DEVELOPMENT OF STRATEGIES FOR EFFICIENT RECYCLING OF SHIPS

A Thesis

Submitted By

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For the award of the degree

Of

DOCTOR OF PHILOSOPHY

(Faculty of Technology)

DEPARTMENT OF SHIP TECHNOLOGY

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

KOCHI -682022

SEPTEMBER 2018

ACHARYA DEVO BHAVA!

Dedicated to my teachers and my superiors in industry.

DECLARATION

This is to certify that the thesis entitled **"DEVELOPMENT OF STRATEGIES FOR EFFICIENT RECYCLING OF SHIPS"** submitted to the Cochin University of Science and Technology in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by me. The contents of this thesis have not been submitted and will not be submitted to any other University or Institute for the award of any degree.

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ACKNOWLEDGEMENTS

The motivation, encouragement and support received from my teachers, colleagues, friends, and others during my research work have helped me to overcome many difficult situations. Support from my well wishers helped me to finish my research work very smoothly.

First of all, I express my sincere gratitude to my guide Prof. (Dr.) Sivaprasad K. for giving me an opportunity to carry out this research under his guidance. I thankfully remember the enlightening discussions with him, which helped me to progress in this research work. Without his help, motivation, inspiration, and above all his invaluable guidance, I would not have been in a position to accomplish my research work.

I am deeply indebted to my teacher Prof. (Dr.) Nandakumar C. G. who has been the main source of inspiration throughout this research work. He has motivated me to register for Ph.D study at a time when I even had not dreamt of it. I gratefully remember his timely and right interventions to keep me on track at times of crises, right from topic selection through the presynopsis until my thesis submission.

I am thankful to Dr. Mariamma Chacko, Head of the Department for permitting me to conduct this research work in the department. I gratefully acknowledge the advices given by my previous guide Dr. E. M. Somashekharan Nair and my previous co-guide Dr. Ing. K. P. Narayanan during the initial stages of this research work. I express my sincere gratitude to my teachers Dr. A. Mathiazhagan, Prof. (Dr.) Dileep Krishnan, Mr. James Kattady, and Dr. Sudheer C. B. for their support during the course of my Ph.D study. I thank other faculty members and staff for all the support given during this research work. I am thankful to Mr. Aubid A., Director, M/s Steel Industrials Kerala Limited, Kannur for permitting me to use the documentation of a ship that was recycled in their shipyard. I also express my sincere thanks to Dr. Abdul Rahim of ClassNK for his whole hearted support and advice. I owe my sincere gratitude to my former colleagues Shaju D. and Ajith Eruvankai (Grandweld Inc. Dubai) for their whole hearted support on the research work on product models. I am also thankful to B. Tech (NA & SB) undergraduate student of Department of Ship Technology Yashwant R. Kamath for helping me on the software related matters.

I am grateful to Ajit Nair and Cdr. Satheesh Babu P. K. for their sincere and whole hearted support, motivation and advices during my research work. I extend my sincere thanks to Dr. Ajay Asok Kumar, Dr. Kesavadev V. K., Dr. Manoj G. Tharian, Dr. Smitha K. K., Dr. C. Prabha, Dr. P. G. Sunil Kumar, Dr. Manju Dominic, Dr. Vikas V. Shenoy, Dr. Bindumol T. V., (Dr.) Cdr. Nitin Agarwala, Dr. Baiju Sasidharan, Vijith V., Baiju M. V., K. Vinida, Rajeeve G., Girish A. G., E. Mohanadasan, Sanjay Bidaye, and J. Gopakumar for their motivation and support during my research work. I convey my gratitude to Dr. Jacob Thomas I.P.S. (Former Director, Kerala Port Department), Former Directors of Indian Maritime University (Kochi Campus) Rear Admiral Prem Kumar Nair, AVSM (Retd.) and Mr. Rajeeva Prakash, and Former Directors-in-charge of Indian Maritime University (Kochi Campus) Dr. B. Swaminathan and Dr. M. Sekar for giving me permission to carry out this research work along with my other responsibilities.

I fail to find words to describe my sincere gratitude to my beloved wife Rakhi S. Anand. Her encouragement, help, support, sacrifices and care were vital for completion of this research work. I am deeply indebted to my loveable children Chethan, Amritha, and Bharath for their emotional support and for all the sacrifices made by them to enable me to carry out this research work. My children missed me whenever I was needed most. I lost my beloved father at the beginning of my research. I acknowledge the love and care showered by him throughout my life. I missed him badly throughout the period of my research. My beloved mother has been a constant source of strength throughout my life as well as during this research work. I gratefully acknowledge her love, care, and support that enabled me to carry out this research work with a peaceful mind during critical periods of my research. I am also thankful to my brother Rajesh S., Capt. Subramanium (Ex-Grandweld Inc. Dubai), my in-laws, my maternal and paternal family members, my friends, classmates, and colleagues for their support and care.

Above all, I am grateful to Almighty for keeping me alive with his blessings to reach the final destination of this research work.

Thrikkakara **Jayaram S**
12-09-2018

ABSTRACT

Ships become uneconomical for further repair and maintenance or conversion after about 30 years of operations. International Maritime Organisation (IMO) has recognised ship recycling as the best option for ships which have reached the end of their operational life. Ship recycling involves a sequence of activities from preparation of an obsolete ship at an offshore location till the dismantling of the last onboard component. Ship recycling activities are labour intensive and are mainly managed with primitive technologies and less-developed management practices. This makes ship recycling one of the most hazardous activities. A deficiency has been noticed regarding documentation on responsibilities of stakeholders of ship recycling.

The guidelines given by various agencies such as IMO, ILO, and Basel Convention do not give a clear methodology to prepare a ship recycling plan. Published literature on ship recycling plans touches only the major activities. It becomes necessary to identify the important processes which are carried out during various phases of ship recycling.

Implementation of a disassembly concept which involves structural disassembling of hull in a progressive manner, analogous to assembly concept in shipbuilding, has not been found to be examined or implemented at a detailed level in the ship recycling industry. Effort has not been put in identifying the desired features of a product model of ship for utilisation during recycling stage of ships. End-of-life ship can be made a transparent product in terms of material content and hazardous nature through enrichment of product model of the ship from a ship recycling perspective and by facilitating the product model's utilisation in the recycling stage. Layouts of most of the facilities which are used exclusively for ship recycling in the major ship recycling countries such as India, Bangladesh, and Pakistan are found to be without a well planned design.

In order to address the issues mentioned above, ship recycling industry needs to develop and implement a number of strategies. This study has developed three strategies for ship recycling. The first two strategies are from the perspective of obsolete ships. The third strategic decision has to be made with respect to the yard where obsolete ships are recycled.

The first strategy is the development of a concept plan named as Ship Recycling Guidance Plan (SRGP). SRGP is intended to facilitate execution of recycling of ships in an efficient, safe, healthy, environment friendly, and sustainable manner. The concept has been developed in the form of a general frame work that consists of two parts viz., Strategic Ship Recycling Guidance Plan (SSRGP) and General Ship Recycling Guidance Plan (GSRGP). SSRGP is intended for addressing the strategic issues relating to efficient recycling of ships while the GSRGP is intended to address the application/operational level of work in ship recycling. Roles and responsibilities of stakeholders in the global ship recycling industrial sector are indicated in the SSRGP as a system model. Steps to be followed in the end of life operation of an obsolete ship for its dismantling, recycling, reusing, and disposal are deliberated in the GSRGP. As part of the GSRGP, a disassembly concept has been proposed for the dismantling of ship structure at three levels. Beaching method has been adopted for the development of SSRGP and GSRGP. The SRGP will be able to function as a reference document that enables a ship recycling yard to generate and implement a recycling guidance plan for each ship to be recycled in the yard.

The second strategy is the development of guidelines for enrichment of product models of ships from a ship recycling perspective. A set of proposals containing ‘Product Modelling for Ship Recycling’ (PMSR) is developed for applying ‘*modelling for*’ concept in ship recycling engineering. The concept of PMSR is presented as a set of guidelines in this thesis in order to facilitate enrichment of product model of ship from a recycling perspective. This will further enable the product model’s utilisation in recycling stage of ship. The PMSR guidelines indicate the aspects to be considered for enrichment of ship product model during each life cycle stage of a ship. The guidelines specify various stakeholders and their roles in facilitating enrichment of the product model during each life cycle stage of ships.

