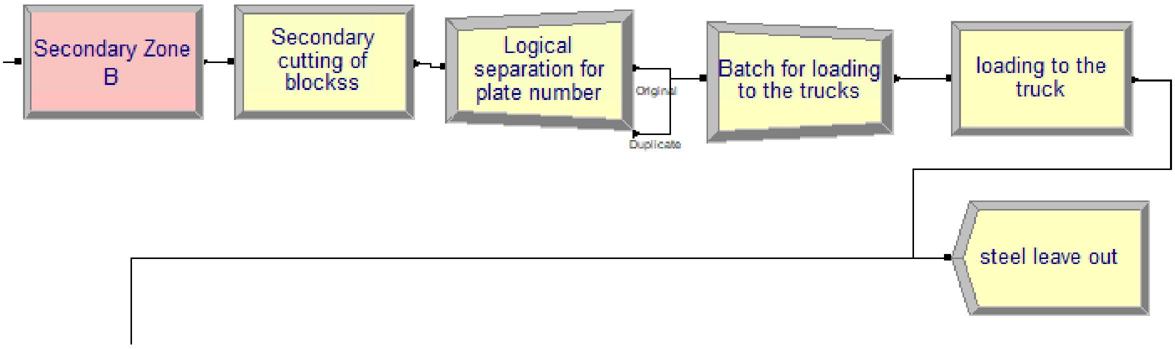


Figure 13. Secondary cutting model in ARENA simulation

The next step is to perform gap analysis through Expert judgment. The purpose of this analysis is to compare the existing condition with IMO requirements. As this paper focuses on the simulation process, the gap will be focused on the ship recycling process. In order to do this, expert judgment was identified and utilised to find the criteria most strongly related to the process. The ship recycling yard criteria were taken from the International Maritime Organization (IMO), resolution MEPC 210 (63), a 2012 guideline for safe and environmentally sound ship recycling. The summary of experts identified & recruited, and their experience is shown in Table 2 while Table 3 presents the criteria used for identifying improvement areas

Table 2. Summary table for participating experts

No.	Experts	Occupation	Education	Years of experience
1	International Expert 1	Academia (Staff and management)	Ph.D. or higher	10+ years
2	International Expert 2	Academia (Staff and management)	Ph.D. or higher	0 – 5 years
3	Local Expert 1	Academia (Staff and management)	Masters degree	0 – 5 years
4	Local Expert 2	Ship recycling yard (owner and manager)	Bachelors degree	10+ years
5	Local expert 3	HSE expert	Masters degree	0 – 5 years

Table 3. Identified ship recycling yard criteria which are likely to impact on the process times

1	Ship Recycling Plan (SRP) development
2	Ship recycling methodology
3	Prevention of adverse effects on human health
4	Safe-for-entry inspection and testing procedures
5	Safe-for-hot-work procedures
6	Housekeeping and illumination
7	Management of hazardous materials
8	Identification, marking and labelling and potential onboard locations
9	Hazardous material handling
10	Spill prevention, control, and countermeasures
11	Treatment, transportation, and disposal
12	Environmentally sound management of hazardous materials

The aforementioned criteria for assessing ship recycling yards is adopted from the IMO "Guidelines for safe and environmentally sound ship recycling" (IMO, 2012). The purpose of identifying the process related gaps was to include their potential effect into the related process model. Regarding the analysis above, the additional processes which were included in the new model are focused on:

1. Safe for entry process and safe for hot work process
2. Preparation before working
3. Inventory of Hazardous Materials (IHM) Inspection
4. Storage activities

After that, the new process model was developed in in ARENA discrete event simulation software as shown below in Figure 14.

