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Designing efficient contemporary ship recycling yards through discrete event simulation

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Abstract

Today, the ship recycling industry is going through a transitional phase in order to comply with the new regulations which are forcing ship recycling yard owners to invest and improve yards. One way to compensate these investments is to optimise the current process and increase the efficiency; however, in the literature there is a gap on detailed approach to optimization of ship recycling processes. This paper aims to develop a framework for the ship recycling industry in order to improve and optimise the ship recycling procedures. This aim is achieved through preparation of simulation models in the ARENA software with current and alternatives practices/processes for every step of ship recycling. The simulation framework developed has been applied for a ship recycling yard in EU as a case study. Bottlenecks in the current process were identified and through simulations alternative solutions were considered to optimise the process. Potential improvements for the yard with simulation approach were summarized in this paper.

Keywords: Ship recycling; discrete event simulation; process optimization

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1. Introduction

Ship recycling is an important step of ship's life cycle which all valuable materials are recovered, reconditioned, reused or recycled. Ship recycling, similar to any other recycling industries, can be considered as the most environmentally friendly option for end-of-life ships. 95-98% as weight of the ships material and equipment can be recycled. Also, a recent study concluded that the production of one ton of steel from hematite ore requires 7400 MJ of energy while releasing 2200 kg of carbon dioxide. However, compared with the above mentioned values producing same amount of steel from scrap requires 1350 MJ of energy and releases 280 kg of carbon dioxide (Yanmaz, 2005).

Ship recycling industry has always existed, but the industry has become truly active after World War II (Lloyd's Register, 2011; McKenna et al., 2012). Until 1980's industry was mostly located in industrialized countries (e.g. Germany, Italy, United Kingdom, the United States and Scandinavian countries) often as a parallel activity to the ship repairing. However, due to the occupational and environmental health hazards, industry shifted to Asia. Currently, 98% of the ship recycling capacity is located in five major countries, Bangladesh, India, China, Pakistan and Turkey (NGO Ship Breaking Platform, 2017). Unfortunately, in some of these countries, the labor is cheap and Health, Safety and Environment legislations are loose. Recycling practices in these countries are heavily criticized for being hazardous to workers, environment and local community. The negative images forced international regulators to develop international regulations and standards.

International Maritime Organization has focused on the occupational and environmental problems of the ship recycling industry and adopted "The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships" which is also known as the "Hong Kong Convention" (IMO, 2009). The convention aims to "*ensure that ships, when being recycled after reaching the end of their operational lives, do not pose any unnecessary risk to human health and safety or to the environment*" (IMO). Convention adopted in 2009 and it will enter into the force 24 months after it is ratified by 15 states (representing 40% of world merchant shipping by gross tonnage (IMO, 2009). Another regulation regarding the ship recycling was adopted by the European Commission in 2013, "Ship Recycling Regulation" (EC, 2013). The main objective of the Ship Recycling Regulation is minimizing the negative effects of recycling the EU-flagged ships (EC, 2016). Both regulations require some changes and investments to be done in the ship recycling yards, especially the yards in South Asia.

Even though the ship recycling yard owners do not prefer to invest and increase the cost, ship owners will have to recycle their ships in the "green" ship recycling yards due to the Hong Kong Convention and EU Ship Recycling Regulation. Apart from the investments, the operating costs of the yards will increase due to the extra costs from the HSE measures and safe operating procedures. In order to compensate the investments and increased costs, ship recycling yards need to increase their revenue from the end of life ships or decrease the costs of the dismantling operations.

One of the answers to the above-mentioned problem is to increase the efficiency and productivity of the ship recycling facilities through optimisation of the ship recycling processes. Optimising the ship recycling processes will not only decrease the costs, but it will also reduce the energy consumption of the ship recycling facilities and reduce the emission. In the literature, there is a gap on increasing the productivity of the ship recycling facilities and detailed simulation approach for ship recycling to optimize the processes.

