Material Flow Analysis Technique for Material Assessment of Ship Recycling Industry

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Abstract

Ship recycling is a viable engineering process of recovering shipbuilding materials by dismantling end-of-life (EOL) ships in a profitable and safe way. There are few dozens of ship-recycling yards existing along coastal belt at Chattogram of Bangladesh. The local ship recycling industry provides the country's main source of steel, recondition equipment and machinery. The industry creates the opportunity of employment, generates revenues for government and contributes to the national shipbuilding industry. This industry promotes economic development for this country. At the same time, the negative image such as environmental pollution, health hazards and few accidents bring major challenges that should be overcome for the constancy of this industry in the long run. There are limited studies that have been found and most were based on preliminary and secondary baseline data analysis. The economic study of the local ship recycling industry particularly the recovery of reusable material and waste material generated from the ship recycling industry was derived on the basis of benchmarks from other countries. As a result, the policy-making decision based on those studies is not technically sound. From this perspective, the paper will discuss the viable economic assessment technique for ship-recycling process by taking help both from existing literature and from other similar industry; justify the sustainability of material flow analysis (MFA) method for calculating the reusable material for local yards; apply the method on actual ground by feeding realistic situation and data. In this research work, more than one dozen shipyards have been selected to accumulate the data for a quite substantial period of time for various types of ships generally handled by the local ship breaking yard in Bangladesh. The study could be helpful for all stakeholder and policymakers who are related with local ship breaking yards of Bangladesh.

Keywords: Shipbreaking, Recycling, Reusable Materials, LDT.

Introduction

Ship recycling is a viable engineering process of recovery shipbuilding material by dismantling end-of-life (EOL) ships in a profitable and safe way. Ship recycling activity was concentrated in industrialised countries mainly USA, UK, Germany, Turkey, etc. until the 1960s. But from the early 1980s, old ships are coming for recycling to India, China, Pakistan,

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Bangladesh and other East Asian yards where health and safety standards are minimal and workers are desperate for work. There are around 150 registers (actually exist around three dozen) along coastal belt at Chattogram of Bangladesh. The local ship recycling industry provides the country's main source of steel, recondition equipment and machinery, it creates the opportunity of employment, generates revenues for government and contributes to the national shipbuilding industry. No doubt this industry promotes economic for this country. At the same time, the negative image such as environmental pollution, health hazards and few accidents bring major challenges that should be overcome for the constancy of this industry in the long run. The restraining nature of the industry is the main problem. As a result, the actual situation, on ground data collection and the actual output of the industry is never assessed extensively. The true fact is that a very few studies have been found so far but mostly those were based on limited preliminary baseline study or secondary data analysis. Even recently, the Ministry of Industries through Safe and Environmentally Sound Ship Recycling in Bangladesh (SENSREC) Project made some studies on economic contribution and hazardous impact assessment and environmental impact on ship breaking industry in Bangladesh. The major limitations of the studies were that they were not based on field data; rather the inventory of hazardous wastes from the ship recycling industry was derived on the basis of benchmarks from other countries. For those, the assessment result is questionable and so any policy-making decision based on the study is not technically sound as it did not follow a standard way and techniques for the vessels that were usually handled by the local ship breaking yards of Bangladesh. On the other hand, Shipbreaking is a global industry and because of the changing socio-economic scenarios of the world, it is necessary to develop the industry in such a way that it is stable in the long run. To fulfil both aspects, extensive study is necessary which will be useful to develop a viable and sustainable recycling method or technique through estimating and calculating reusable and waste material from the different types of EOL ship by achieving both international standards for Health Safety and Environment (HSE) and total quality management (TQM).

It is a research paper and which will discuss the viable economic assessment technique for ship recycling process by taking help both from existing literature and from other similar industry; justify the sustainability of material flow analysis (MFA) method for calculating the reusable material for local yards; apply the method on actual ground by feeding realistic situation and data. In this research work around one dozen recycling yards have been selected to accumulate the data for various types of ships generally handled by the local ship breaking yard in Bangladesh. Data collection format has been designed segregation all the materials from ship breaking into metal and reusable items. After processing all data collected from different shipyards, the amount of actual output of reusable material including component and waste materials have been calculated for different types of ships. Again material flow analysis (MFA) technique has been applied to analyse and plan the ship recycling process so that the ship recycling yards can be managed in a better way by appropriately handling waste and resources. The study could be helpful for both policymakers and stakeholders who can able to assess the actual output in terms of both reusable and waste materials generated by local ship breaking yards of Bangladesh and they can plan to achieve some minimum standard to become stable in the long run.

Outline of the Methodology/Experimental Design

It is a research work to determine viable economic assessment method for ship recycling process and justifies the sustainability of material flow analysis (MFA) technique for calculating the reusable material for local yards and applies the technique on the actual ground by feeding realistic situation and data. Those data have been collected by authors from physical involvement in the local recycling yards since the last six years. For data collection, necessary help has taken from different stakeholders including yard’s owners and Bangladesh Ship Breakers Association (BSBA). Output and results will be based on actual and on ground data and take considerable help/guideline from the methodology followed in the available literature. This paper will discuss the viable economic assessment technique for ship recycling process and determine the reusable material calculating sustainable tools of local yards on the basis of on ground situation and data. More than one dozen shipyards have been selected to accumulate the data for a quite substantial period of time for various types of ships generally handled by the local ship breaking yard in Bangladesh. The basic data of this research work are all types of reusable materials and component including hazardous materials of different types and size of more than two dozen of EOL ships dismantle in Bangladesh and shown in table 1. It is to be mentioned here that average complete dismantle time for an EOL ship may vary from 6-9 months in case of many local ship breaking yards in Bangladesh. For data analysis, calculation and determination of numerical values both material flow analysis (MFA) software STAN and Microsoft Excel have been used. However, nuclear waste and other releases, such as emissions of atmospheric pollutants and diffuse emissions of pollutants to the water, will not include in the scope of this research work. In case of missing or unreliable data, benchmarks available in literature will be used for calculations and development of the assessment model.

Table 1: Summarised fact and figure of sample Recycle EOL ships in Bangladeshi yards.

SN	Ship Category/Type	Sample Ships	Range of LDT	Manufacturer /Build Year
1	Bulk Carrier	5	11834 to 21592	1978 to 1986
2	Tanker	5	11182 to 29324	1981 to 1989
3	Cargo	5	5008 to 18302	1984 -1990
4	Container	6	6698 to 16053	1977 to 1992
5	Other Ships	5	5625 to 25997	1966 to 1981

Present Global and Bangladesh Ship Recycling State

Ships are generally removed from the fleet after the end of life (EOL) through a process is known as ship recycling or scrapping. Ship owners and buyers negotiate scrap prices based on few factors; ship's empty weight or LDT and prices in the scrap metal or recycle market. The world-wide ship recycling industry dismantles average 1000 large ocean-going vessels per year, such as container ships, cargo & bulkers, oil & gas tankers (LNG, LPG), passenger ships and other types of ships, in order to recover steel and other valuable metals or recyclable items. However, at present, almost all ship recycling activities are concentrated in five countries: the three South Asian countries (India, Bangladesh, China and Pakistan), China, and Turkey. Further capacity is available in North America (US, Canada, Mexico) and within the European Union (amongst others Denmark, Belgium and UK). At present, South Asia is undoubtedly the global centre for ship recycling activities. Global major recycling yards are located in India, Bangladesh, Pakistan, China and Turkey. These countries are main ship recycling centres in terms of annual lightweight tonnage (LDT) recycled. The ship recycling yards compliant with either the international standards for HSE management or the ship recycling regulations such as Hong Kong convention and EU ship recycling regulation are considered harmless to the environment, health and safety of the workers. The annual global capacity of green recycling was around 780,000 LDT in 2012.