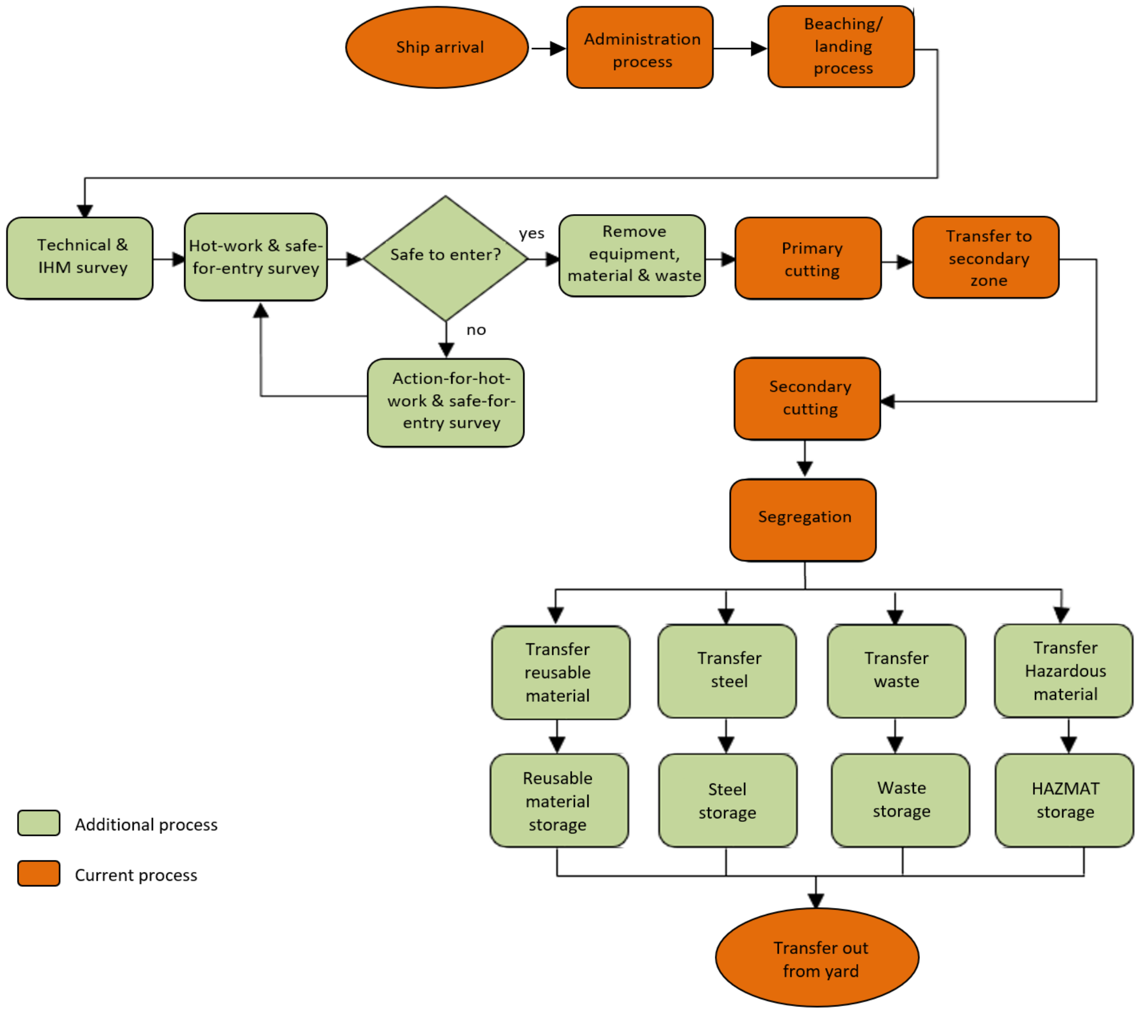


Figure 14. The new process models.

Analysis was performed through an expert judgment technique that combines the field observation and questionnaire to assess the current condition of the vessel and identify the process related gaps compared to the current laws and regulations, with some additional process. Started with pre-recycling survey, after the administration step, the next process should be an Inventory of Hazardous Materials (IHM) check to identify any hazardous materials on the vessel (Figure 15).

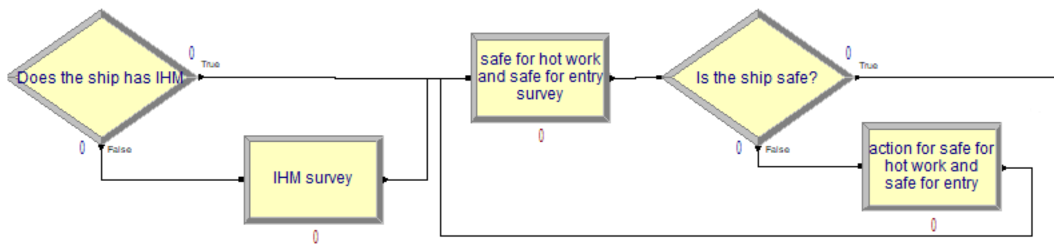


Figure 15. Pre-Recycling Survey model in ARENA simulation

Continued with preparation and segregation, before proceeding to the primary cutting process, all general cleaning is conducted, while hazardous materials and liquid waste are removed from the ship as well as cables, equipment, and other installations. Discharge of any remaining fuel is also performed. All materials are calculated with the assign module after this process and transfer to the segregation zone C as seen in

Figure 16.