Following the proposed guidelines, it would be possible to create a ship very closer to a real transparent ship. Ship product model enhanced with the features proposed in this thesis can also function as a ‘Ship Construction File-specific’ (SCF-specific) document that contain recycling related information which is specified by IMO as part of the Goal Based Ship Construction Standards. Two dimensional (2D) views of different onboard parts of a typical bulk carrier, which have been developed based on the proposed guidelines of PMSR, are depicted in this thesis. These 2D views show the desired features of a ship product model for its utilisation during recycling stage.

Layout design of a ship recycling yard is strategically important since the physical layout of any workplace will have a major role in maintaining the flexibility and efficiency. So, as the third strategy, generation of conceptual ship recycling yard layout has been attempted to in this research work. This study proposes a simple and well structured methodology for design of optimal concept layouts of ship recycling yards. Facilities in ship recycling yards are selected based on the recycling processes described as part of the GSRGP according to the type of obsolete ships. A methodology in the form of steps to be followed in designing the layout is developed in this thesis. In addition, a list of activity areas to be included in a ship recycling yard, methods to estimate quantitative values of flow intensities and space requirements of a ship recycling yard, and the relative closeness ratings between various activity areas in a ship recycling yard have been developed. Using a case study, a physical layout of ship recycling facility has been laid out in the form of a drawing.

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NOTATIONS

Symbols

e_m	Equivalent movement factor given in SLP
N	Number of elements
N_D	Number of disassemblies
N_{PD}	Number of primary disassemblies
N_{PS}	Number of plates or stiffeners
N_{SD}	Number of subdisassemblies
P	Product
Q	Quantity
R	Routing
S	Supporting services
T	Time or Timing
W	Weight/unit of element
W_D	Weight of each disassembly
W_{PD}	Weight of each primary disassembly
W_{PS}	Weight of each plate or stiffener
W_{SD}	Weight of each subdisassembly
N_{SD}	Number of subdisassemblies
t	tonnes

ABBREVIATIONS

Symbol	Definition
2D	Two Dimensional
3D	Three Dimensional
ACMs	Asbestos Containing Materials
AHU	Air Handling Units
ASSRY	Alang Sosiya Ship Recycling Yard
bhd/bhds	Bulkhead(s)
CAA	Computer Aided Approval
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computerised Numerically Controlled
CFCs	ChloroFluoroCarbons
CO_2	Carbon Dioxide
Comm	Communication
DASR	Document of Authorisation to conduct Ship Recycling
DNV	Det Norske Veritas
DO	Diesel Oil
EIA	Environmental Impact Assessment
ER	Engine Room
FFAs	FireFighting Appliances
FRP	Fibre Reinforced Plastic
FSMA	Flag State Maritime Administration
Fwd	Forward
GA	General Arrangement (drawing)
GSRGP	General Ship Recycling Guidance Plan
HFO	Heavy Fuel Oil
HKC	Hong Kong Convention, 2009
HM/HMs	Hazardous Material(s)
HVAC	Heating, Ventilation, and Air Conditioning
HW	Hazardous Waste(s)

IASR	International Agency for Ship Recycling
ICIHM	International Certificate on Inventory of Hazardous Materials
IHM	Inventory of Hazardous Materials
ILO	International Labour Organisation
IMO	International Maritime Organisation
IRRC	International Ready for Recycling Certificate
ISO	International Organisation for Standardisation
LDT	Light Displacement Tonnes
LOA	Length OverAll
LSA/LSAs	Life Saving Appliance(s)
m/c	Machinery
MDO	Marine Diesel Oil
Nav	Navigation
NCC	Numerically Controlled Cutting
NGO	Non-Governmental Organisation
NHM/NHMs	NonHazardous Material(s)
P & S	Port and Starboard
PC	Personal Computer
PCA	Pollution Control Authority
PCB	PolyChlorinated Biphenyl
PLM	Product Life cycle Management
PPE	Personal Protective Equipment
RAC	Refrigeration and Air Conditioning
SBC	Secretariat of the Basel Convention
SCF	Ship Construction File
SCSR	Statement of Completion of Ship Recycling
SILK	Steel Industrials Kerala Limited
SLP	Systematic Layout Planning
SR	Ship Recycling
SRFMP	Ship Recycling Facility Management Plan
SRFP	Ship Recycling Facility Plan

SRGP	Ship Recycling Guidance Plan
SRP	Ship Recycling Plan
SRSMA	Ship Recycling State Maritime Administration
SRY/SRYs	Ship Recycling Yard(s)
SS	SuperStructure
SSRGP	Strategic Ship Recycling Guidance Plan
STEP	STandard for the Exchange of Product model data
TBT	TriButyl Tin
TSDF	Treatment, Storage, and Disposal Facility
WEEE	Waste Electrical and Electronic Equipment
WL	Water Line
UN	United Nations
UNEP	United Nations Environment Programme
VHF	Very High Frequency

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Ships become uneconomical for further repair and maintenance or conversion after about 25 years of operations. Decommissioning of a ship can be defined as the permanent withdrawal from service and subsequent operations to bring it to the dismantling facility (SBC 2003). International Maritime Organisation (IMO) has recognised that ship recycling contributes to sustainable development and it is the best option for obsolete ships (IMO 2009). The critical roles of recycling of ships include the disposal of older, uneconomical, and unsafe ships from operations and the reuse or recycling of salvageable equipment, onboard construction materials, and other items.

Ship recycling involves a sequence of activities from the preparation of an obsolete ship at an offshore location till the dismantling of the last onboard component, which are carried out during the final phase of the life cycle of a ship. International Maritime Organisation (IMO) has defined 'ship recycling' as the activity of complete or partial dismantling of a ship at a ship recycling facility in order to recover components and materials for reprocessing and reuse, whilst taking care of hazardous and other materials. IMO has included the associated operations such as storage and treatment of components and materials on site in the definition, but not their further processing or disposal in separate facilities (IMO 2009).

In this thesis, the term '**ship recycling processes**,' in general, refers to the engineering activities which are carried out in the recycling industry as part of end of life of a ship. Efficient recycling of ships refers to the recycling of ships which is safe, healthy and environment friendly at the sametime economically viable.

Number of methods have been adopted in various parts of the world for docking the ships to facilitate recycling. The methods currently in practice are beaching method (tidal beaching method), dry dock method (graving dock method), slipway method (nontidal beaching method or landing method or slip landing method or slipway landing method), and alongside method (quayside method or pierside method or pier breaking method or floating method) (Hougee 2013; Litehauz 2013, Lloyd's Register 2011; Mikelis 2012).

Beaching method is practised in the major ship recycling countries located in South Asia such as India, Bangladesh, and Pakistan (Hougee 2013; Lloyd's Register 2011; Sivaprasad 2010; Litehauz 2015). Dry dock method is practised in some of the European countries. Slipway method is employed mainly in Turkey. (Hougee 2013; Lloyd's Register 2011). Alongside method is practised by yards in China, United States of America and European countries (Hougee 2013; Litehauz 2013; Lloyd's Register 2011).

Global annual ship recycling volume in terms of both the number of ships and the gross tonnage of ships in the year 2017 and the cumulative values of the ship recycling volume during the period from 2006 to 2015 are presented in Table 1.1 based on the statistics available from various sources (NGO Shipbreaking Platform 2017; JICA 2017). From Table 1.1, it can be seen that the ship recycling industry has been concentrated mainly in five countries, viz., India, Pakistan, China, Bangladesh, and Turkey. Among these, the Asian countries, viz., India, Bangladesh, and Pakistan are holding the major share of ship recycling volume.

Method of structural disassembling of hull would vary depending on the method that is adopted for docking and securing a ship. In the case of beaching method, dismantling would take place usually from forward to aft i.e. commencing from the bow. Hull structure may be dismantled blockwise or unitwise depending on the experience of the personnel, handling capacity and availability of space in the ship recycling yard (SRY). Hull may be pulled towards the land progressively after removal of each unit. In dry dock method and slipway method, dismantling would take place from top to bottom, starting with the deckhouses and superstructure, as well as from forward to aft. For alongside method, the dismantling process would progress in the vertical direction, from top to bottom. The dismantling would commence from the superstructure and extend down to the inner bottom level. By controlled ballasting, the aft or forward end of the remaining hull would be lifted clear of water and removed. The last part of the remaining empty floating hull, called 'canoe', may then be lifted out as one piece or taken to a dock for further dismantling (Hougee 2013; Lloyd's Register 2011; Sivaprasad 2010).