The main aim of this study is to increase the productivity of ship recycling yards and optimize their procedures towards achieving cost efficient and responsible facilities for future. This aim will be achieved through preparation of simulation models in the ARENA discrete event simulation software with current and alternatives practices/processes for every step of ship recycling. This approach will also assist the industry to improve their operations. It will be possible to implement this framework to all different docking techniques; different surface preparation technologies, cutting technologies, lifting technologies are being implemented in the models for the simulations. This paper summarizes the simulation framework developed for the ship recycling industry and the application of the framework for a ship recycling yard in EU as case study. Improvements achieved in the yard with simulation approach were also summarized in this paper. Bottlenecks of the current process model of the yard were identified through simulations and alternative solutions are also being considered to optimize the process.

2. Literature

As mentioned before, literature is very limited on simulation approach on ship recycling. There are lot of studies focusing on the simulation approach for the manufacturing process of different industries (Al-Khafaji and Al-Rufaifi, 2012; Coskunturk, 2006; Frazzon et al.; John and Jenson Joseph, 2013; McDonald et al., 2002; Said and Ismail, 2014; Sankaran et al., 2015; Topcu, 2015; Wahab et al., 2014) or the electronic waste recycling centre design (Capraz, 2013; Limaye and Caudill, 1999). Simulation approach is also used widely in the maritime industry; harbour operations, ship loading and off-loading operations, ship operations were modelled and simulated to improve the efficiency of the ports, ships and operations by many different researchers; (Aksoy, 2011; Esmer et al., 2013; Franzese et al., 2004; Goldsman et al., 2002; McLean and Biles, 2008; Merkuryev et al., 1998; Shu and Zhang; Tahar and Hussain, 2000).

Moreover, simulation approach was also used in the ship building industry to improve the performance as well as to support decision making. To name a few; Alfeld et al. (1998) developed a software to simulate ship construction processes in order to support the decision process, Shin et al. (2004) modelled subassembly lines at a ship yard and simulated the production process, Greenwood et al. (2005) modelled panel construction station in order to improve the productivity and solve the bottlenecks in the current production process, Lamb et al. (2006) used simulation approach for performance improvement in shipbuilding processes, Ozkok conducted several studies in the different stages of ship construction to improve the construction process (Ozkok and Helvacioglu, 2013).

Simulation approach was also used by the researchers in the ship recycling area in order to support the ship recycling facilities. However, none of these studies were focused on the optimization of the ship recycling processes. Alkaner et al. (2006) worked on the ship recycling yard planning through taking the multi-dimensional and multi objective nature of the problem into account. Alkaner et al. (2006) used discrete event simulation and the principles of shipyard development in order to find the optimum ship recycling yard layouts for different methods. However, the layouts in the paper are generic and it is hard to implement the methodology for different scenarios. Pylarinou et al. (2009) developed a web based tool in order to support the decision making on the planning of ship recycling processes. The proposed system uses -event simulation models which was also proposed in authors' other papers (Koumanakos et al., 2006) (Charalambia Pylarinou et al., 2008). Using the tool, yard owners can simulate the recycling process to see costs and time allocated to the recycling of the ship. Tool simulates the recycling process according to yard owners input data. The proposed system in the study is user friendly and there is no expertise on simulation is required. Ship owners are able to see their options of recycling yards with environmentally safe and cost effective methods. Tool is good for estimation, however, using the tool it is not possible to optimise the production process of a ship recycling.

3. Methodology

The methodology followed in this paper is summarized in Figure 1. The methodology used consists of seven basic steps. The first step of the methodology was to investigate the case study yard in order to identify the problems in the system and to find the opportunities. As a second step, system was formulated with a simple conceptual model to identify the data needs as well as to set a basis for the ARENA model. In the third step, a data collection study was conducted identify the inputs to the simulation and current performance of the ship recycling yard. Then the ARENA model was developed using the conceptual model and collected data from previous steps. At this step it is important to verify that the simulation model executes as intended. In the final step, the analysis of the current and the alternative scenarios for the system were run in the ARENA software and performances of these scenarios were compared.