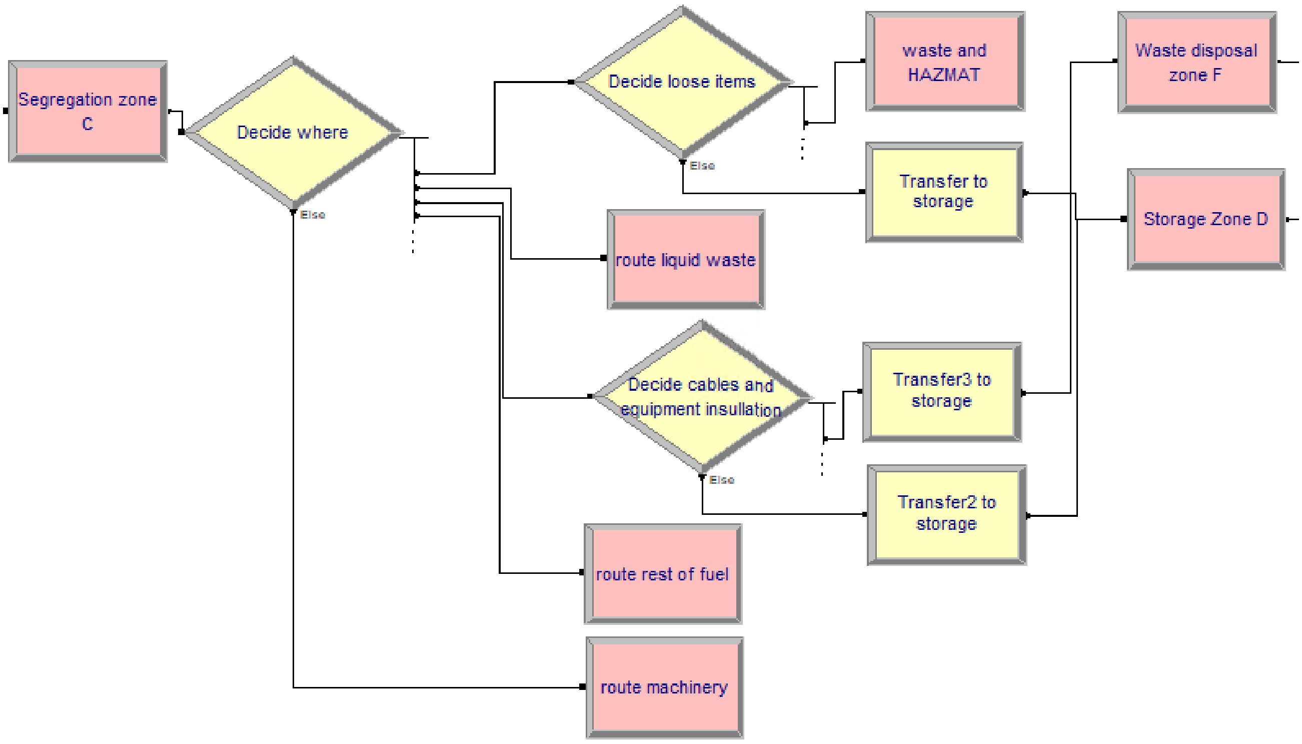


Figure 16. Segregation in the zone C module

Furthermore, it continues transferred to zone D/ storage (Figure 17). It is essential to add a proper segregation process. The treatment process of hazardous materials and wastes should be applied after segregation and should also include a detailed description of how recycled materials, reusable items, and wastes are handled and disposed of in a safe and environmentally sound manner