Table 1.1 Global Annual Ship Recycling Volume by Location in %

Country	In the year 2017		During the period 2006-2015
	No of ships recycled	**Gross tonnage of ships recycled**	**Gross tonnage of ships recycled**
India	28.60	28.90	29.41
Bangladesh	23.60	31.70	27.19
Pakistan	12.80	19.70	13.97
China	11.70	11.10	22.08
Turkey	15.90	6.70	3.66
Others	7.40	1.90	3.68

At present, some of the countries or regions like European Union (EU 2013), India (Ministry of Shipping 2017), and Bangladesh (Ministry of Industries 2011) have formulated their own regulations for recycling of ships in facilities under their jurisdiction. International Labour Organisation (ILO) is concerned with the implementation of ILO standards and guidelines on occupational safety and health in the ship recycling industry (ILO 2004). United Nations Environment Programme (UNEP) has adopted the Basel Convention in 1989 and it has entered into force in 1992 (SBC 2014). Basel convention deals with the control of transboundary movements of hazardous wastes and their disposal and it may be applicable in the recycling of ships on a case to case basis as the ships intended for disposal usually contain hazardous wastes. The 'Hong Kong International Convention for the Safe and Environmentally Sound Recycling Of Ships, 2009' (HKC) by the International Maritime Organisation (IMO) has stipulated the rules and regulations for recycling of ships and it is applicable to the ships as well as the ship recycling facilities globally (IMO 2009). Pending ratification by majority of the Flag States, the HKC is yet to enter into force.

The regulations envisaged by IMO require every new ship to maintain an Inventory of Hazardous Materials (IHM) which identifies the hazardous materials contained in the ship's structure or equipment, their locations onboard, and their approximate quantities. IMO regulations also require the recycling facility to develop a ship-specific recycling plan, taking into account the information provided by shipowner. The recycling plan shall include information concerning the establishment, maintenance, and monitoring of 'safe for entry' and 'safe for hot work' conditions; and how the type and amount of materials, including those identified in the Inventory of Hazardous Materials, will be managed (IMO 2009).

Guidelines and recommendations on various aspects of ship recycling have been developed by a number of agencies like IMO (IMO 2012a, 2012b), Secretariat of Basel Convention (SBC 2003), International Labour Organisation (ILO 2004), European Commission (COWI A/S and DHI 2007), United States Environmental Protection Agency (EPA 2000), Occupational Safety and Health Administration of US (OSHA 2010), and Department of Environment, Food and Rural Affairs of UK (DEFRA 2007) in order to facilitate recycling of ships in a safe and sustainable manner.

1.2 STRATEGIES FOR SHIP RECYCLING

Ship is considered to be a complex product consisting of a number of material types used for its construction, a large number of various types of machinery, and a wide variety of piping and electrical systems. Dismantling of such a complex structural system requires careful planning and close monitoring during every stage in order to make it safe, environment friendly, and efficient.

Ship dismantling, especially that carried out in the Asian countries is considered to be one of the most hazardous activities. In India, based on the official data from 1995 to 2005, the average annual incidence of fatal accidents in the shipbreaking industry is found to be 2 per 1000 workers as against the corresponding value of 0.34 in the mining industry that is considered as one of the most accident prone industry (Demaria 2010).

Ship recycling sector happens to be labour intensive and managed with poor management practices and primitive technologies (Garmer et al. 2015). This can be attributed to various factors such as reduced profit margin in ship recycling; utilisation of only limited number of qualified technical personnel in SRYs; and lack of managerial, technical, and infrastructural development of countries in which the SRYs are located. A need is felt to develop systematic plans for better management of the ship recycling activities and to develop guidelines for applying advanced information technology applications such as product models in the ship recycling sector.

At present, many of the SRYs in the major ship recycling countries seem to manage the work without any significant development of necessary infrastructure. Layouts of most of the SRYs are found to be without a well planned design. Only limited publications are available regarding the design parameters for layout design of actual SRYs. More over, there are severe restrictions, especially in the Asian countries, on accessing the SRYs and on documenting the data related to the layout design of SRYs. There appears to be a **need to develop a methodology** which is simple, technically sound, and well structured for preliminary layout design of SRYs.

Strategy can be defined as an activity which involves setting up of the objectives, determining the actions to achieve the objectives and mobilising the resources to execute the actions. In order to achieve the objectives, ship recycling industry needs to use many strategies. The recycling strategies shall be developed taking into account the factors relating to safety, environment, health, productivity, quality, availability of resources, and sustainability of the industry. The objectives of the recycling strategies shall be to provide information, enhance support, remove barriers, provide resources, and to improve on the present condition of the industry. Development of strategies in ship recycling will help to focus on the efforts to get things done by taking advantage of resources and emerging opportunities; to respond effectively to resistance and barriers; and to ensure a more efficient use of time, energy, and resources.

The present study has approached the strategy development for ship recycling from two perspectives, firstly for ships and secondly for SRYs. Two recycling strategies have been proposed in this thesis from the perspective of ships for implementation by both shipowner and SRY. The first strategy is the development of a guidance plan for ship recycling, which will cover both strategic level and operational level of ship recycling activities. The guidance plan shall be able to function as a reference technical document that enables a SRY **to generate and implement a recycling guidance plan for each ship to be recycled in the yard**. The second strategy is the development of guidelines for enrichment of product models of ships from a ship recycling perspective. Implementation of these guidelines shall facilitate utilisation of the ship product models even during the recycling phase of a ship's life cycle. The recycling strategy from the perspective of SRYs involves the development of a methodology to facilitate design of efficient concept layouts of SRYs.

1.3 STUDY CONDUCTED BY USING VISUAL DOCUMENTATION AND BY SITE VISITS

A detailed study has been conducted by using visual documentation of the physical dismantling of a general cargo ship that was carried out at the SRY of Steel Industrials Kerala Limited (SILK) located in Azheekkal in the Kannur district of Kerala. The documentation consisted of 49 gigabytes of data consisting of both videos and photos. A number of visits have also been made to the above mentioned yard to observe the recycling processes executed in the yard.

1.4 SCOPE AND OBJECTIVES

Engineering and technological aspects of ship recycling activities have to be given a comprehensive framework which will facilitate execution of recycling of ships in a safe, healthy, and environment friendly manner. Various aspects of this framework, from the perspective of both ships and SRYs, have been addressed in this thesis. The objectives have been set as given below:

i. To develop a concept guidance plan for ship recycling, which can act as a reference document that will enable ship recycling yards to generate and implement a recycling guidance plan for each ship to be recycled.

ii. To propose guidelines for enrichment of product models of ships from a ship recycling perspective, which will facilitate the ship owners and ship recycling yards to utilise the product models in the recycling stage of ships.

iii. To develop a methodology for generation of efficient layouts applicable for ship recycling yards, which will enable the prospective yards to design an efficient layout during the initial stages of development of the yards.

1.5 ORGANISATION OF THE THESIS

A general introduction to the research topic and the objectives has been given in Chapter 1. In Chapter 2, review of literature on relevant topics related to ship recycling has been included. Chapter 3 describes the ship recycling guidance plan which has been proposed in this research as one of the recycling strategies for ships. Chapter 4 provides guidelines for the enrichment of ship product models from a recycling perspective, which has been proposed as the second recycling strategy for ships. It also contains desired features of a walk-through model, which have been demonstrated by the use of Two Dimensional (2D) views. Chapter 5 gives a methodology for generation of efficient layouts for SRYs, which has been proposed in this research as one of the recycling strategies for SRYs. Chapter 6 contains summary and conclusions of the present research work.

Screenshots of a Three Dimensional (3D) product model, enriched with some of the features proposed in Chapter 4 for engine room area and one of the cabins in the accommodation area of a ship, have been presented in Appendix A. A summary of various lacuna areas in the present ship recycling system and the recommendations in this thesis for resolution of these lacunas have been presented in Appendix B.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A comprehensive review of the literature has been made and is presented under three categories, viz., ship recycling guidance plan, product model for ship recycling, and layouts of ship recycling yards (SRYs).