Fig. 1 Representation of the methodology followed in this study

3.1. Investigation of the yard

3.1.1. Introduction to the Selected Ship Recycling Yard and Ship Recycling Process Followed

In this paper, a ship recycling yard in Europe has been selected as a case study (which cannot be named due to confidentiality). The initial estimation of the investors for the yard is to recycle 60000 tons scrap volume yearly, in other words, 12 medium size vessels of 5.000 t. Current process flow of the yard is simplified and represented in the Figure 2.

Fig. 2 Simplified process flow of the case study yard

The yard has a quay and a ramp to handle the preparation for recycling and primary cutting of the end of life vessel. In the quay area, ship is cleaned from the hazardous materials and all the removable equipment and machinery are removed in this stage so that the ship is lightened and can be towed up the ramp where hull will be cut for smaller pieces and transferred to secondary cutting areas with crane.

Once the blocks are cut on the previous stage of the dismantling, there are transferred to the secondary cutting zone for further dismantling. The main purpose in this step is to cut the steel for smaller pieces to facilitate easier transport to the steel mills. The yard in question prepares the plates with maximum dimensions of 1 meter in length, 0.5 meters in width and 0.5 meters in height. Similar to the previous step, shear cutters, oxy-fuel cutters and other methods are used. During cutting operations separation of metal and other non- hazardous materials are done as well as classification and storage of waste removed from the primary cutting in the quay. Classification of scrap metals as steel and non-ferrous. Also, all waste, materials and equipment will be placed separately and prepared for further processing and treatment.

3.1.2. Staff in the yard and their roles

Currently there are three cutting teams in the ship recycling facility. Each of these teams has one cutter and one helper. In the beginning of the dismantling operation, all teams are located in the primary cutting zone. But once the blocks starts to be transferred to the secondary cutting zone, teams switch to the secondary cutting zone depending on the number of blocks in the secondary zone. Blocks are transferred to the secondary zone with crane as mentioned before and crane operator is employed in the yard for crane operations as well handling and loading small pieces with polygrab.

3.1.3. Identification of the problems

Even though there are simulation studies in the ship recycling area, literature is very limited. There is a need for a study to improve the efficiency of the processes. As mentioned before majority of the ship recycling capacity is currently located in the developing countries. Thus the ship recycling processes followed is not organized. Furthermore, the processes followed, especially in South Asia, are criticized by the regulatory bodies, non-governmental organizations, public and local people due to the damage caused during these practices. One of the most performed activities in the ship recycling yards is the cutting of the steel. During this process oxy-fuel torches are being used by the workers due to the very low investment cost, low training need and ease of operation. However, especially in the secondary cutting zone, performances of the cutters are very low. Thus in the observed ship recycling yards, secondary cutting zone was mostly the bottleneck of the system. When the area capacity of the secondary cutting zone is reached, production in the primary cutting zone has to be stopped as the blocks is transferred to the secondary zone once they are cut in the primary zone. This causes delay on the clearance of the primary zone for the new ships which in long term decreases the capacity of the ship recycling yard. The summary of the problem that causes slow production is given in Figure 3 to help the reader to get a clearer picture of the situation.