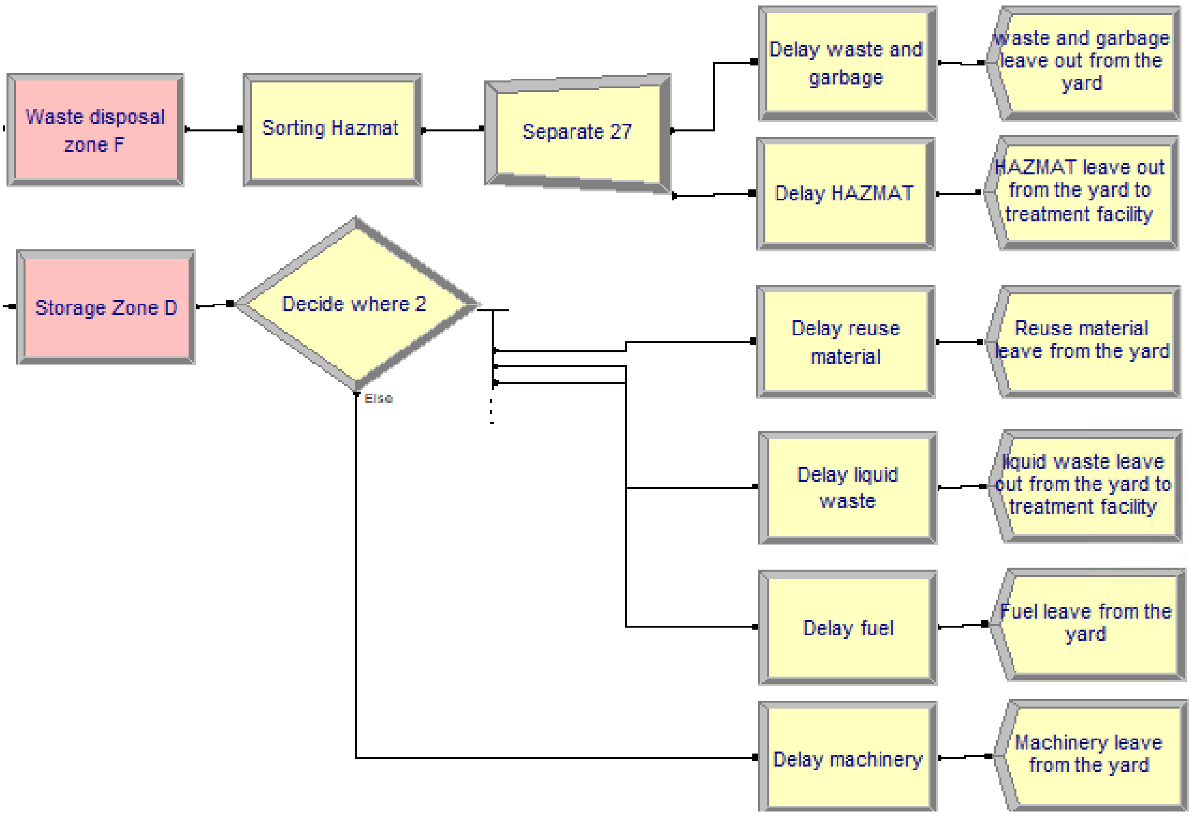


Figure 17. Segregation module in the zone D

The decide module will direct the entities according to the 'Material Index' that was introduced previously.

4 Results

After the simulation was developed and data collection was identified to the system as an input, the model was run 100 times with OptQuest in ARENA simulation.

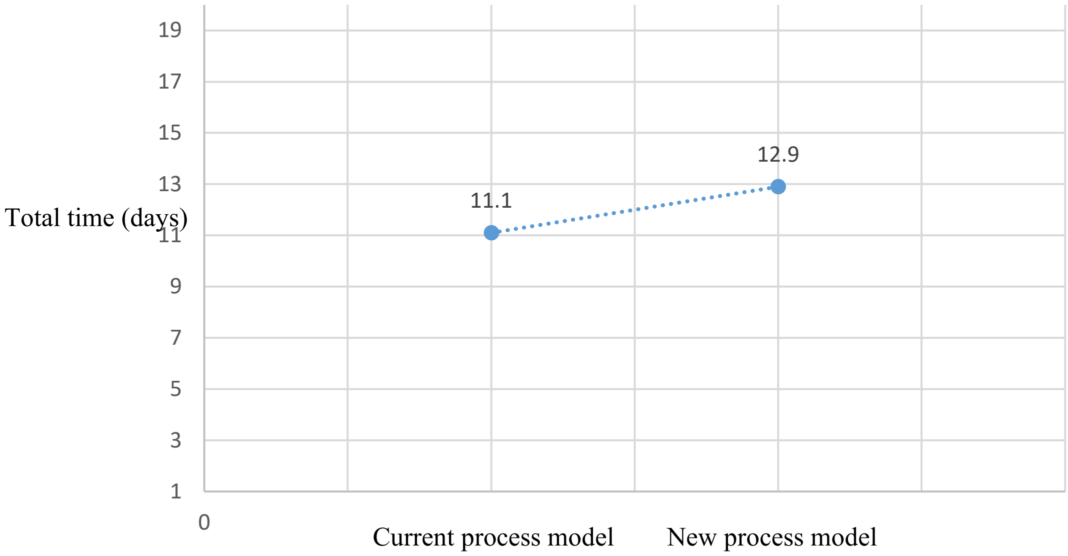


Figure 18. Total times for each process model.