Under the subsection on ‘ship recycling guidance plan,’ a brief review of literature on ship recycling plans, stakeholders in the ship recycling industrial sector, and the methods and the processes practised for recycling of ships have been presented. The subsection on ‘product model for ship recycling’ includes review of literature on product models of ships during various life cycle stages of ships. A brief review of literature on layouts of SRYs and the methods in practice for layout design of shipyards are presented under the subsection ‘layouts of ship recycling yards.’

2.2 SHIP RECYCLING GUIDANCE PLAN

McKenney (1994a, 1994b) has proposed a block breaking method, which is an adaptation of the concept of zone outfitting methods practiced in shipbuilding, for the ship recycling application. This study has recommended disassembling ships into blocks in a dry dock prior to removal of items inside them and then disassembling the blocks in a disassembly enclosure that is outside the ship. EPA (2000), DNV (2000), and OSHA (2010) have briefly described various main steps in recycling of ships, which are in practice, without going further into the details about the subprocesses as well as their sequences over the entire ship recycling process.

Secretariat of the Basel Convention under United Nations Environment Programme (SBC 2003) has proposed guidelines for environmentally sound management of the dismantling of ships, which comprises recommendations and information on processes, procedures and practices. An assessment of the prevailing practices and standards of ship dismantling in the major ship recycling countries has been made in this report. This document has also reported about the main steps in three different phases of the dismantling process. A list of the broad categories of stakeholders involved in three stages of ship recycling based on the locations of activities such as offshore, intertidal zone and land, have also been listed in this document along with a description of the perceived roles of the international agencies such as UNEP, IMO, ILO, shipping industry, and environmental groups.

Guidelines have been given by IMO (2003) and IMO (2005) targeting all stakeholders in the ship recycling process in order to minimise the potential problems related to health, safety and protection of the environment in the recycling facilities. These guidelines have sought to consider recycling as the best means to dispose of ships at the end of their operating lives. These documents also provide guidance in preparation of ships for recycling, in minimising the use of potentially hazardous materials, and in minimising the waste generation during a ship's operating life.

ILO (2004) has published guidelines, especially for Asian countries and Turkey, for assisting shipbreaking yards and regulatory authorities for implementation of ILO standards and recommendations on occupational safety and health, and working conditions in SRYs. In these guidelines, division of shipbreaking activities into three core phases, viz., preparation, deconstruction, and material stream management, has been considered for easy identification of individual activities and consequently the tasks which are hazardous to safety and health of workers. These guidelines have claimed that using this approach, shipbreaking can be undertaken in a controlled manner and thereby eliminate or minimise the risks associated with the work to be undertaken. In these guidelines, a 'model safe shipbreaking plan' which incorporates the above division of shipbreaking activities into three phases has been presented as an example along with the general guidelines for its preparation. It has been recommended to apply a logical and systematic approach to shipbreaking operations in order to carry out the work safely with due protection of workers from the inherent occupational hazards. These guidelines have also specified the responsibilities of some of the stakeholders as part of creating a legal framework for safe recycling of ships.

Wijngaarden (2005) has put forward two concepts for dismantling ships. First concept is based on an early vessel separation method in which a ship is to be cut into a fore part and an aft part in the afloat condition, with the aft part going to be supported by a floating dock after the separation. The two parts are to be dismantled in two separate facilities. Second concept consists of utilising a jetty for stage-wise dismantling of engine room and deckhouses of ships, and using beachside yards for dismantling of steel hulls.

Thomas (2006) has indicated various options for a ship that has reached its end of life. He has presented a concept of a Ship Recycle Plan, which is based on a logical method, to identify, assess, and manage environmental, safety, and project risks in recycling of ships. The study has also discussed about the required preparation activities of ship prior to its handing over to a recycling facility. Requirements for a set of interlinked registers, either in electronic format or paper based documents, which should be utilised for the development of the plan have also been mentioned in this paper.

Department of Environment, Food and Rural Affairs of United Kingdom (DEFRA 2007) has presented a brief outline of the basic processes to be carried out for initial dismantling of a ship in a wet berth and final dismantling in a dry dock. This document has also made recommendations on storage and transportation of various materials removed from the dismantled ship.

Misra and Mukherjee (2009) have proposed to divide the whole ship dismantling activity into three stages, viz., offshore-road, intertidal zone/docking facility, and shore/port. They have listed various stakeholders involved in each of these stages. Overall roles and responsibilities of stakeholders under the broad categories of regulatory authorities, environmental groups, workers, shipowners, shipbreakers, brokers, and the trading community have been specified by them. They have also presented a flow chart which shows the main activities involved in ship recycling, from the decommissioning of ship to the disposal of materials. Procedures followed for dismantling of ship, including those for cutting and surface preparation, have been reported in this book. They have provided guidelines for developing a ship recycling plan in accordance with the requirements of IMO.

IMO (2009) has stipulated the rules and regulations for safe and environmentally sound recycling of ships and these regulations have been adopted by the ‘Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009’ (HKC). It covers the requirements for ships and ship recycling facilities as well as the reporting requirements. Requirements for ships include those applicable with respect to design, building, operation, and maintenance of ships; preparation for recycling of ships; and surveys and certification. Requirements have also been provided regarding the control and inventory of hazardous materials during various life cycle stages and regarding ship recycling plan as part of preparation for ship recycling. However, the HKC is still awaiting ratification by the majority of Flag States.

Tilwankar et al. (2010) have presented a typical ship recycling plan that is followed uniformly by SRYs in Alang, India where beaching method is practised. They have reported about the division of the complete recycling activities into twelve work activities ranging from the first activity consisting of inspection, preparation, and certification to the last activity of sending the graded steel for rolling and the scrap steel for melting.

Infrastructure Leasing and Financial Services Ecosmart Limited (IL&FS Ecosmart 2010) has published a technical guidance manual for shipbreaking yards in order to assist in carrying out environmental impact assessment (EIA). It contains information related to the rules and regulations, necessary permissions, and the enforcing authorities applicable during various stages of ship recycling in India. This manual has provided a broad description of the steps followed for recycling of ships using any of the methods.

Sivaprasad (2010) has considered division of ship recycling activities into four stages based on the locations in which the activities are carried out, viz., offshore-quay side, intertidal zone, beach, and land. He has listed various processes which are involved in each of the above stages. He has identified the major stakeholders of ship recycling system and he has listed their roles and responsibilities for the case of beaching method of ship recycling. The study has also proposed a ship recycling content estimation method for the measurement of productivity in ship recycling processes.

Lloyd’s Register (2011) has briefly described some of the key stakeholders in ship recycling, such as the agencies involved with the regulatory aspects, member associations, and environmental pressure groups. It has been concluded that the definition of 'shipowner' as per the (HKC) includes cash buyer also and therefore, the cash buyer shall be made responsible as a shipowner. Ship recycling methods which are in practice in different parts of the world have also been described in this report.

IMO (2011) has provided guidelines for preparation of a ship-specific recycling plan in accordance with the requirements of HKC. This document gives general guidance on the information that should be collected and reviewed by the SRY for developing the recycling plan, and guidance for the recommended content of the recycling plan. These guidelines require the ship recycling plan to contain description on how a specific ship will be recycled in a safe and environmentally sound manner. In the ship recycling plan, IMO requires to include various steps in the ship recycling process and the sequence of the recycling processes. The dismantling sequence is required to be ship-specific and to take into account the cutting operations and locations of hazardous materials. IMO (2012a) has given recommendations for safe and environmentally sound recycling of ships and has specified the responsibilities of four stakeholders, viz., the Ship Recycling State, Ship Recycling Facility, Shipowner, and the Flag State.

Urano (2012) has made a review of various ship recycling regulations and he has examined the current issues related to the industry. Efforts by various regions including European Union, China, and Turkey and the contributions by Japan in addressing the issues in ship recycling have been analysed in the study. He has also discussed about the demolition method and the processes carried out for a pilot green ship recycling project of a pure car carrier which was recycled in Japan in compliance with the HKC and by adopting afloat method.