A total of 933 ships of a combined 44.4 million DWT were scrapped in 2016. In 2016, Bulker and containership recycling activity was very strong and accounted for 65% and 18% of total demolition respectively in terms of DWT. Bangladeshi recycling yards shared 31% of world demolition and that was decreased from 35% of the previous record. In term of DWT, Bangladesh still represented the largest share of demolition activity as they scrapping 199 vessels of a combined 13.6 million DWT in 2016. On the other hand, Indian yards experienced a recovery after a comparatively slow 2015, with 340 ships of a combined 12.5 million DWT recycled in 2016. This led Indian share of total demolition to rise from 20% in 2015 to 28% in 2016 in DWT. Other potential shipbreaking countries are Pakistan, Turkey, China, Denmark and Belgium. Major shipbreaking countries and their share in no of EOL ships and year of built of scrap ships recycle in 2016 have been shown in fig 1 and 2 respectively below.

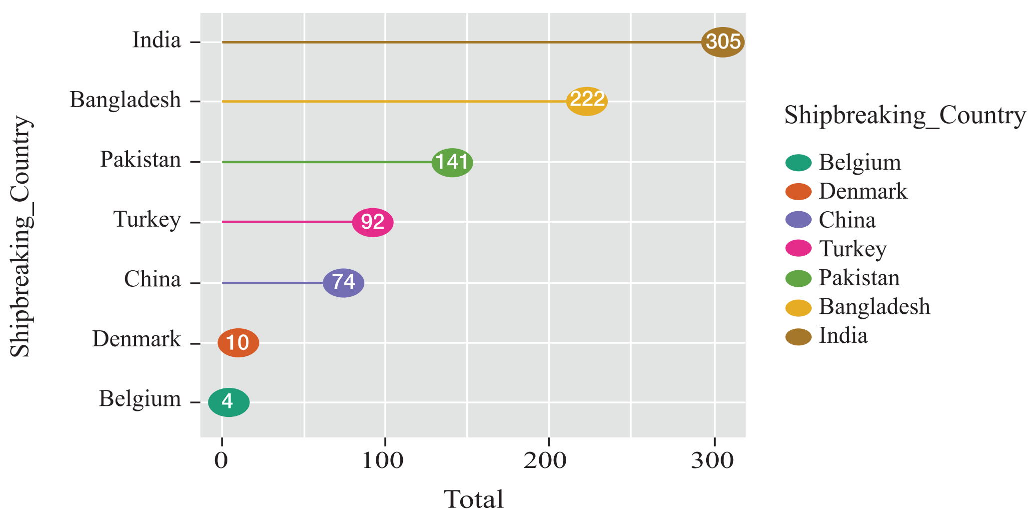

Figure 1: Major ship recycling countries of the world in 2016.

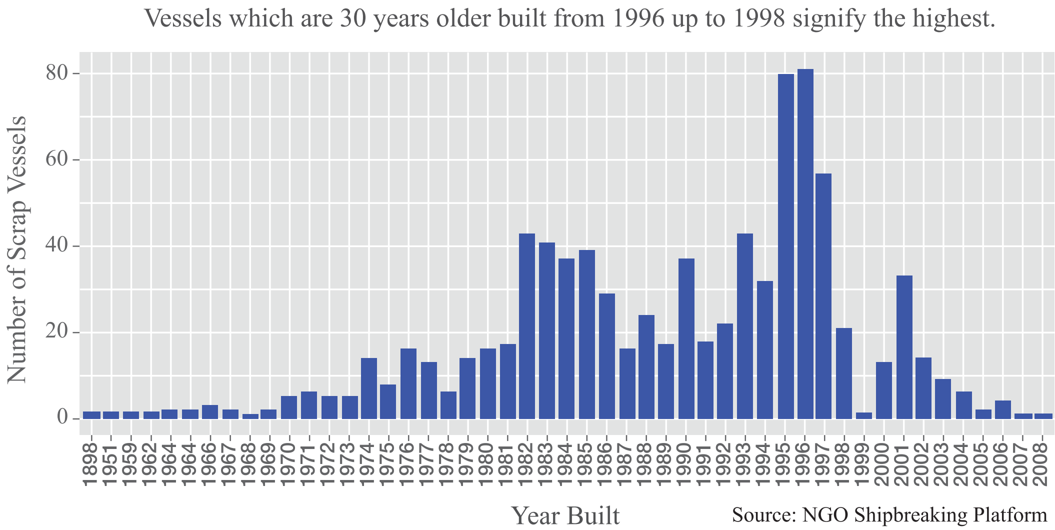

Figure 2: Year of built of scrap vessel recycled in 2016.

In Bangladesh, an average of 200 different types of obsolete ships are recycled annually in different yards located in Chittagong. Those different types of ships are the bulk carrier, tanker, container carrier, cargo carrier, passenger or ferry, refrigerator ship, LPG, LNG, floating pontoon/restaurant, and other different types of ships. In fig 3below, the total number of different types/category of ships recycled annually in Bangladesh between the years 2009 to 2015 has been shown. Again, from on-ground statistics of ship recycling yards of Bangladesh, we can see that average 2,000,000 Light Dead-Weight Ton (LDT) different types of obsolete ships are recycled annually in different yards in Bangladesh. In figure 4 below, total LDT of different types/category of ships recycled in Bangladesh between the years 2009 to 2015 has been shown. Reusable material factor and average materials output per year has been shown in table 2 below.

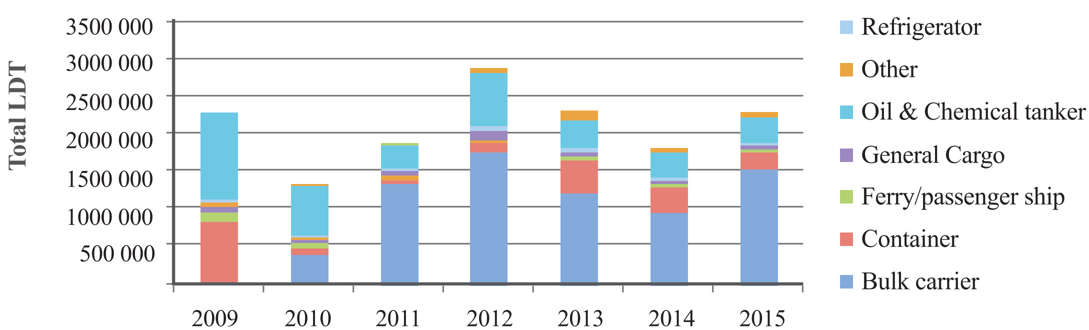

Figure 3: Total LDT of ships recycled in Bangladesh by type/category (2009 to 2015).

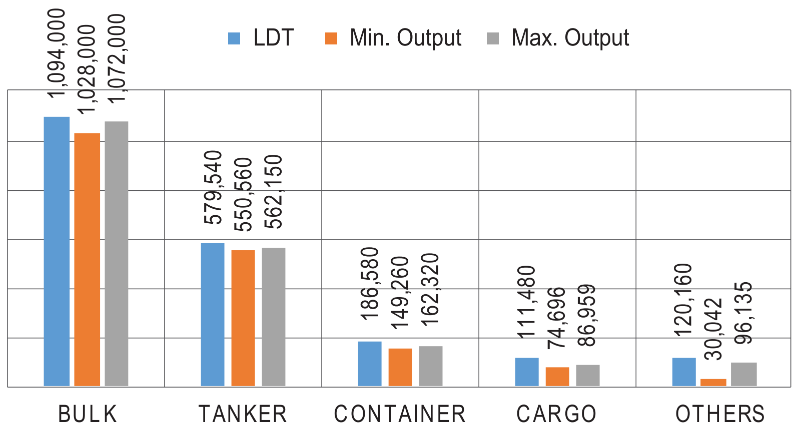

Figure 4: Average annual LDT vs average annual reusable material output (2009 to 2015).

Table 2: Reusable material factor and average materials output per year (2009 to 2015).