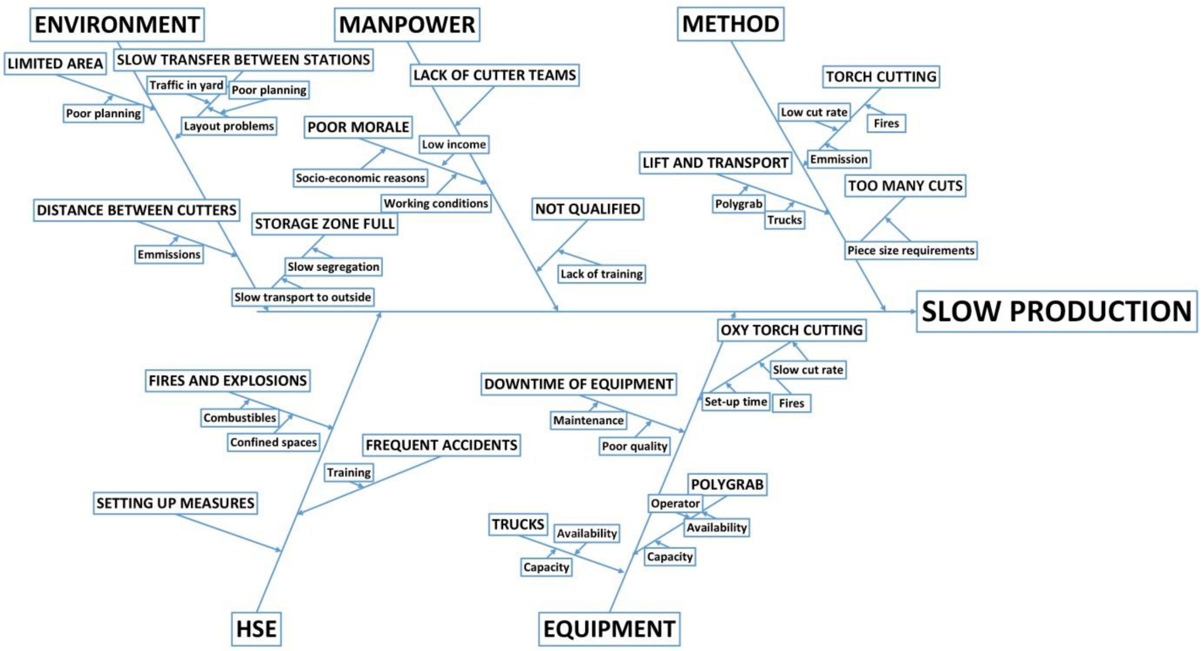

Fig. 3 Problems that affect the productivity

The problems that are affecting the productivity was analyzed under five areas; environment, manpower, method, equipment and HSE.

The main cause of the problem can be considered as the manpower. First, in the question yard, number of the cutting teams, three, is very low in order to reach the capacity goals. Workers switch between primary and secondary zones, however, current numbers limits the secondary zone productivity.

Second important problem is the method used. Torch cutting is mostly used in the current process to cut the steel into smaller pieces. The main aim of cutting the steel plates to smaller pieces not only transportation but also to fit the requirements of the steel mills. As mentioned before, mill requires the plates with the maximum dimensions of 1 meter in length, 0.5 meters in width and 0.5 meters in height. However, the size limit of the mill increases the number of cuts which increases the overall time and resource consumption. The alternative mills should be considered as a solution. Also, due to the low cut rate of the oxy-fuel torch, this method slows the production line. Some of the steel sections are covered with oil, fuel and other combustibles, therefore, small fires due to the torch cutting are very common in ship recycling yards. Also due to the emission during the cutting job, workers need to stand with distance to each other. Pre-treatment of the surfaces can be considered as a solution for this problem.

In the environment part, most important criteria is the size of the individual areas. During the planning stage of the yards, it is often neglected to plan the cutting areas fit-for-purpose. Most of the time, secondary cutting areas are designed smaller than it should be which causes the production to stop in the primary cutting zone, as there will not be space to put the blocks for further cutting. Another problem is the slow transfer between the stations. Other than the planning issue, another cause of this is the capacity of the transport equipment. In the question yard, it was observed that the number of the transport equipment was causing the problem. In the yard, there is a fixed crane in the place with 60 tons capacity for transfer from primary to secondary zones. Once the materials are segregated after the cutting step, they are transferred to the mills with trucks. This transfer step is done with polygrabs or excavators with magnetic attachments. In the yard that is investigated in this study, polygrab is used for this task. Yard in question has only one Polygrab with 20 tons capacity. Unfortunately, current capacity of the lifting equipment limits the ship recycling yards production. Also, there is only one staff that can operate the crane and Polygrab which is also another parameter that will be investigated to increase the performance. Moreover, number of the trucks is also another criterion that can be looked at to increase the capacity.