The existing model (model 1) needs 11.1 days where the working hours are 08.00-17.00 with a one-hour break during noon, which is close to the real-time needed in the actual ship recycling process. The improved model (model 2) shows double the time compared to the existing model.

Table 4. The maximum waiting times in the queue for each model.

Model	Process	Delay (in hours)
Existing model	Hold for primary cutting 2	13.40
Improved model	Secondary cutting	2.11

To identify the most optimal resource management, several scenarios were examined. For the existing model, as a control, the following resources utilized in the ship recycling process were focused on cutter and cutting tool The type of process is discrete. The low and high bound for cutting tool and cutter are 10 and 30, with the suggested number being 14. For the improved model, the low and high bound for cutting tool and cutter are 10 and 30, with the suggested number being 12.

Additionally, the processes bottleneck can be minimized. In the existing model, the process which has the biggest delay/queue is "Hold for primary cutting 2". Therefore, to optimise this process the goal will be to minimize this holding time.

In this case study, a key constrain was to keep metal output stable. The optimisation result from the existing model for the control, objective and metal output (explained prior) are demonstrated in the Table 5 and Table 6.

Table 5. Optimisation Result for the current process model

Simulation	status	crane	crane operator	cutter	cutting tool
3	Feasible	1	1	14	14

In the improved model, the process which has the biggest delay/queue is secondary cutting. It has the same goal as the existing model, to minimize the queue while keeping the output stable.

Table 6. Optimisation Result for the new process model

Simulation	status	crane	crane operator	cutter	cutting tool
3	Feasible	1	1	12	12

5 Discussion:

The increment of total times for the ship recycling process with additional processes regarding the IMO regulation (improved model) is two-times the existing process. Although there is an increment to the total time for the improved model, there is a 20% reduction of resources (cutter and cutting machine) caused by a proper and optimize procedure. On the other hand, there are additional resources for additional processes in the improved model; 1. Safe for entry survey process, 2. Safe for hot work survey process, 3. SRP preparation process, 4. Preparation before working, 5. IHM Inspection, 6. Storage activities, 7. Transport waste and hazmat to certified 3rd parties.

As mentioned, IMO regulation is being implemented, while EU Ship Recycling Regulation has already been implemented, including the list of certified ship recycling yards for European ships. If ship recycling yards can improve their standard and get included in the EU list, they will be able to operate in a broader market than an uncertified ship recycling yard, becoming one of the triggers for owners to upgrade limited ship recycling yards.

Although this paper achieved the aim of developing a framework for ship recycling yards to provide a better understanding of problems relating to resource optimization and the gap between current regulation and existing yards, there are several limitations to be improved for future research, including: the IMO criteria included and the gap analysis only relating to the process. However, the process analyzer in ARENA software can also be used as an additional tool for both understanding and improvement.

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References

AlKheder, S., Alomair, A., & Aladwani, B. (2020). Hold baggage security screening system in Kuwait International Airport using Arena software. *Ain Shams Engineering Journal, 11*(3), 687-696. doi:https://doi.org/10.1016/j.asej.2019.10.016

Caprace, J.-D., Moreira Freire, R., Assiss, L. F., Martin Pires, C., & Rigo, P. (2011). Discrete event production simulation in shipyard workshops. *Proceeding of the 21th COPINAVAL*.

Chabane, H. (2004). *Design of a small shipyard facility layout optimised for production and repair.* Paper presented at the Proceedings of Symposium International: Qualite et Maintenance au Service de l'Entreprise.