SN	Type of Ship	Average LDT (MT) per year	Reusable Material Factor (%)		Average Reusable Material per year (MT)
1	Cargo	111,486	0.67	Min.	74,696
			0.78	Max.	86,959
2	Bulk Carrier	1,094,566	0.94	Min.	1,028,892
			0.98	Max.	1,072,675
3	Tanker	579,542	0.95	Min.	550,565
			0.97	Max.	562,156
4	Container	186,583	0.8	Min.	149,266
			0.87	Max.	162,327
5	Others	120,169	0.25	Min.	30,042
			0.8	Max.	96,135
6	Total	2,092,346		Min.	1,833,461
				Max.	1,980,252

Ship Recycling Management Technique and the State of MFA

MFA as an Analytical Technique: The author of this article gathered inspiration from both operations management and environmental engineering to implement a well-known technique to improve the ship recycling industry. Therefore, this article reviews the analytical technique of both domains. This article concludes that MFA, an analytical tool used in environmental engineering, is the most practical tool for calculating material output from the ship recycling industry. The methodology and input data for carrying out MFA on a ship recycling yard has explained in brief. In this research work, the MFA is implemented using two dozen different types and size of EOL ships. The article also explained the importance and shortcomings of applying MFA to the ship recycling industry.

Operations Management Technique: Operations management is the methodical planning, execution and control of operations. Operations are a total term that includes services and manufacturing. Operations management involves scheduling work, assigning resources, managing inventories, assuring quality standards and process-type decisions such as capacity decisions, maintenance policies, equipment selection, worker training options and the sequence for making individual items in the product-mix set. In the last few decades, due to significantly increased levels of competitiveness in the modern industry, a range of methodologies and techniques aimed at improving the performance, productivity and profitability of the operational activity have been developed. These techniques can be broadly classified into two main categories: diagnostic tools (process mapping, process flowcharting, value stream mapping, pare to analysis, fishbone diagrams, etc.) and improvement tools (just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM), theory of constraints (TOC), business process reengineering (BPR), etc.). A wide variety of such management practices, methods, tools and techniques are encompassed under a production approach called lean manufacturing, based on the Toyota Production System.

Manufacturing and Production Technique: It involves the transformation of inputs (labour, machines, and materials) into desired goods and services. The inputs are combined by the process, often including many sub-processes, resulting in the production of units of goods or the creation of types of services. Ship recycling is a one-of-a-kind production system where the inputs are the ship, labour and equipment (such as cranes, gas torches, forklifts, etc.) which are transformed into outputs (such as ferrous scrap, non-ferrous scrap, re-usable items, waste, etc.) as a result of various processes, such as pre-cutting, cutting and post-cutting. Lean thinking has been successfully applied to the industries where inputs are transformed into outputs. This includes the manufacturing, healthcare, construction and process industry. However, it needs to be investigated further whether lean and other aforementioned tools can be implemented to improve sustainable and effective ship recycling process.

Lean Manufacturing Technique: The starting point of lean manufacturing is to identify measure and eliminate ‘waste’ from the system to improve its performance. ‘Waste’, in the context of lean thinking, means any activity in a process that does not add value to the final product. The most sought after areas of improvement using lean tools are inventory and quality management because both these areas significantly drive down the costs in a normal production system. However, their application to the ship recycling industry is not feasible because the high fluctuation in demand and supply on both the input and the output side of the ship recycling process and the quality of the finished product of ship recycling i.e. scrap does not depend much on the ship recycling process. Instead, it depends on the construction, operation and maintenance of the ship.

Diagnostic Technique: The diagnostic technique like as process mapping can be useful in understanding the basic ship recycling process and identifying the problem areas. It can be targeted both for developing and make sustainable ship recycling process and to improving the entire ship recycling industry. In any industrial process usually, there are three types of flows. Such as information, product and resources. The information flow contains the technical data controlling the operation itself. The product flow is initiated due to the transformation of raw materials into delivered products as a result of the industrial process. The flow of resources includes the people and means required to make the product. Resources must enter the system and leave the system as 'used' resources. The product flow or the flow of materials is the most critical flow because it influences the revenue generation and the cost factors of a ship recycling process. That's why a process mapping tool that focuses on material flow is ideal for analysing and improving the ship recycling process.

Improvement Technique: For ship recycling industry application of improved technique can be helpful. As an example; a technique to improve the efficiency and effectiveness of people, equipment, space, time and energy can result in reduced costs and increase profits. Such technique can help re-engineer the ship recycling process to utilise the resources (such as labour, machinery, cranes, equipment, etc.) further up the economic hierarchy of materials to extract as much value from the EOL ship as possible. However, in the case of sustainable ship recycling, a yard must also employ resources to handle the materials which are lower down the economic hierarchy (such as hazardous materials) as it improves the environment and the workers' health as well as safety.

Operations Management Technique: It presents a limited application within the 'green' ship recycling industry due to its unique challenges as discussed earlier. However, the environmental engineering technique might be more suitable for the ship recycling industry because this industry handles EOL ship's products having hazardous materials. Hazardous materials need proper treatment and disposal to protect human health and the environment in a workable process.

Environmental Engineering Technique: It is the learning process concerning the management of natural resources and the reduction of pollution and contamination of the environment caused by anthropogenic activities. Environmental studies require a thorough understanding of the material flows within and between the environment and the anthropic area. For this purpose, a tool based on the mass balance principle and system analysis called material flow analysis (MFA) has been developed. MFA is an analytical technique of systematic assessment of flows of materials within a complex system defined in space and time. MFA is applied in different fields such as environmental management, industrial ecology, resource management and waste management. An MFA can also contribute to the design of better products that can be easily recycled once they become obsolete and turn into 'waste'. MFA can potentially be used by production, manufacturing and commercial entities as a standard analytical technique in decisions on materials management to locate and examine inputs, outputs and source of waste materials. So, MFA can be a suitable technique to analyse and subsequently improve the ship recycling process.

Consideration: Two aspects must be considered before applying MFA to a ship recycling yard. (1) From a systems perspective, an analysis of a ship recycling yard is a micro-level analysis; nation or economy-wide analysis being the macro-level; while local (city, river lake, basin) analysis being the meso-level analysis (2) From the environmental management perspective, a ship recycling yard is essentially a waste management system managing EOL ships. MFA is applicable for waste management on any system defined in space and time, from both a treatment process plant and up to a nation. Moreover, the applicability of MFA in waste management as a decision support technique as well as a micro-level system flow mapping tool is very well documented.

Importance of MFA and Its Software STAN: By using the software STAN an MFA can be carried out. STAN is useful not only to produce a graphical representation of a waste management system but also to determine the types of materials that flow into, within and out of the system. MFA can help both to manage the waste in such a way that the recycling process is not threatening to human health as well as the environment and at the same time, to assists resource conservation as well as allows segregation of non-recyclables from recyclables so that inappropriate disposal strategy (landfill or energy recovery) can be implemented. I consider the waste of a ship recycling yards as any substance, material or object originating from dismantling an EOL ship and is required to be discarded and disposed of appropriately in accordance with applicable laws, regulations and management standards. An MFA applied to a ship recycling yard on an EOL ship and that can help determine the flows of materials through each stage of the recycling process. A known material flow for each ship can help a recycling yard determine the required number and capacity of resources (such as cranes, forklifts, machinery, etc.) for each step of the recycling process, earning a potential of each material stream, and the scale of waste generated during the recycling process. Such parameters can assist in developing a detailed plan of recycling a ship by increasing the efficiency of resources and by using effective waste management strategies which is friendly to human health and the environment. In fact, waste management strategies such as 'waste to energy' and optimum collection of reusable material for any recycling yards willing to invest in advanced technologies that are suitable to handle the heterogeneous waste generated by recycling of ships. The results of an MFA study can help determine the technical and economic feasibility of such capital intensive, advanced waste management technologies.