In this article, a feasibility study using discrete event simulation was conducted in order to address the above mentioned problems. Amongst these problems number of workers, capacity of the lifting equipment and layout of the yard are selected as the parameters of this study due to the ir to increase the performance of the ship recycling yard. Different combinations of worker numbers, equipment types and numbers, cutting technologies were tested combined with surface cleaning technologies.

3.2. Formulation of the Model

For this study, a 59 meter barge is selected as a case study in order to have simple simulation. Overall length of the barge is 59.36 meters, beam is 10.61 meters and the depth is 3.72 meters. A recycling plan has been prepared for the barge with the shipyard's technical team. For the simplicity, blocks of the barge were splitted into five different groups; two different fore blocks, side blocks, aft blocks and double bottom blocks. After this initial study in the ship recycling yard, process in the yard is simplified and representation of the process is given the Figure 4. After this step, requirements of the data to model the operation have been data identified and a data collection study in the yard was conducted.

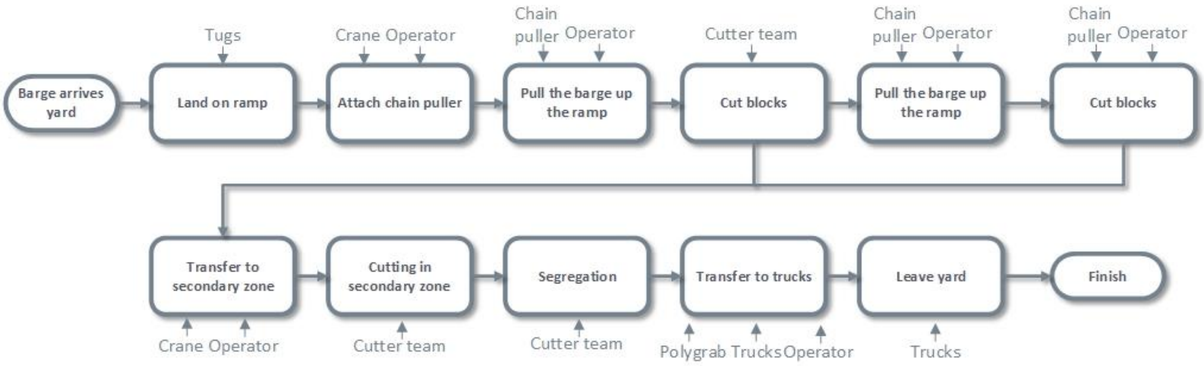

Fig. 4. Simplified model structure

3.3. Data collection study

A data collection study has been conducted in the yard. Current operation times of cutting the different blocks with different steel thicknesses and structural elements (plates, profiles and fittings etc.). Also, cutting positions of the workers (downhand, side or overhead) were also taken into account. In addition to the cutting data, other operational data such as the number the crane loading times, Polygrab loading times, transfer times of the blocks were recorded during this study. Also, cost data relevant to this specific operation was also collected in order to conduct a cost-benefit analysis.

3.4. Translation of the model to ARENA

After the conceptual model and data collection, model was translated into the computer environment using the ARENA Simulation software. To simplify the flow, model was organized into four different submodels; preparation for ship recycling, primary cutting zone, transfer and cutting in secondary zone and transfer to trucks and leave yard.