Chang, Y.-C., Wang, N., & Durak, O. S. (2010). Ship recycling and marine pollution. *Marine Pollution Bulletin, 60*(9), 1390-1396. doi:https://doi.org/10.1016/j.marpolbul.2010.05.021

Demaria, F. (2010). Shipbreaking at Alang–Sosiya (India): An ecological distribution conflict. *Ecological Economics, 70*(2), 250-260. doi:https://doi.org/10.1016/j.ecolecon.2010.09.006

Du, Z., Zhang, S., Zhou, Q., Yuen, K. F., & Wong, Y. (2018). Hazardous materials analysis and disposal procedures during ship recycling. *Resources Conservation and Recycling, 131*, 158-171. doi:10.1016/j.resconrec.2018.01.006

Fariya, S., Gunbeyaz, S., Kurt, R., Sunaryo, S., & Djatmiko, E. (2019). *Developing sustainable green ship recycling facilities in Indonesia: Investigation of current situation.* Paper presented at the Sustainable Development and Innovations in Marine Technologies: Proceedings of the 18th International Congress of the Maritme Association of the Mediterranean (IMAM 2019), September 9-11, 2019, Varna, Bulgaria.

Fariya, S., Suastika, K., & Manfaat, D. (2016). *Technical Analysis of the Development of Ship Recycling Yard in Indonesia*.

Favi, C., Campi, F., Germani, M., & Manieri, S. (2018). Using design information to create a data framework and tool for life cycle analysis of complex maritime vessels. *Journal of Cleaner Production, 192*, 887-905. doi:https://doi.org/10.1016/j.jclepro.2018.04.263

Goo, B., Chung, H., & Han, S. (2019). Layered discrete event system specification for a ship production scheduling model. *Simulation Modelling Practice and Theory, 96*, 101934. doi:https://doi.org/10.1016/j.simpat.2019.101934

Gunbeyaz, S. A., Kurt, R. E., & Baumler, R. J. W. J. o. M. A. (2019). A study on evaluating the status of current occupational training in the ship recycling industry in Bangladesh. doi:10.1007/s13437-019-00164-0

Gunbeyaz, S. A., Kurt, R. E., & Turan, O. (2018, April 16-19, 2018). *Designing efficient contemporary ship recycling yards through discrete event simulation.* Paper presented at the Transport Research Arena TRA 2018, Vienna.

Gunbeyaz, S. A., Kurt, R. E., & Turan, O. (2020). Investigation of different cutting technologies in a ship recycling yard with simulation approach. *Ships and Offshore Structures*, 1-13. doi:10.1080/17445302.2020.1846916

Hartanto, H., Victoria, O. A., & Chuasanga, A. (2019). MARITIME TRANSPORTATION OF INDONESIAN POLICY. *Jurnal Pembaharuan Hukum, 6*(1), 36-44.

Hasbullah M. (2016). Development Strategy for National Shipbuilding Yards to Effectivity and Efficiency 585 increase the National Shipping Fleet (in Indonesian), . *Jurnal Riset dan Teknologi Kelautan, vol. 14,586 no. 1, ,* pp. 103 - 114.

ILO. (2001). *WP.167SECTORAL ACTIVITIES PROGRAMMEAn Issues PaperWorker safety in the ship-breaking industries*.

IMO. (2012). *RESOLUTION MEPC.210(63) GUIDELINES FOR SAFE AND ENVIRONMENTALLY SOUND SHIP RECYCLING* Retrieved from

Jain, K. P., & Pruyn, J. (2018). Investigating the prospects of using a plasma gasification plant to improve the offer price of ships recycled on large-sized 'green' yards. *Journal of Cleaner Production, 171*, 1520-1531. doi:https://doi.org/10.1016/j.jclepro.2017.10.108

Jain, K. P., Pruyn, J. F. J., & Hopman, J. J. (2017). Material flow analysis (MFA) as a tool to improve ship recycling. *Ocean Engineering, 130*, 674-683. doi:https://doi.org/10.1016/j.oceaneng.2016.11.036

Ju, S., Sung, S., Shen, H., Jeong, Y.-K., & Shin, J. G. (2020). System development for establishing shipyard mid-term production plans using backward process-centric simulation. *International Journal of Naval Architecture and Ocean Engineering, 12*, 20-37. doi:https://doi.org/10.1016/j.ijnaoe.2019.05.005

Kamrani, M., Hashemi E.A, S. M., & Rahimpour Golroudbary, S. (2014). Traffic Simulation of two Adjacent Unsignalized T-Junctions during Rush Hours Using Arena Software. *Simulation Modelling Practice and Theory, 49*, 167-179. doi:10.1016/j.simpat.2014.09.006

Kurt, R. E., McKenna, S. A., Gunbeyaz, S. A., & Turan, O. (2017). Investigation of occupational noise exposure in a ship recycling yard. *Ocean Engineering, 137*, 440-449. doi:https://doi.org/10.1016/j.oceaneng.2017.03.040

Kurt, R. E., McKenna, S.A., Attila, B.D., Turan. (2013). *Improving Occupational Health & Safety Standards within the Ship Dismantling Industry through Accident, Incident & Near Miss Investigation and Reporting*. Paper presented at the International Conference on Ship Recycling SHIPREC2013.