The Advantage of MFA: There are many advantages of using MFA. Such as; an analysis technique in a ship recycling yard. However, the quality of results depends on the quality of the input data. Data collection has historically been a problem in the ship recycling industry, because of uncertainty and disbelief among recycling yards and a lack of coordination among the various stakeholders. On the other hand, since research in this field of study is still in its preliminary stage. Various authors have discussed this issue of unavailability of data hampering the research in ship recycling. However, the author discusses above, the methodology to collect data and carry out MFA on local ship recycling yards. It is a better technique to determine and calculate reusable material and waste output of any EOL ships. It is a viable option for any recycling yards to economic assessment and determines the benefit of the recycling process.

Methodology and Input Data for MFA: For carrying out an MFA on any ship recycling yards, following steps need to be followed. It can start with defining the space and time boundaries of the system. Then, the reusable material composition of EOL ship(s) must be determined. At the same time, the waste material composition of EOL ship(s) to be recycled and disposed of must be determined. Then, various steps of the ship recycling process must be recognised. Then, flow diagrams can be created using suitable or open source software like

'STAN'. Finally, the flow diagrams need to be analysed. The flow diagram has been shown below in fig 5. Again, the feedback to design phase of the ship's life cycle has been shown in fig 6 below.

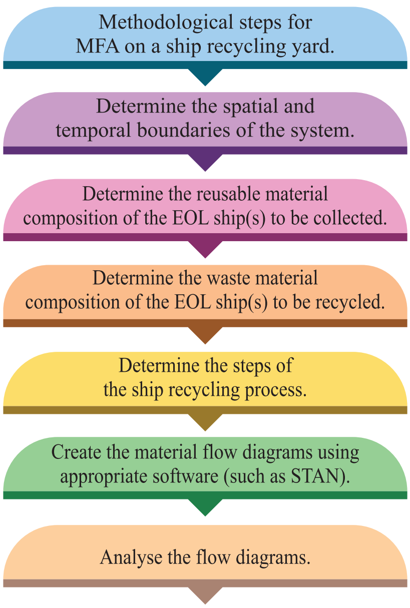

Fig 5: Methodological steps for MFA on a ship recycling yard.

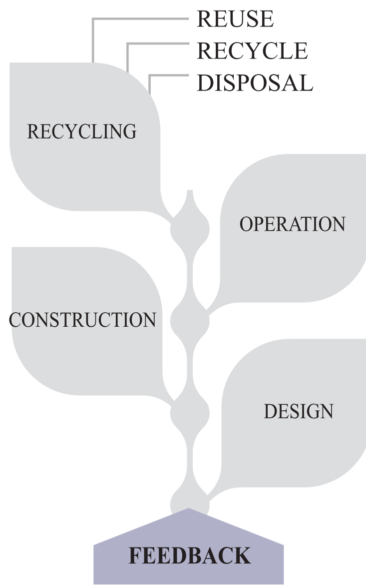

Fig 6: Feedback to design phase of the ship's life cycle.

Spatial and Temporal Boundary: The spatial boundary of an MFA for ship recycling can range from all world-wide ship recycling yards to a single ship recycling yard. The temporal boundary can range from a few years to a single day. The choice of spatial and temporal boundaries depends on the objective of the MFA. In this article, since the objective of MFA is to make sustainable recycling process for local recycling yards which can carry out an MFA on each ship it will recycle to determine the areas of improvement within the recycling process. Therefore, the spatial boundary is the recycling yards themselves while the temporal boundary is the time required to complete two dozen recycling project (around 26 types and size of different dismantled ships).

Quantification of the Material Composition of EOL Ships: The study carried out by Jain and his team determined that out of the nine studies available on the quantification of material composition of EOL ships, none present a methodology that can be used by the ship recycling yards to determine the material composition of an individual ship. Therefore, they presented a methodology which determines the material composition of a 2006 built 11044 T lightweight bulk carrier on the basis of its lightweight distribution provided in its stability manual. The material composition of the case ship calculated by Jain and his team does not contain the values for the material stream 'liquids, chemicals and gases' (LCG) because they considered that the most of the LCG material stream is operationally generated and is not part of the ship's lightweight. The material composition of the case ship corrected for LCG material stream is compiled and the value for LCG material stream is taken from a study carried out by Andersen for a bulk carrier. But for this article author consider realistic data taken by him from more than one dozen local yards of 26 different types and sizes of EOL ships since last six years. The more interesting fact is that different types, categories and size of EOL ships have been selected from different local yards to make the study more authentic and realistic. The general and exclusive data, analysis, result, graph and output has been described in detail in my PhD research work.

Optimum Steps and Phases of MFA Technique

Steps of the Ship Recycling Process: The required number of feasible steps needs to be finding out of an MFA on a ship recycling yard to determine the optimum steps of the ship recycling process. Though ships are recycled by employing different docking methods (i.e. beaching, slipway, alongside and dry dock) in different parts of the world, the process of dismantling and recycling a ship takes place in a series of steps which are independent of the method employed to dock the vessel. Ship recycling is generally performed by cutting away large sections of the ship's hull, which are then moved to shore for further dismantling. The entire recycling process can be divided into three main phases – pre-cutting, cutting and post-cutting. Each phase of the ship recycling process is a process in itself because some form of transformation takes place. The pre-cutting process involves various surveys and hull preparations for gas cutting. The cutting process is the process where actual cutting of steel hull and machinery into small pieces takes place. The post-cutting process involves sorting and segregation of materials. Each of these processes can be examined further to determine

Table 3: Reusable material of an EOL ship can be divided into following four broad categories.

A	**Metal items.**	Plate (Heavy), Plate (Light), Brass, Copper , MS Pipe, Nickel, G.I./Bar, Copper, SS Sheet, Aluminium Zinc, Hose pipe, Hatch Cover Plate/Tank Cover, Nut, Bolt, Washer, Anchor, Bar & Angle, Cast Iron, Shaft Plate, Chain & Cable, S.S. Scrap, Welding Rod, Other Ferrous material including scraps, Other Non-ferrous material including scraps, etc.
B	**Machinery equipment and accessories.**	Main Engine, Generator, Gear Box, Shaft, Propeller Shaft, Rudder, Air Compressor, CNG Bottle, Co2 Bottle, Pump, Bearing, Carburettor, Condenser, Radiator , Water Heater, Heat Exchanger, AC Plant, Unit AC, Evaporator, Oil Separator, Reduction Gear, Engine Head, Mechanical Tools, Machinery Spare Parts, etc.
C	**Electrical item.**	Electric Cable, Switchgear, Transformer, Motor, Computer, Electric Goods, Kitchen Item, Socket, Plug, DVD /Movie Player, Camera, Communication Set, Navigation Item, Equipment (Radar, GPS, Echo-sounder, etc.), Washing Machine, Electric Oven, TV, Fan, Electrode, Pad / Tab / Mobile set, Electrical & Electronics Spare Parts, Electrical & Electronics Tools, etc.
D	**Outfit and other reusable items.**	Door, Hatch, Window, Port Hole, Ladder, Capstan, Windless, Crane, davit Trolley, Winch, Life Boat, Lifebuoy, Life Raft, Life Jacket, Fire Extinguisher, Air Bottle, Gate Valve, Seawater, Freshwater, Fuel, Lubricant & Hydraulic oil Line Valve etc.

other processes that take place within them. Reusable material of an EOL ship can be divided into four broad categories and that has been show in table 3.

Pre-cutting: The pre-cutting process comprises of all the activities of the ship recycling process that takes place before the cutting of an EOL ship starts. It consists of various sub-processes such as the removal of loose items; removal of liquids; removal of hazardous materials; removal of insulation, flooring and tiling, cement works, removal of cables and electrical equipment. The economic value stream and non-economic value stream originating from pre-cutting is an input for post-cutting where further separation and sorting takes place.