In the preparation for ship recycling part, the arrival of the barge to the yard, landing, attaching the puller mechanism and pulling the barge up the ramp is included. After this step, simulation continues with the operation in the ramp, i.e. primary cutting zone. In this area, blocks are first separated from the hull and attached to the crane to be transferred to secondary cutting zone. In the secondary cutting zone, blocks are further cut into smaller pieces into the transferrable parts where they are afterwards loaded into the trucks with Polygrab. The carrying capacity of the trucks limits the transfer of the blocks; therefore, three blocks can be carried at a time. The barge has been split into the five different groups of blocks, in total of 30 blocks, due to the carrying capacity limit of the crane and health and safety requirements.

4. Results

After the simulation model is created and data collected were identified to the system as input, the model was run for 100 repetitions. In the current case of the yard, selected barge is dismantled around 300 hours, which is approximately 13 working days (For the workers, a schedule has been created where the working hours are 8.00-17.00 with one hour break during noon). In the current production, there are only three cutting teams and one operator who is responsible of both the polygrab and the crane which creates two bottlenecks, secondary cutting zone and the loading into the trucks. Since the cutting team is limited, once the parts are transferred to the secondary cutting zone, each block has an average waiting time of 40 hours as the cutting teams are focused to the block cutting in the primary cutting zone. In addition, polygrab operation is slow, dependant of the availability of truck and the crane operation has more priority. Following recommendations can be made for the yard,

- Current cutting size of the scrap steel is too small and creates too many cuts, therefore increases the overall time. Bigger size of scrap steel such as 1 meter in all lengths for transport can be considered. The difference in the offer between 1 meter and 0.5 meter scrap blocks should be compared with the extra expenses that the 0.5 meter cutting creates.

- Number of cutting teams should be increased in order to avoid the queueing problems in the secondary zone.

- It could also be beneficial to employ one more polygrab/crane operator to avoid the bottlenecks in the loading to the trucks stage.

As a next step, the recommendations discussed above were applied to the current model. As a first step, the cutting size of the scrap steel was changed. When the plate size is increased to 1 meter (new case) from 0.5 meters (current case), the overall dismantling time of the barge reduces to approximately 210 hours (Fig 5.). The decrease in the time for the new case is important, however, the most important difference is in the use of torch, which is around 50% lower compared to the current case. This means, the new operation generates 105 kg less CO_2 compared to the initial case (Considering that the 1kg of LPG burnt generates 3.023 kg of CO_2 (Deshpande et al., 2013)). Only disadvantage of the bigger pieces is that the some mills offer lower price per ton for this scenario, however, this can also be neglected as in this case the overall reduction in the production time balances the loss due to the low offer per ton.

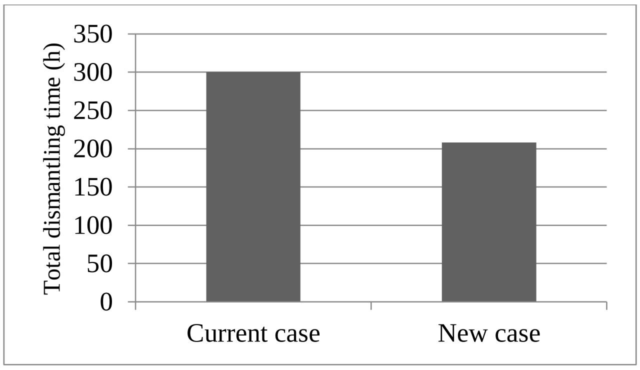

Fig. 5. Comparison of production time for different scrap steel sizes

Secondly, the number of cutting teams were increased to five as previously planned by the yard. Increasing the number of the workers shortens the production time to 192 hours, which is 8 working days, it is important to compare the cost of the workers to the revenue. Even though this change in the number of workers increases the yards worker cost by 60%, in the long term the annual revenue of the yard increases by 40% (increase in the staff cost will be 7% of the new annual revenue). Comparison of the total dismantling times for different cutter numbers is shown in figure 6.