McKenna, S. A., Kurt, R. E., & Turan, O. (2012). A methodology for a 'design for ship recycling'. In *The Environmentally Friendly Ship* (pp. 37-44). London: Royal Institution of Naval Architects.

Neeraj, R. R., Nithin, R. P., Niranjhan, P., Sumesh, A., & Thenarasu, M. (2018). Modelling and simulation of discrete manufacturing industry. *Materials Today: Proceedings, 5*(11, Part 3), 24971-24983. doi:https://doi.org/10.1016/j.matpr.2018.10.298

OSHA. (2010). *Safe Work Practicesfor Shipbreaking*.

Ozkok, M. (2012). The effects of matrix module structure on shipyard panel line's throughput. *Polish Maritime Research, 19*(3), 65-71.

Ozturkoglu, Y., Kazancoglu, Y., & Ozkan-Ozen, Y. D. (2019). A sustainable and preventative risk management model for ship recycling industry. *Journal of Cleaner Production, 238*, 117907. doi:https://doi.org/10.1016/j.jclepro.2019.117907

Patel, V., Munot, H., Shah, V., Shouche, Y. S., & Madamwar, D. (2015). Taxonomic profiling of bacterial community structure from coastal sediment of Alang–Sosiya shipbreaking yard near Bhavnagar, India. *Marine Pollution Bulletin, 101*(2), 736-745. doi:https://doi.org/10.1016/j.marpolbul.2015.10.003

Patel, V., Patel, J., & Madamwar, D. (2013). Biodegradation of phenanthrene in bioaugmented microcosm by consortium ASP developed from coastal sediment of Alang-Sosiya ship breaking yard. *Marine Pollution Bulletin, 74*(1), 199-207. doi:https://doi.org/10.1016/j.marpolbul.2013.07.001

Plinere, D., & Aleksejeva, L. (2019). Production scheduling in agent-based supply chain for manufacturing efficiency improvement. *Procedia Computer Science, 149*, 36-43. doi:10.1016/j.procs.2019.01.104

Rafet Kurt, O. T. (2010). *Human factors in ship dismantling – A safety approach: Reality Vs Best practice*. Paper presented at the Dismantling Of Obsolete Vessels.

Reddy, M. S., Basha, S., Joshi, H., & Ramachandraiah, G. J. C. (2005). Seasonal distribution and contamination levels of total PHCs, PAHs and heavy metals in coastal waters of the Alang–Sosiya ship scrapping yard, Gulf of Cambay, India. *61*(11), 1587-1593.

ShipDismantl. (2010). *Cost Effective & Environmentally Sound Dismantling of Obsolete Vessels.* Final Project's report

Song, Y. J., & Woo, J. H. (2013). New shipyard layout design for the preliminary phase & case study for the green field project. *International Journal of Naval Architecture and Ocean Engineering, 5*(1), 132-146. doi:https://doi.org/10.2478/IJNAOE-2013-0122

Stuart A. McKenna, R. E. K., Osman Turan. (2013). *SHIP DIGEST: Vocational education for the ship dismantling industry*. Paper presented at the International Conference on Ship Recycling, Sweden.

Welaya, Y. M. A., Naby, M. M. A., & Tadros, M. Y. (2012). Technological and economic study of ship recycling in Egypt. *International Journal of Naval Architecture and Ocean Engineering, 4*(4), 362-373. doi:https://doi.org/10.2478/IJNAOE-2013-0103

Yin, J., & Fan, L. (2018). Survival analysis of the world ship demolition market. *Transport Policy, 63*, 141-156. doi:https://doi.org/10.1016/j.tranpol.2017.12.019

Yujuico, E. J. T. R. P. A. P., & Practice. (2014). Demandeur pays: The EU and funding improvements in South Asian ship recycling practices. *67*, 340-351.