It is assumed that the economic value stream of pre-cutting process is comprised of loose items (such as furniture, lifesaving appliances, firefighting appliances, galley appliances, household appliances, spare parts, paint drums, etc.) having second hand value; liquids (such as waste oil, lube oil, fuel oil, hydraulic oil, etc.); non-hazardous re-usable insulation (glass wool) and copper cables. The non-economic value stream is assumed to comprise of hazardous materials such as asbestos and asbestos-containing materials, PCB, glass, Ozone-depleting substances, etc.; ballast water; sewage and other waste that needs to be disposed of safely. Based on the above assumptions, it is estimated by MFA that around 2.5% and 4% of LDT of the sample ships would originate as NEVS and EVS respectively from the pre-cutting process. The remaining ship (93.5% of LDT) would flow into the next process, cutting.

Cutting: The cutting process is divided into two sub-processes: primary cutting and secondary cutting. The primary cutting is the process where a ship's hull is cut into ferrous blocks and non-ferrous items are extracted from the hull. The ship's machinery is cut from the base either to be sold in the second-hand market as reusable machinery or to be fed into the secondary cutting as scrap machinery. The separation of machinery into reusable and scrap machinery is depicted by the sub-process machinery separation. The machinery is turned into scrap if it fails to sale in the second-hand market. Both primary cutting and secondary cutting sub-processes are connected by a separation of ferrous, non-ferrous and machinery sub-process. It also depicts the transfer of bigger blocks from the primary cutting area to the secondary cutting area. The ferrous

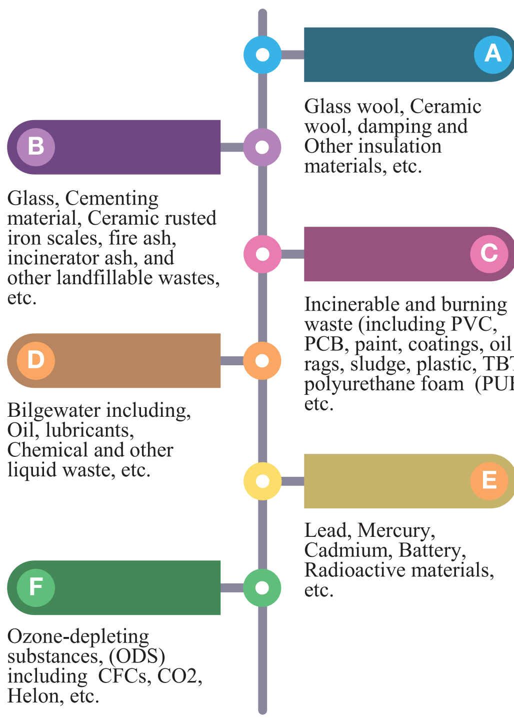

Table 4: Waste material of an EOL ship can be divided into following six broad categories.

blocks and obsolete machinery which has no second-hand value (in scrap machinery) fed as an input to the secondary cutting. Non- ferrous items, owing to their small size, do not need to be fed into the sub-process secondary cutting. The secondary cutting is the process where ferrous blocks are cut into steel plates and smaller pieces of steel scrap while the scrap machinery is cut into the smaller pieces of machinery scrap. The processes of primary cutting and secondary cutting are executed mainly using gas cutting torches. The cutting process results mainly in an EVS owing to the high value of ferrous and non-ferrous scrap. The only NEVS out of the cutting process is paint chips and other waste which can neither be sold in the second-hand market nor can be recycled as scrap. Based on the values of material streams (Table 3) above ship can be divided into six broad categories and that has been shown in table 4.

Post-cutting: The post-cutting process comprises three sub-processes. Those are collection and storage, separation and segregation, and finally transportation. The EVS and NEVS of the first sub-process are picked-up from their respective originating sources for storage. Eventually, EVS is fed to the sub-process transport, where products are sent either for reuse or recycling. The NEVS originating from sub-process collection and storage is fed into sub process separation and segregation, where products are further separated into NEVS and EVS. The sub-process separation and segregation is an important activity of the post-cutting process where further separation of products which were originally considered as non-economic value owing to their large amount of waste takes place. For example, a machinery component, such as a valve or pipeline insulated with asbestos, may be initially considered as NEVS. However, it can be further separated into metal (EVS) and asbestos insulation (NEVS) if the cost of separation (asbestos removal) can be offset by the metal value. The NEVS and EVS originating from the sub-process separation and segregation is fed into the sub-process transportation, where the EVS is transported either for reuse or recycling and the NEVS is transported either to landfill sites or to downstream disposal sites. All downstream activities (including reuse, recycling, disposal, landfill, incineration, etc.) are considered out of the system boundary of the ship recycling process as these activities do not take place on the ship recycling yard. Based on the assumptions as mention above, it is

estimated by means of an MFA that 1.5 to 2.5% of LDT of the sample ships would be sent for disposal (in most cases to a landfill and incineration site) and 75 to 96% of LDT of the case ship can either be reused or recycled. Detail calculation result, analysis fact and figures for different types of EOL ships has been explained in my PhD research paper. Cutting and post cutting result of different types/categories of six sample EOL ship dismantle in local yards in Bangladesh has been shown in fig 4 to 9. These figures also assume that around 20 to 30% of the weight of the NEVS can be extracted as EVS during the separation sub-process of the post-cutting process. This value can change depending on the separation capacity and techniques employed by the recycling yard. The amount of EVS and NEVS obtained from each sub-process of recycling the sample different types of ships as derived from the MFA diagrams for the applied assumptions has shown in my PhD research paper.

Analysis of MFA Technique

Material Flow Diagrams: In order to develop the material flow diagrams using STAN, data for the input and output flow of each process must be fed by the user as far as practicable. In case the input or output flow is not known, a user can feed the transfer coefficients of the processes. A transfer coefficient of a process defines the relationship between the input and output flows of a process. For example, an input flow to a process can be divided into two or more output flows based on the defined ratios. Such data can be generated by reconciling the material composition data of the ship. Based on such data, STAN calculates the value of each flow. If the user-defined data is not sufficient to perform such calculation, STAN displays an error message. The flows of materials of an EOL case ship on a recycling yard are presented in the next section of this article.

Assumptions: The aim of carrying out an MFA for the sample ships is to understand the expenditure and income associated with its recycling. Thus, all material streams originating from each process are categorised into two major streams; economic value stream (EVS) and non-economic value stream (NEVS). EVS stream is the stream having the products which can either be sold for reuse or recycling, resulting in cash in-flow for the recycling yard. NEVS is the stream having the products which need to be disposed of either at a waste treatment facility or at landfill sites resulting in cash outflow for the recycling yard. The distribution of material streams into the EVS and NEVS can differ for yards as depending on the factors such as location, recycling practices, second-hand market, regulations and time. Since this article does not focus on specific recycling yards, so there are few assumptions. The assumptions made here represent a scenario where there is an existing scrap market (local market in Bangladesh) for ferrous and non-ferrous scrap and a second-hand market for items such as mechanical equipment, electrical and electronic waste, outfit, household items, insulation items, liquids (waste oil, sludge, fuel oil, lube oil, hydraulic oil, etc.) and machinery. In Bangladeshi local market, scraps of any materials, waste liquid from EOL ships, old insulation materials, and all sorts of electrical and mechanical items, old household items, and furniture can be sold. It may be surprising to develop and developing countries that, almost everything collects from EOL ship can be sold and used by local people of Bangladesh. About the cost and price of collection and selling of reusable materials in the local market has not discussed in this article.

Shortcoming: A shortcoming of using MFA as a planning tool on a ship recycling yard is that it relies extremely on the input data. This data, in most cases, is either difficult to obtain or inaccurate. This can be overcome by improving the way information is passed to the recycling yards or direct physical involvement of the researcher. The shipbuilding yards should develop a document defining the material composition of ships in the form of a list of materials and their weights available on a ship. This is in line with the principle of extended producers' responsibility. It must also be updated during the ship's lifetime as required by the Hong Kong Convention for the Inventory of Hazardous Materials described how such a document can be developed (in the form of ship's lightweight distribution) and added to the ship's stability manual.