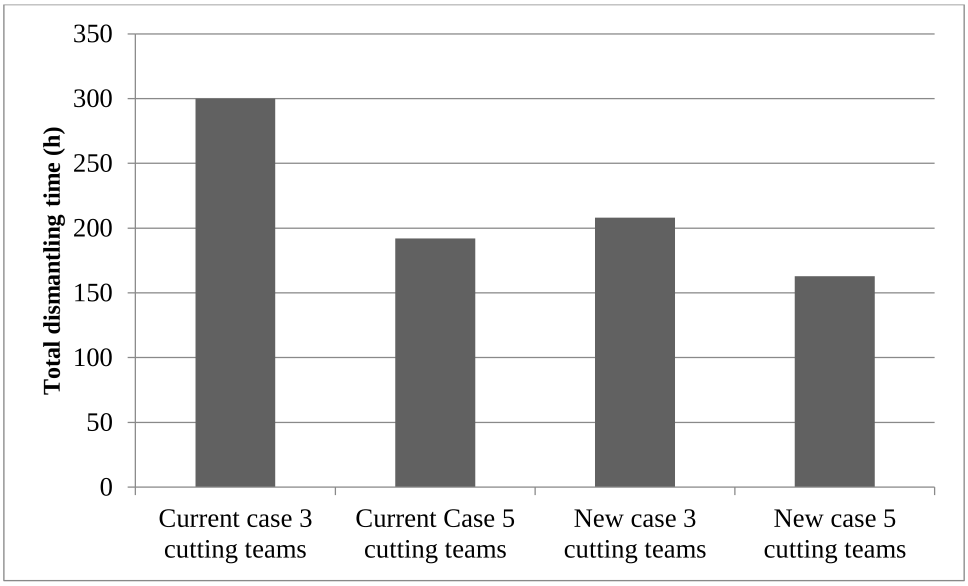

Fig. 6. Comparison of production time for different team sizes and steel sizes combined.

Lastly, employing one more Polygrab/crane operator while keeping the cutting teams as it is, slightly decreases the production time (to 281 hours). This slight improvement in the recycling capacity, increases the overall revenue by 7% when the costs are reduced from the overall gain.

5. Conclusions

The costs of the ship recycling yards will increase as the result of the “Hong Kong Convention” and “European Ship Recycling Regulations”. This increase in the cost can be mitigated by optimizing the practices in the yards. However, in the literature, there is no study that focuses on the productivity improvement of the ship recycling yard. Therefore, this study has focused on increasing the efficiency of primary and secondary zones in a selected ship recycling through simulation approach. Also, there is a need for a framework to optimise the production of the ship recycling yard that is easy to use-even by anyone that has no simulation knowledge. This can support the industry, especially the industry in EU where the costs of the ship recycling yards are higher due to the high worker costs and laws and regulations. By increasing the productivity and reducing the cost, European ship recycling yards can be taken to a level to compete with the ship recycling yards in South Asia.

A barge was selected as a case study and different parameters that can affect the productivity in a ship recycling yard was put into test compared with the current situation. The overall aim of this study was to demonstrate that the discrete event simulation can be a powerful tool for the productivity problems in the ship recycling yards. In the case study shown in this study, only with the improvements in the primary and secondary cutting zones more than 30% decrease in the operation time which leads to 40% increase in the annual revenue was achieved.

In addition to the production times, more efficient yards can also mean energy efficient yards. This case study shows that with a slight change in the ship recycling method, around 50% less torch time has been achieved. If 105 kg reduced CO_2 production (as a by-product) can be achieved in a small case study, in the bigger picture so much more can be achieved. There is a need for a full-scale study in order to show the benefits discrete event simulation can provide in the long term taking all the parameters identified in the figure 3 including the area planning into account.

As a future study, full optimisation of a different ship recycling zones can be conducted using the discrete event simulation methodology. The different technologies that can be used in ship recycling tasks should be tested in a full scale ship recycling yard. Moreover, other operations those use tools such as saws, mechanical shears, hand held shears can also be taken into account. Apart from the technologies, using the discrete event method, the yard planning can be conducted to find the optimum layout for improved productivity and decreased transport times in the yard.

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