Hiremath et al. (2015) have reported about the absence of any structured study or published literature that provides clear understanding about the stages and steps involved in the present practice of recycling of ships and the associated complexities. They have opined that this knowledge gap will adversely affect matters such as the development and dissemination of safe and environment friendly practices of ship recycling, modernisation of the sector, and improvement on compliance with the ship recycling regulations. This study has investigated recycling of six types of ships and has documented a ‘typical ship dismantling and recycling procedure’ followed in Alang, India on the basis of data collected from the ship dismantling yards and the interactions with field personnel. The whole ship recycling process has been divided into twelve main work activities. A brief description of each of the above work activities, together with the time required for its completion, and the input and output of each activity have been provided in this paper. This study has also estimated and compared the weight distribution of various types of ships. They have pointed out that clear understanding of the processes and steps involved in ship dismantling sector will enable to quantify the impact of the industry, to improve the process conditions, to generate the information which is useful to reduce risks to environment and humans, and to implement the spirit embedded in the ship recycling regulations.

Hiremath et al. (2016) have tracked the actual processes involved in recycling of two numbers each of bulk carriers, general cargo ships, and container ships, which are the three predominantly handled ship types in the recycling yards in Alang, India. They have developed a ship-specific recycling plan for these types based on the field data. They have referred to the earlier investigation by Hiremath et al. (2015) and have presented further division of the work activity involving structural dismantling of the ship into subtasks based on the actual processes practised in the yards. This study has concluded that the above types of ships have been dismantled in a similar manner since these shiptypes have comparable structural arrangements as well as similar environmental and safety considerations. They have commented that the guidelines given by IMO do not give a clear understanding on how to prepare a ship recycling plan. They have attempted to fulfil this gap by their study. A method to estimate the man-days required for recycling a given ship of known Light Displacement Tonnes (LDT) has also been proposed in this study.

Government of India (Ministry of Shipping 2017) has formulated 'Shipbreaking Code (Revised), 2013' and it has entered into force in February 2017. This revised code has considered activities such as beaching, cutting, breaking, and dismantling of ship; reprocessing, reducing, and reusing of the components and materials there from; and the associated operations including storage, treatment, and disposal of the components and materials as part of ship recycling activities. This revised code has presented a flow diagram that shows the sequence of processes involved for obtaining clearances from various authorities for the ships which are destined for recycling in the Indian yards.

JICA (2017) has reviewed the present condition and has assessed issues of the ship recycling industry in Gujarat, India, with respect to the processes, occupational safety and health, and environmental considerations. The main processes and their sequences based on the present practice of ship recycling in the Alang-Sosiya Ship Recycling Yard (ASSRY) has been presented in this report in the form of a flow chart.

2.3 PRODUCT MODEL FOR SHIP RECYCLING

Martin (1979) has defined product model as a 'logically structured, product oriented database' and has stated that it is all about properly organising information. He referred the product model as comprising of logically complete database subsets tailored to the requirements of specific yard functions such as structural design, material control, and production control. He stated that each of these models could be explicitly linked to other models in the database. He has identified that the design information contained in the product model can be used by other yard functions to estimate material requirements, to define work content, to issue purchase orders, and to schedule the work.

Pratt (1995) has given a brief description of some of the techniques used for modelling and virtual prototyping in product realisation in the field of mechanical engineering. The study has considered division of product realisation process into three stages such as design, manufacturing engineering, and production. This study has referred to solid models as models consisting of geometry alone whereas product models as containing additional engineering semantics. He has mentioned that different types of product models are generated and utilised for various purposes during the course of product realisation and that each of such models is usually generated for some relatively narrow purpose. Most of such models are generated from a primary Computer Aided Design (CAD) model which has a higher level of detail and geometric accuracy than the other types of models. He has added that one of the major concerns of the developers of integrated computer aided product realisation systems is about the transmutation of such models from one type into another.

Johansson (1996) has reported that in shipbuilding, a ship's product model is successively built up during the design process with both geometric and nongeometric information and it is then further extended with production engineering information such as definition of building strategy and assembly structure. He has mentioned that in product model concept, an information database about the ship is stored in a structured way that is specialised for the shipbuilding industry. It is an approach alternative to the traditional information flow which is in the form of drawings, part lists, documents etc. He felt that it is more appropriate to consider the ship's model as a 'product information model' in order to stress on the difference between the information based model and a geometry based model of a product. He has highlighted the advantages of using a product model, as against 2D drawings, for developing complex areas like engine room. He has recommended to make a shipbuilding CAD/Computer Aided Manufacturing (CAM) system efficient by basing it on the product model concept and by addressing all the phases in the design process so that information could be used between various stages. He has discussed various requirements to be satisfied by a product model based system for use in shipbuilding. Also, he has stated that the implementation of the product model concept together with the associated systems and procedures in a shipbuilding yard could lead to cost reduction, increased productivity, and competitiveness.

Baum and Ramakrishnan (1997) have assessed the applicability of 3D product modelling technology to shipbuilding and have presented a technical approach for quantifying the cost benefits of using 3D product modelling technology for shipbuilding. The benefits in using 3D product modelling technology in ship design and production have been identified in the study as elimination of component interferences; increase of the dimensional accuracy of design data; reduction in design rework related to inadequate visualization, engineering changes, and manual data recreation; and improvement on the productivity in product design. It has been mentioned that the product model can be utilised by the yards to provide data for automated manufacturing processes, planning, construction-specific drawings, and exchange of data with contractors. They have also identified that the 3D product model of a ship enables concurrent engineering, which allow for design alternatives and consideration of factors such as manufacturability, accessibility, and maintainability at an early design stage; acts as a single source of ship's data for data generation and management; allows for design automation that increases productivity and facilitates generation of nearly error-free 2D drawings; enables to perform dynamic 'walk-through' of ship models; helps the shipyards to reduce paper work; and enables the yards to deliver a product model of the ship to owner for supporting life cycle maintenance.

Barry et al. (1998) have stated that CAD/CAM offers opportunities to improve productivity, through automation, and life cycle management. They have reported that digital data can be easily transferred from one form to another, like CAD files to Computerised Numerically Controlled (CNC) code for driving automated machinery, and also can be linked to a diverse range of other data for which the links may also be through the internet. They have made recommendations for shipyards of various sizes to tailor CAD/CAM to their needs. They have identified eight key concepts to improve productivity, viz., process re-engineering, integrated product model, design for Numerically Controlled Cutting (NCC) production, advanced outfitting/group technology, a flexible standard product line, concurrent engineering, advanced workflow control, and statistical process measurement and control. They have considered product model to be the essential communication tool for concurrent engineering. They have mentioned that product models have advantages also in the presentation of the information. 3D drawings as well as isometric or perspective drawings, which enable workers to understand and plan their work in a better way, can be easily generated from a product model which can be considered to be a powerful tool to maintain a consistent database and to facilitate coordination between design and production. They have suggested a concept to create a product model using a Personal Computer (PC) based system.

Ross and Garcia (1998) have summarised the evolution and the prevailing state of the art of ship product model. They have stated that product model technology can simplify the tasks of design, production, and procurement in shipyards because data is entered just once into the system and the whole yard can operate from the same database i.e. the product model. They have listed the characteristics of an advanced product model such as single integrated database; graphical user interface with a consistent format; topological relationships among components of the ship design; macros and parametric tools; and open structure to allow for data retrieval to support manufacturing functions like numerically controlled cutting and bending, material handling and tracking, robotics interfacing, development of build strategy, and project management. They have stated that the product model, being a single database, enables high level of integration, allows carrying out of concurrent engineering, and prevents inconsistency of information. This study has examined two practical applications of product model technology: a new construction project in a small shipyard and a conversion project in a large yard. They have claimed the latter as the first project in which a complete 3D product model of hull structure as well as outfitting was generated for a ship conversion project. The example on conversion has illustrated the generation of product model for only a portion of a ship. They have concluded that the ship product model technology can be applied for newbuilding as well as conversions of ships in a practical manner, and can also be extended to ship repairs.