Results: Summarise fact and figure as an average reusable material factor and annual reusable material output of those samples 26 different type/category EOL ships have been shown in table 1 above. The researcher has determined that there are average 1,833,461 MT (minimum) and 1,989,252 MT (maximum) reusable materials have been collected annually from ship recycled industry of Bangladesh. To calculating and determining the number of reusable materials and factor, Researcher has taken help from free commercial software like Microsoft Excel and Material Flow Analysis (MFA) software STAN in addition to manual calculation. The researcher has found that my manually calculated result of reusable material vary up to 0.4% with STAN software result, whereas no variation found with MS Excel result. In table 2 above, average reusable material factor and amount of materials output per year in MT for different types of recycled ships in Bangladeshi yards has been shown. Again, the most basic level of the reusable material flow diagrams for recycling of five sample bulk, container, tanker, cargo and other EOL ships (out of 26 sample ships) which recycled in local yards of Bangladesh, developed by software STAN has been shown in figure 7 to 11 respectively. Estimation and output of reusable material of different types and sizes of 5 bulk and 6 containers, 5 tankers, 5 cargos and 5 other types of EOL ships by using MFA technique has been shown in figure 12 to 16 respectively. The detail and exclusive data, compilation, analysis, result, graph and output of reusable material of 26 EOL ships have been done by using MS Excel broadsheets and programming.

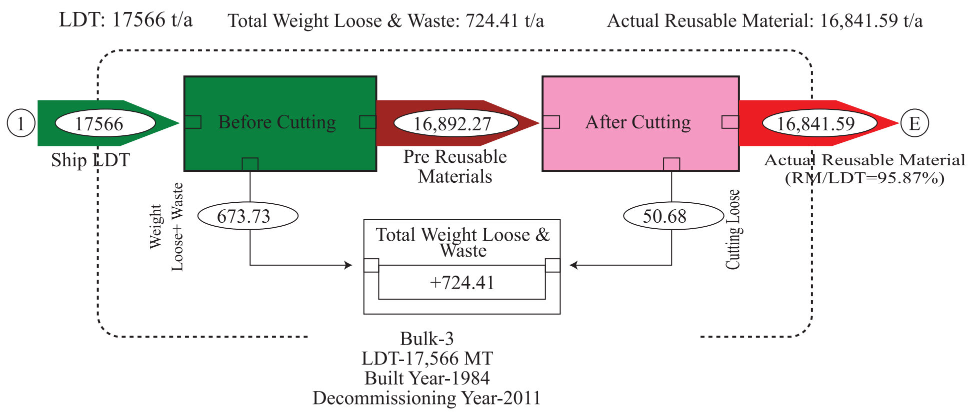

Figure 7: Reusable material flow diagrams for recycling of sample bulk EOL ship.

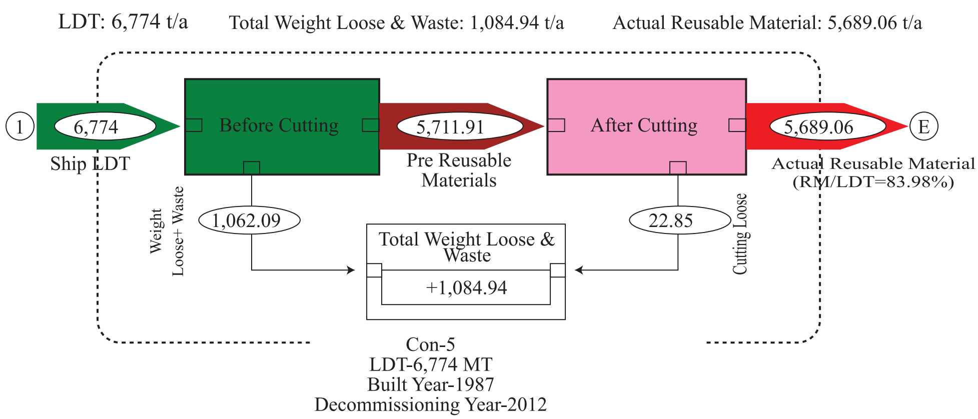

Figure 8: Reusable material flow diagrams for recycling of sample container EOL ship.

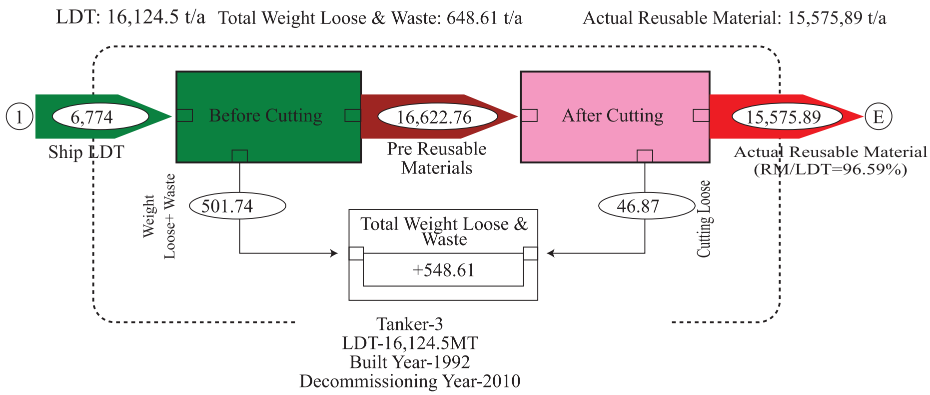

Figure 9: Reusable material flow diagrams for recycling of sample tanker EOL ship.

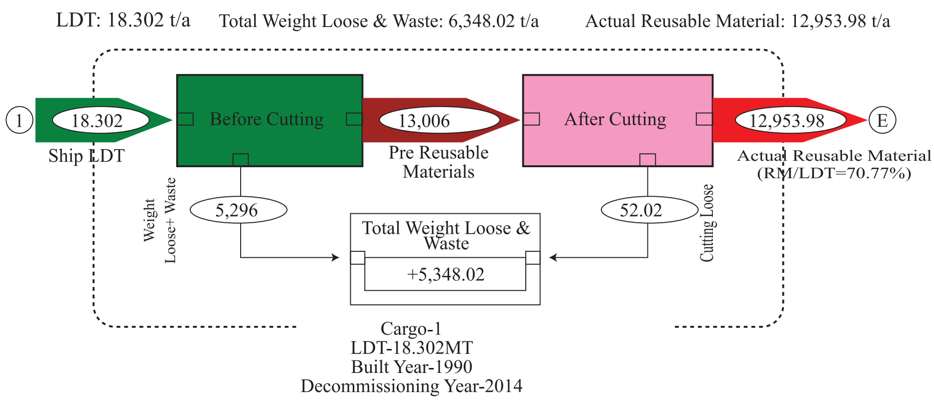

Figure 10: Reusable material flow diagrams for recycling of sample cargo EOL ship.

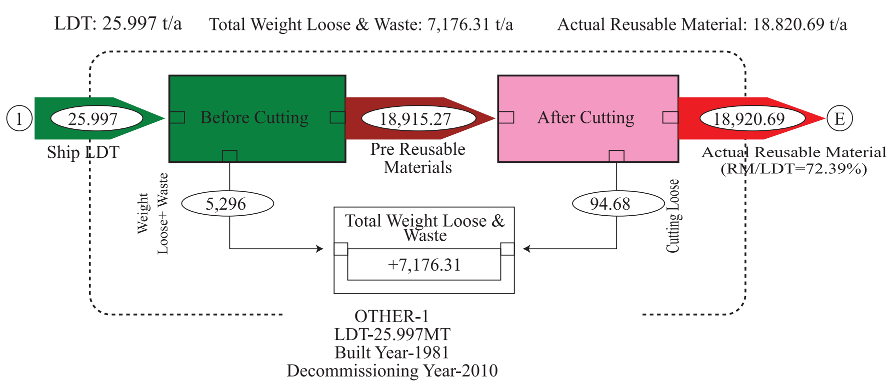

Figure 11: Reusable material flow diagrams for recycling of sample ore carrier EOL ship.

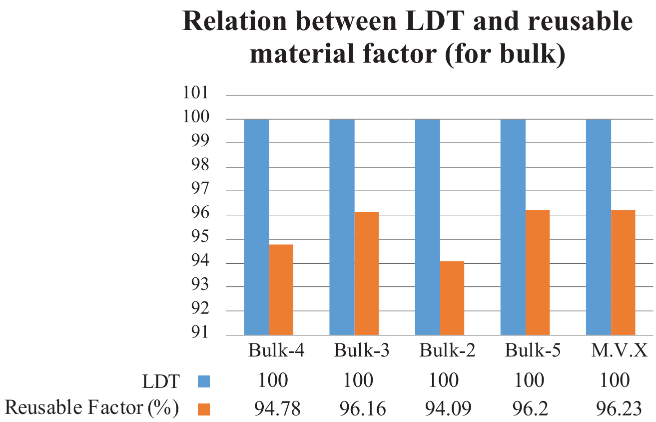

Figure 12: Output of reusable material of different types and sizes of 5 bulk EOL ships.

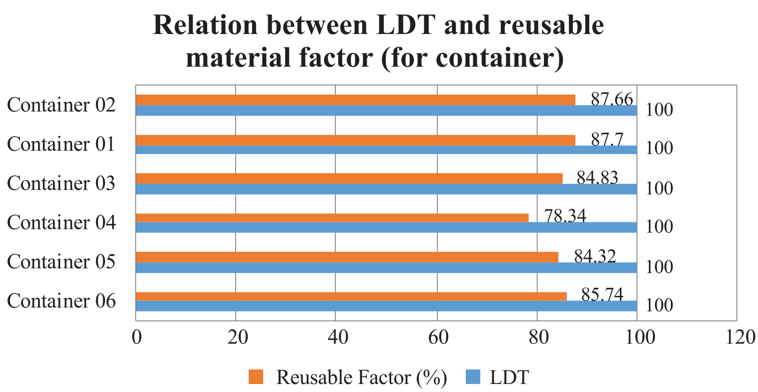

Figure 13: Output of reusable material of different types and sizes of 6 container EOL ships.

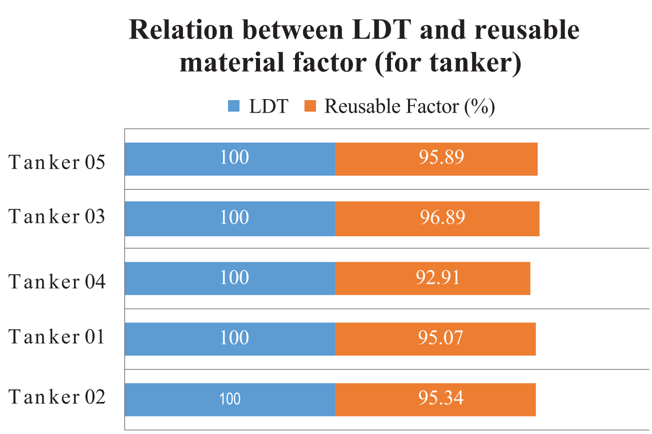

Figure 14: Output of reusable material of different types and sizes of 5 tanker EOL ships.

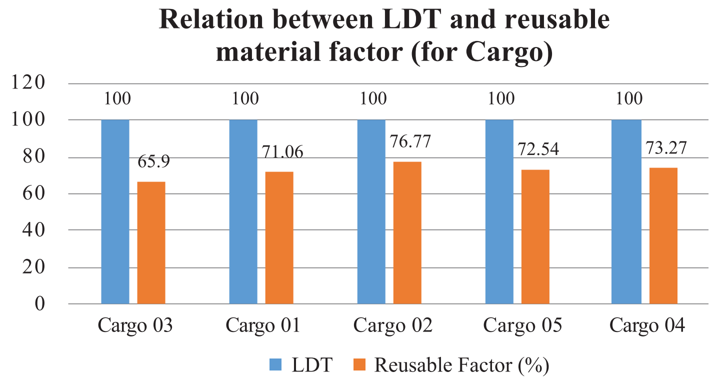

Figure 15: Output of reusable material of different types and sizes of 5 cargo EOL ships.

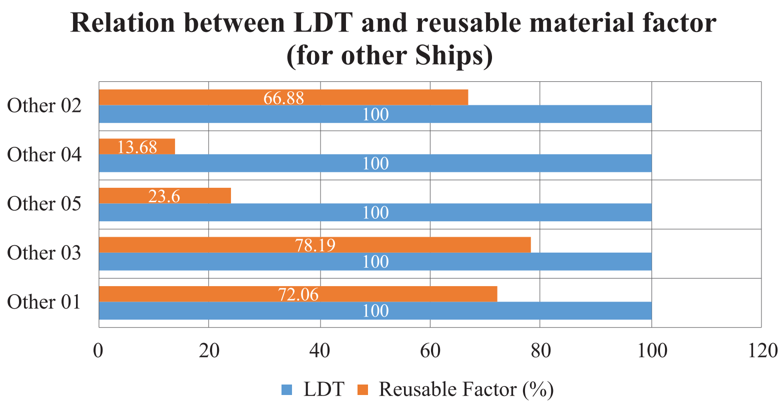

Figure 16: Output of reusable material of different types and sizes of 5 other EOL ships.

Argument

Data Accuracy: The results of the MFA mainly depend on the accuracy of input data and the understanding of different sub-processes of the ship recycling process. It is not possible to conduct an MFA study on a ship recycling yard without knowing the material composition data of ships, design and building construction and the relation between the input and output flows of each sub-process of the ship recycling process. The material flow analysis carried out in the above of this research determined the quantity of waste and recyclables generated as a result of dismantling six samples of EOL ship carrier under the applied assumptions. Actually, any ship recycling yards recycle several ships at the same time in most cases. Therefore, an MFA need to be carried out for all the ships together. In that case, the spatial boundary still remains the same but the temporal boundary must be determined on the basis of the time frame for which the analysis is to be carried out. Material composition data must also be available in an aggregate form for all the ships that would be recycled within the set time frame. Nevertheless, an MFA carried out on a ship-by-ship basis provides enough details to a ship recycling yard to visualise, plan, execute and improve its processes. However, in my PhD research paper MFA has been carried out on 26different types, categories and sizes of EOL ships which dismantled in local yards in Bangladesh.

MFA Scenarios and Practical Output

The flows of materials shown in the preceding MFA diagrams depict the ideal amount of materials that can be derived from the case ships for the assumptions made in this research. In the actual situation, the amount of each material that can be derived from the case ships depends on the recycling process employed. For example, the amount of input material and percentages of the EVS and NEVS coming out of separation sub-process may differ. Some amount of ferrous and nonferrous material might also go into the separation sub-process. There might be no EVS coming out of the removal of insulation, flooring and tiling, cement work, the subprocess of the pre-cutting process depending on the demand of reusable insulation in the market and the possibility of removing insulation in good condition at a reasonable cost. For an example, in South East Asian countries, intact glass wool insulation panels are purchased by resellers to cater the needs of cold storage firms and other industries requiring insulation material. Again, there is a strong demand for almost all the materials/ products recovered from EOL ships by the network of secondary processing firms located around the ship recycling yards in Bangladesh. Various scenarios and possibilities of material flows exist depending on the recycling process employed and socio-economic state of local yards. The MFA can be used as a tool to visualise, estimate, plan, and compare different scenarios that can arise as a result of the recycling of any EOL ship.