Ross and Abal (2001) have described 3D product modelling technology within the context of small shipyards by addressing the design and construction of newbuilds. In this study, a 3D product model system has been defined as “a computer program that supports the analysis and informational needs for engineering, design, construction, and maintenance of a ship.” They have mentioned that by having a single database, the necessity of transferring information among different databases can be avoided and thereby avoiding the risk of information loss or errors and incompatibilities. The capabilities of product models of ships and the advantages in using the product models have been listed. Case studies on three shipyards which had upgraded from their traditional methods in design and production to the 3D product modelling technology have been presented in this study. They have concluded that the small shipyards which used 3D product modelling technology had achieved both improved quality in production and significant savings in labour cost, labour hours, materials cost, and construction time. It was also established that 3D product modelling has provided more benefits to those yards which also upgrade their production facilities and processes. They have considered 3D product modelling technology to be not widely applicable for repair and small conversions of ships; however, they have anticipated that the applicability will increase in future as many of the ships to be converted would have been originally constructed to 3D product model designs.

Contero et al. (2002) have analysed the impact of quality of product model data in the implementation of collaborative engineering in an extended enterprise framework, with reference to automotive industry. They have introduced the new concept 'extended modelling' and defined it as "a modelling methodology that integrates different perspectives from the product development process in the frame of the extended enterprise collaboration" and pointed out that using a common modelling strategy between partners will facilitate reuse of the generated model and improvement of the effectiveness of downstream applications. They have recommended establishing 'modelling for X' methodologies, especially for manufacturing, analysis etc., analogous to 'design for X' methodologies.

Whitfield et al. (2003) have reviewed the product modelling techniques applied to ships. They have examined the present state of the art and its shortcomings and have proposed future directions in order to solve the issues on integration between applications. They have covered the representations of ship product data, techniques used for product modelling and their integration issues, and the life cycle issues. They have addressed the ship product modelling techniques that provide a central store of neutrally formatted data that is common to all ship design tools. Such techniques help to ensure consistency among various models that are generated using disparate software tools. They have indicated that the requirement, representation, and utilisation of the product model will change from phase to phase during a ship's life cycle. For example, 3D geometrical data is being used extensively during design and production phases and bill of materials during the disposal phase. They have considered the construction of the ship Standard for the Exchange of Product Data (STEP) to be the most significant development. They have also reported that much consideration has not been given about the nature of product model for utilisation in the postcommissioning stages of ships.

Goldan and Kroon (2003) have reported about advancements in digital photogrammetric measuring techniques and about utilisation of these techniques in combination with CAD/CAM for generation of as-built models of ships for repair applications, such as repair of damaged areas on the ship hull. They have described the advantages and difficulties in implementation of the above techniques.

Oetter and Cahill (2006) have proposed design guidelines to be used for product data model based on its long term intentions. They have reported that most of the ship designers and shipbuilders limit the modelling of information only to the level that is enough to build and classify a ship. They have indicated that by having detailed product models coupled with third party maintenance, training, and logistic support operations, tremendous reduction in life cycle operations cost can be achieved by the shipowners and operators. They have described the issues for consideration in determining the scope of work in product modelling of ships for production design and for life cycle design. They have applied 'modelling for' concepts, such as 'modelling for construction', 'modelling for engineering support', 'modelling for production support,' and 'modelling for life cycle support,' in the product modelling of ships in order to decide on the scope of modelling effort required for various applications during design, production, operations, and maintenance. The benefits of utilising product data models of ships for operations, maintenance, and training have been indicated in this study.

In order to comply with the IMO requirements on inventory of hazardous materials for the new ships, Gramann (2006) has proposed to develop an inventory software tool which can link the data received from manufacturers or suppliers, on materials and equipment onboard, to the shipyard's software assembly system. He has indicated that such a linking inventory software tool would reduce the manpower and keep the data manageable and should automatically generate a ship specific inventory. He has suggested to assure data security, with respect to changes on the computer systems, for a minimum period of 30 years thus enabling the accessibility of data after the operational life of a ship by the recycling yards in terms of the exact information about hazardous items and the utilisation for the occupational safety and environmental protection measures. He has recommended to conduct document search, inspections, and sampling and analysis of materials for obtaining information about the material contained in existing ships.

Briggs et al. (2006) have described the processes to integrate product model data for design, engineering, and production of ships with the product model data for life cycle support of ships. This study has discussed about the utilisation of product model data in various processes in a ship's life cycle, viz., ship operation, damage control, maintenance, and repair.

Okumoto et al. (2006) have described the concept of simulation based production in shipbuilding, which was primarily intended to facilitate production with less-skilled workers. This study has presented four examples of their successful application in a Japanese shipyard. This study has listed the advantages of using CAD/CAM technologies as decreasing lead time, effective production without backtracking, decreasing material cost, non-skilled production, and increased work safety.

Kim et al. (2007) have developed a digital mock-up system to construct product information model for shipbuilding. The above system has used available economic development tools and it has been proposed for small and medium sized shipyards which do not have their own technology to develop product model or can not make significant investments in professional computing facilities. The practicability of the system has been verified in this study by applying it to four different types of commercial ships.

Kassel and Briggs (2008) have proposed an alternate approach to the data exchange which is based on general purpose STEP (Standard for the Exchange of Product Model Data) application protocols, in the case of product models of ships.

Dilok et al. (2008) have examined the strategies employed in various industries in the context of design for deconstruction or disassembly for their suitability to shipbuilding industry. They have proposed 'design for dismantling' philosophy in the case of shipbuilding, to enable ship's components to be easily reused, remanufactured or recycled at the end of its life and thereby minimise their environmental impact. Guidelines to incorporate the design for dismantling philosophy in ship design have been given in this study. They have emphasised the need to maintain an accurate green passport and to incorporate the changes on design and changes on equipment into it by the successive owners and to finally hand over the document to the recycling yard. They have also discussed about the ways to address the principles of maximising equipment reuse and material recycling from the initial stage of ship design.

Papanikolaou et al. (2009) have defined 'Design for X' concept as "the optimization of a ship with respect to specific important performance indicators and properties, such as design for safety, design for efficiency, design for arctic operations and design for production." Application of the above 'Design for X' concepts' to ships has been discussed by them. The concept of 'design for safety' has been newly proposed in this study. They have presented recent developments in 'design for production' and 'design for arctic operations' and have reviewed 'design for efficiency' with particular emphasis on fuel savings and reduction of air emissions.

Jang and Hong (2009) have forecasted the utilisation of an integrated set of software tools for ship design and production and the extension of these tools to the management of ship throughout its life cycle. They have anticipated the future ships to be designed and built according to a product model approach (PMA) philosophy that is being evolved in the industry. This study has considered the first building block for this process to be the generation of a central database, which includes material properties, structural geometry and element relationships. They have described 'single product models' as "single 3D CAD data models incorporating hull structure, propulsion, steering, piping, electrical, Heating, Ventilation, and Air Conditioning (HVAC) and other systems, which make up a complete ship" and have reported that the shipbuilding industry has started developing and using single product models to improve the management and efficiency of design and production of ships. This study has identified the issues related to the CAD interoperability, i.e. sharing of CAD models between various applications and suggested solutions. A review on Computer Aided Approval (CAA) processes which involve review and approval of ship design and construction based on digital documents as well as data model files has also been included in this report.

Sivaprasad (2010) has proposed to generate a ship product model, as part of the best practices to be followed in the ship recycling industry. The product model has been recommended to be a data model of the ship in its 'as is' condition at the time when it is ready for recycling. It has been suggested to identify materials and processes based on the product model and to use the model as a preprocessor for generating input to the expert systems for ship recycling applications. He has recommended for considering the ‘design for ship recycling’ concept, which was proposed in this study, during the generation of the product model. For effective implementation of the ‘design for ship recycling’ concept, he has proposed an ‘extended life cycle model’ of ships by adding a few stages, such as concept design, marine surveys, conversion, and lay-up, to the conventional life cycle stages.

Sivaprasad and Nandakumar (2012a) have defined ‘design for ship recycling’ as “a set of design and development activities spread over the entire life cycle stages of a ship, incorporating ideas for design/selection of structural parts, equipment, material, and knowledge base that will facilitate clean and safe partial or end of life recycling of ships and her components.” Sivaprasad and Nandakumar (2012b) have assessed the scope of expert system for ship recycling and have presented a web based expert system.

Jain et al. (2015) have reported that the first three phases in the life cycle of a ship, such as design, construction, and operation, are closely related to each other whereas the fourth and the last phase i.e. ship recycling has no interaction with the other phases. This has been attributed to the designing of ships by taking into account only the operational requirements and not giving any focus to the ship recycling activities during the design stage. This study has emphasised the need to create a link between the design and recycling phases of ships so that feedbacks can be given to the ship design stage. They have suggested that such links can be created by studying the actual recycling process of ships and assessing the problem areas that can be provided with solutions in the design and construction stages. This could lead to optimisation of ship recycling process, by allowing a reduction in the costs for recycling as well as an effective disposal of hazardous items, after a period of 25 to 30 years when such better designed ships reach their end of life. They have presented an overview of the ‘design for ship recycling’ concept and underlined the necessity to design ships for recycling. They have proposed a methodology for detailed scientific study of ship recycling process, which can be used to improve the ship designs by incorporating the requirements of SRYs to achieve cost effective green ship recycling. They have emphasised to make an inventory detailing all the hazardous or non-hazardous materials on board, with the cooperation from the suppliers, and have stated that this would give exact locations of materials that are utilised in various areas of a ship. They have also mentioned that such information can be stored in the 3D drawing of ships with the advanced computer technology.

Andrade et al. (2015) have reported about a lack of literature on the application of product life cycle management (PLM) techniques in ship design. They have divided the PLM concept that is applied to ship design into six key elements such as database; modelling and simulation tools; value chain processes; product hierarchy management; product management; and project management. According to the modelling purpose, virtual prototyping methods have been divided into visualization, fit and interference of mechanical assemblies, testing and verification of functions and performance, evaluation of manufacturing and assembly operation, and human factor analysis. This study has described the application of PLM methods in each of the life cycle stages of ships, from conceptual ship design to decommissioning, and the utilisation of virtual prototyping in each stage. For the decommissioning stage of the ship, this study has suggested to use virtual prototyping as a tool for planning the scrapping process in order to make the operation safer and inexpensive. For this stage, this study has proposed to use the virtual prototyping methods such as visualization, evaluation of manufacturing and assembly operation, and human factor analysis. They have proposed an integrated design platform, which merges PLM and virtual prototyping concepts, to facilitate the ship design process and to apply the PLM concept to the ship value chain. This study has suggested ways for implementation of the proposed methodology of integrated design platform in each of the life cycle stages of ships. Their proposal also involves providing the information about structure, material components, toxic components etc. during the decommissioning stage.

Smogeli (2017) has illustrated the concept of cloud-based digital twin and has described about the introduction of it for maritime applications, from concept design to decommissioning of ships. He has considered a digital twin as a digital representation of a physical object, such as ship, which can contain various digital models and collections of information and processes related to the object throughout its life cycle.

Morais (2018) has provided a detailed description of digital twin from a shipbuilding perspective. He has mentioned that the idea of digital twin implies that there is only one exact digital replica for each ship and the digital version will get updated for every changes which are made to the ship. He has listed about the information that should be linked to the model in order to make a true digital twin.

2.4 LAYOUTS OF SHIP RECYCLING YARDS

McKenney (1994a) has examined the feasibility of establishing a ship scrapping facility in Philadelphia. He has reviewed the current methods of dismantling of ships and has proposed a block breaking method, analogous to zone outfitting methods in shipbuilding, for a ship wet berthed in a dry dock. McKenney (1994b) has proposed a block breaking method, which consists of disassembling ships into blocks in a dry dock before removal of items inside them and then disassembling the blocks in a disassembly enclosure that is outside the ship. He has specified various criteria, related to business structure, location, and site, which must be considered in order to establish a ship scrapping facility.

Meller and Gau (1996) have made a review of the literature of the previous ten years regarding the layout design problem and have presented the trends in the layout design methodologies, algorithms, and objectives. As per the reviewed literature, they have mentioned that the main objective of facility layout problem has been to minimise the material handling costs subject to the constraints on area requirements and locational restrictions of various departments in the facility. They have identified the two traditional approaches for finding an optimal solution to the layout problem, viz., the quadratic assignment problem approach and the graph-theoretic approach.

Yang et al. (2000) have reported that most of the existing literatures on layout design problems belong to two major categories: algorithmic approaches and procedural approaches. They have cited that the algorithmic approaches use simplified objectives and design constraints for arriving at a surrogate objective function and then obtain the solution of the objective function. They have noticed that these approaches usually include only quantitative data and the evaluation of design solutions can be made by comparing the values of the objective functions. They have stated that the quantitative results obtained through these approaches had not been found to be capturing all the design objectives and that further modifications had been required to satisfy various design requirements including department shapes, material handling systems, and space utilisation. In addition, it is a prerequisite for the designer to be trained in mathematical modelling techniques in order to use algorithmic approaches for solving layout design problem of fabrication facilities. This study has also reported that the procedural approaches are capable of incorporating quantitative and qualitative objectives in the layout design process. These approaches involve division of the design process into several steps and solution of these in a sequential manner, and the evaluation of the layout alternatives is done at the last step. They have concluded that the success in the implementation of a procedural approach depends on the generation of quality design alternatives that are developed by an experienced designer, and therefore inputs from an expert during the design process is necessary for an effective layout design. They have opined that the systematic layout planning (SLP), which was proposed by Richard Muther (Muther and Hales 2015), is relatively straightforward and is a proven tool which is in practice for layout design over the past few decades. In this study SLP procedure has been used to solve the layout design problem of a fabrication facility and analytic hierarchy process has been used for evaluation of the design alternatives.

The necessity to introduce a new generation ship dismantling facility that is environmentally compliant and the need to employ advanced technology in such a facility has been pointed out by DNV (2001). An outline of a model ship dismantling facility, which is configured for large and steel intensive ships, to be located in Europe has been presented. The capacity of the yard has been arrived at based on a projected throughput for a facility and future scrapping volumes of European ships. The key functionalities of a ship dismantling yard, viz., wet berths, primary dismantling facility, large capacity cranes, facilities for secondary dismantling activities as well as sequential breakdown into component elements, external storage areas, and secure storage areas has been specified in this study. This study has identified the factors which would affect the selection of primary dismantling facility as size range of ships to be accommodated, product mix of ships to be processed, prevailing site topography and ground conditions, and the annual throughput of ships to be deconstructed.

Secretariat of the Basel Convention (SBC 2003) has examined the gaps between the practices in the existing ship dismantling facilities and an environmentally compliant model ship dismantling facility. It has provided recommendations on procedures, processes, and practices in ship dismantling for implementation in the ship dismantling facilities in order to achieve environmentally sound management. Key functionalities of a model ship dismantling yard which are listed in the guidelines include containment of hazardous materials, workstations for secondary dismantling and sequential breakdown into component elements, workstations for removal of hazardous and toxic materials, temporary storage areas for benign materials and steel work, secure storage areas for hazardous wastes, storage areas for fully processed equipment and materials, and proximity to proper disposal facilities. A conceptual layout of a model shipbreaking yard that shows the subdivision of the yard into seven zones has been presented in these guidelines. However, these guidelines have not considered the application of the requirements to various types of dismantling sites and various methods of docking of ships.

Chabane (2004) has investigated the possibility of supplementing the shipbuilding activity in a small shipyard with substantial repair workload without disrupting its work organisation to achieve economic sustainability in periods of fluctuating demand. He has made an extensive analysis of work processes in both shipbuilding and ship repair by taking into consideration the current practices in shipyards. Based on the above analysis, he has carried out layout design for three cases, viz., a shipbuilding facility, a ship repair facility, and a mixed shipyard facility for handling both shipbuilding and repair activities. These layouts have been optimised by means of SLP procedure proposed by Muther. He has opined that the SLP procedure provides a well structured pattern for the layout design process and the optimisation technique is graphical. SLP technique has been found to be efficient for situations in which the available data are not sufficiently detailed as in the case of an early design stage of a project. Sophisticated quantitative methods that are available require accurate and reliable data, and getting such data is unlikely especially for a new design. He has recognised that the activity chart originally proposed by Muther contemplates qualitative parameters, in lieu of quantitative parameters, and this is useful for projects in which detailed quantitative information are not available in the design stage and for supporting or auxiliary services in which flow of materials is not relevant. He has also specified the space requirements of various activity areas in a shipbuilding facility and repair facility based on standard data and statistics relating to similar shipyards. Activity relationship chart, activity relationship diagram, space relationship diagram and a layout alternative for the facilities have been presented in this paper. He has identified five requirements, viz., existence of potential customers, availability of skilled force, financial funding, selection of a suitable product mix, and implementation of an efficient production process, to be fulfilled in the development of a new shipyard to make it economically viable.