Literature Review

Comparison with Other Industries: It would be worthwhile to discuss why it is important to develop a methodology for material quantification of EOL ships by comparing the ship recycling industry compared with other industries like the aircraft and the vehicle recycling industry. The recycling approach of the shipping industry resembles the approach used by the aircraft recycling industry. The aircraft recycling involves disassembly of reusable components and then shredding the remaining hull to obtain ferrous and non-ferrous scrap using the separation technologies. Similarly, the ship recycling industry is predominantly based on salvaging as many components as possible having second-hand value in the market and then cutting the ship's hull into plates, frame and blocks of sizes that are readily accepted in the scrap market. On the contrary, the vehicle recycling industry mainly relies on shredding the vehicle hull to obtain ferrous and non-ferrous scrap for recycling using the separation technologies because of the non-existent market of reusable components. Moreover, the vehicle recycling industry has a frequent supply of small units unlike the ship recycling industry having an intermittent supply of large units. Though, the ship recycling industry resembles the aircraft recycling industry in following a similar recycling approach; its earning model is similar to that of the vehicle recycling industry, contrary to the earning model used by the aircraft recycling industry. It depends more on scrap value than on component value. This is the reason why material quantification related studies are abundantly available within the literature of the vehicle recycling industry while the literature of aircraft recycling industry is more focused on disassembly of reusable components. In conclusion, the ship recycling industry is similar to both vehicle and aircraft recycling industry in certain aspects; yet the difference not only due to large size and various types of ships but also due to large age range, infrequent supply and dynamic composition of ships due to change in regulations over time makes it difficult to instantly apply the existing quantification models of other industries. The strong market presence for EOL ship's machinery, equipment and other reusable items is similar to that of aircraft recycling while high demand for high-value non-ferrous scraps such as special bronze and ferrous scrap in the form of plates and blocks in the scrap market is similar to that of the vehicle recycling industry. Both these factors make it vital to quantify the material streams of an EOL ship to calculate cost and income of recycling a ship.

The Material Composition of EOL Ships: For this study, all the available research papers and technical reports on material quantification of EOL ships were reviewed. Unfortunately, unlike the car and aircraft industry, the number is very limited (around a dozen). The very small number of studies available on this subject is attributed to ship recycling yards being unconvinced about sharing the information and data. The prevalent scepticism is mainly due to continuous scrutiny of recycling yards by environmental watchdogs. Other stakeholders, such as classification societies and ship recycling consultants are bound by the non-disclosure agreements of the proprietary data. The literature review found that the studies used four different methods to quantify material streams of EOL ships. This includes interviews of ship recyclers, sampling on a few ships, sampling on the beaches of a few recycling yards, and an input-output method applied at a particular recycling yard based on the approximate historical data of few ships. While Andersen et al. (1999) aimed to quantify the materials of environmental concerns available on an EOL VLCC ship by sampling; Hiremath and Sarraf attempted to quantify waste streams of various ship types on an aggregate level whereas Reddy attempted to quantify the waste generated by Alang, ship breaking yard in Gujarat, India in terms of MT per day by sampling on beach. Although all four authors attempted to quantify only the waste streams while ignoring other material streams such as ferrous, non-ferrous, machinery etc., their studies are unfortunately not comparable due to different move toward of research used by them. The study carried out by Hiremath is the most accurate of these studies because the authors used a relatively large sample set of 241 ships. However, both the type of ships demolished and the materials on board vessels change over time. The first change was due to economic circumstances and the second due to changes in regulations. As an example, IMO started banning asbestos by means of SOLAS convention in 2002, which was eventually banned totally for use on all installations on all ships in 2011 (Lloyds Register, 2011). This means resampling will need to be done regularly to make sure the values of emission factors remain correct. It was also noted that bilge water was assumed as part of LDT, but as it is operationally generated, it should be part of DWT used GT to represent the ship size, which is rather impractical as GT is a measure of volume rather than a weight. As Sarraf had no access to proprietary data of Inventory of Hazardous Materials (IHM) of various ships available with classification societies, so his making estimation was difficult and inaccurate.

Different Studies of EOL Ships and Contribution of Author: On the other hand, the results obtained by Reddy et al (2003) are the most inaccurate, as his calculation had discrepancies and calculation based on unrealistic assumptions; such as the only source of waste collected at Alang, beach and had no extrapolation of the amount of waste found in three months to the value for one year. The studies carried out by Adak, Andersen, Demaria, Hess and Sujauddin are an attempt to quantify all the material streams of EOL ships using different research ideologies. While Adak and Hess focused on material quantification of three major ship types General cargo, Bulk carrier and oil tanker, Demaria and Sujauddin focused on ships in general. These estimates are on an aggregate level based on the experience of ship recyclers and waste disposal data published by government agencies in India and Bangladesh. They are mere approximations of the number of material streams of an EOL ship. Unexplained weight losses of 9% to 16% of the weight of the vessel are reported by Adak and Hess. This weight loss might be due to margins of error and wrong declarations. In East Asia, there have been few instances of discrepancies in declared import weight and material sold for re-rolling. The wrong declarations can be for several reasons; the material stream is either escaped to the environment, is dumped illegally either into the sea or at nearby villages, or quite simply done for tax evasion. The study carried out by Andersen for classification society DNV is the only one that focused on individual ships Tanker and Bulker to calculate their material composition by sampling on a VLCC ship and using empirical estimations available in the ship design literature to calculate the weight of machinery, outfitting and steel. This is the most detailed and comprehensive of all the studies. Other studies on ship recycling have used this data as well. The major drawback of this study is the use of inaccurate and backdated data. So it is clear that all of these studies use aggregate data for large groups of ships, none of these studies presents a methodology that can be used by recycling yards to determine the number of various material streams for a particular ship. However, K P Jain and his team had presented a methodology to quantify the material streams of an EOL ship using the information available from the ship at the time of offering. In this article, the author has present a methodology to quantify the material streams of an EOL ship using the information available from a group of different types, categories and size of EOL ships (26 in number). So the author wants to say that, it is more authentic and close to accurate for estimation and decision-making process for the stakeholders.

Conclusion

MFA is better Technique in ship recycling. It is established in this article that analytical technique MFA can be used by ship recycling yards to better plan the ship recycling process by establishing the flows of materials through different sub-processes taking place within a recycling yard. The flexibility of MFA as a technique or tool in terms of spatial and temporal boundary settings makes it very useful, not only for planning and improving the ship recycling process on particular yard for one or more ships but also for understanding and predicting the outputs of the ship recycling industry on the local, regional, national and global level. MFA diagrams indirectly contribute to reducing recycling costs and increasing revenue. Moreover, MFA helps to determine the maximum revenue potential of recycling a number of ships within a particular time frame. Ship recycling yards can work on optimising their revenue potential by finding ways to generate income from the waste anticipated to be generated as a result of recycling the EOL ships. Again, MFA can be used to compare waste management strategies such as landfill, waste to energy conversion, incineration, etc. This article discussed the technique available within the field of production and environmental management that are potentially applicable to the ship recycling industry for achieving its objectives. So ship recycling can be considered as a reverse engineering process with the help of MFA technique. MFA can be used as analytical tools for environmental management as it is a natural fit due to the involved waste and environmental management issues. MFA has emerged as an essential technique that can improve ship recycling and materials and waste management at ship recycling yards by determining the earning potential of each project as well as planning the utilisation of resources to attain maximum profit.

MFA can be used by recycling yards for understanding the material flows within the recycling process, for comparing the status quo with different recycling scenarios, as a decision-making technique to decide on waste management strategies. It can use as a calculating tool to determine the amount of material generated for reuse and disposal. It can also use as an analytical technique to plan the recycling process by calculating required material handling capacity and anticipated recycling steps. This paper also discusses a standard and viable ship recycling process that can be used by a recycling yard to dismantle different types of EOL ships irrespective of the docking method employed. In this article, it has been proved that by using MFA and software STAN it is possible to determine and calculate (almost accurately) reusable and waste materials of any type and size of EOL ships dismantle of any yards. Finally, the author wants to say that MFA can be used as a viable and sustainable ship recycling technique to an economic analysis of the recycling industry. So MFA is a better technique and that can be used as a decision-making tool for ship recycling industry as a whole.

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