ILO (2004) has recommended dividing the ship breaking area into zones in order to ensure that each type of material is positioned and handled without posing any hazard to the safety and health of workers and has described the activities to be conducted in each zone together with the hazards that can be encountered. A general layout showing the subdivision of the shipbreaking area that can prevent and reduce the risk of accidents from the materials being handled, processed, and stored is also presented in this document.

Alkaner et al. (2006a) have considered the development of industrial facilities as a process that consists of extensive interaction among a number of layout design parameters and have stated that the result of the activity can directly be used as an input for decision making between the layout alternatives as well as selection of the final design. They have proposed a systematic approach for planning a generic ship dismantling yard. They have examined the types of current ship dismantling facilities and the current ship dismantling practices in the major ship dismantling countries. They have noticed that it is computationally infeasible to obtain optimal solutions for layout problems because of the multitude of objectives, number of design variables, and the complexity of problems. Therefore, they have suggested to go for sub-optimal solutions. They have also stated that because of the high computational difficulty of layout problems, heuristic methods give good sub-optimal solutions. They have used the SLP methodology to generate layout variants for case study of a dismantling yard. However, scope of this study was limited to the key zones in a dismantling facility, viz., the primary dismantling zone along with the docking system alternative and the secondary dismantling zone. They have introduced a streamlined modelling approach for the critical facility components. Eight layout variants have been generated, based on expert judgement and opinion, at the concept development stage for the primary and secondary phases in ship dismantling processes and their schematic representation have been presented in this paper.

Alkaner et al. (2006b) have made a comparative analysis between ship production and dismantling from a process characteristics point of view. They have listed key performance indicators for both processes. The areas of comparisons included health and safety regulations for both processes, use of equipment and facility, and environmental impact of yard operations. They have identified that the major difference between the two is associated with the uncertainties of the product at its end of life. They have reported about the absence of documented and economically proven production planning and scheduling mechanisms to deal with disassembly. They have stated that the products which are designed for disassembly are one of the requisites for a workable partially automated system in dismantling and that the use of automation in ship dismantling has not been foreseen. They have discussed the concepts such as 'Design for Environment' (DfE) and 'Design for Dismantling' (DfD) which are intended for improving the life cycle performance of the ship and for integrating the last stage of the ship, i.e. dismantling, with the design and construction stages. This study has also given guidelines for implementation of these concepts.

DEFRA (2007) has given a general overview of technical and regulatory requirements concerning operation of ship recycling facilities in the UK. The technical part has covered the requirements related to preparation of a facility to undertake ship recycling activities such as site, staff, equipment, and infrastructure; and the requirements at each ship recycling stage including preparation of the ship for recycling, the recycling process, and the waste management. The regulatory part has mentioned about the regulatory requirements relating to the development and operation of facilities for ship recycling. This document has also indicated approximate site areas for small, medium, and large facilities for ship recycling and has presented an indicative general layout of a medium sized SRY.

Fafandjel et al. (2009) have recommended to employ SLP procedure for improvement of production process design. They have used the method to solve a layout design problem of a pipe production workshop in a shipbuilding yard, which was a multiple objective decision problem. They have stated that the algorithmic approaches are more effective for solving quantitative layout design problems and that these approaches may not be adequate to provide quality solutions to their multi-objective decision problem. They have recognised that SLP procedure is having the features of simplicity in the design process and objectivity in the multiple criteria evaluation process as compared to the algorithmic approaches and have suggested to use SLP for solving qualitative problems during the preliminary design stage of the layouts.

Matulja et al. (2009) have proposed a methodology to generate a preliminary optimal layout design of production areas in a shipyard based on SLP procedure. The methodology consists of four phases, viz., establishing the closeness relationships of the selected production areas based on a survey of experts, generation and evaluation of layout variants, selection of the most optimal layout by using an analytical hierarchy process, and a sensitivity analysis to check the stability of the selected layout. The methodology has been verified in the optimisation of a real shipyard's layout design. They have given a brief account of the characteristics of layouts of production areas in a shipyard.

IMO (2009) has stipulated the regulations for ship recycling facilities, which include requirements on control and authorisation of facilities as well as requirements with respect to Ship Recycling Facility Plan (SRFP).

IL&FS Ecosmart (2010) has given a brief account of various aspects of shipbreaking industry in India, the conceptual aspects of pollution control and Environmental Impact Assessment (EIA) for the shipbreaking projects. It has also given guidance on the legislative requirements and the procedures for obtaining EIA clearance for shipbreaking yards in India. Infrastructural requirements of a shipbreaking yard and the considerations to be given while sizing a ship recycling plot have been specified in the guidelines.

IMO (2012a) has developed guidelines, primarily targeting ship recycling facilities, for safe and environmentally sound recycling of ships and for global uniform implementation of requirements of the HKC. The recommendations are related to various aspects such as facility management, facility operation, compliance with requirements on worker safety and health, and compliance with requirements on environmental protection. These guidelines describe the recommended content and the format of SRFP, which is required to be submitted by ship recycling facilities as per the HKC (IMO 2009). Layout of a SRY has been given as part of the facility information for guidance purpose.

IMO (2012b) has provided recommendations for parties on establishing mechanisms for authorising the ship recycling facilities in accordance with the requirements of the HKC. These guidelines are primarily for use by Competent Authorities. They are also useful for ship recycling facilities in the preparations for the authorisation process.

Watkinson (2012) has conducted a case study on ship recycling facilities which employ beaching method and has identified the actions to be undertaken in the short, medium, and long term to enable them to be compliant with the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, 1989 and the HKC. The proposed actions are given for both facility operators and competent authorities and are for dealing particularly with the environmentally sound management of hazardous wastes and materials, and other wastes.

Urano (2012) has made a brief review of a project that was proposed by Japan for reforming SRYs in India. This study has also discussed about the work procedure and the time schedule which were followed and the demolition techniques; for cutting, paint removal, and environmental protection against pollution; which were utilised for executing a pilot green ship recycling project of a pure car carrier which was carried out in Japan in compliance with the HKC and by adopting afloat method.

Litehauz (2013) has made a review on the currently applied ship recycling methods and has identified environmentally sound and cost effective alternatives to the beaching method of ship recycling, such as pier breaking method and slipway method. This study has presented the cost aspects of upgrading noncompliant ship recycling facilities to model facilities complying with the standards of environmentally sound management specified by Basel Convention. The cost analysis has been carried out for three model facilities that are having dismantling capacities of 25000 LDT, 50000 LDT and 100000 LDT. This study has listed various equipment required during each phase of dismantling and has made an assessment of the suitable locations for upgraded facilities.

Song and Woo (2013) have proposed a methodology, which is based on actual product data of a target ship and actual shipbuilding operation data, for the preliminary phase of the layout design of a shipbuilding yard. They have stated that the four kinds of engineering parts required for shipyard layout design are civil engineering, building engineering, utility engineering, and production layout engineering and the most important part among these is the production layout engineering since its outcome is the foundation of other parts and since it determines the capacity of the shipyard during its operational life cycle. They have indicated that the production capacity of a shipyard is mostly determined by the resources secured, area of the yard, and the extent of proximity of the work stages or activity areas. This study has suggested to conduct the initial layout design of shipyards with reasonable input data and a logical methodology since it may be hard to change majority of the resources and activity areas from their originally installed condition even if there is a need to increase the production capacity.

MECON Limited (2013) has described the features of a new ship recycling facility, which consists of ten plots, to be established near Mundra West Port in India. The facility has been planned to recycle ships of sizes up to about 16000 LDT. A brief analysis of various methods of docking of ships for recycling has been given in the report. This study has identified various factors determining the type of docking method as geographical features such as nature of soil, tidal range, sea currents, and climate; prevailing environmental and other legislation; economics of operation; availability of infrastructure; and skill of the workforce that is available. The docking method that has been selected for the proposed project is using air bags. This report also has given a brief account of the preparations necessary for the air bag method of docking the ship. It has been stated in the report that the size of the individual plots will depend upon the number and types of ships to be recycled at any point of time, requirements related to occupational safety, and general working conditions. The components of the ship recycling plots together with their area requirements have been specified in the report. Amount of various materials and items which are expected to be recovered has also been estimated. In this report, anticipated environmental impact due to the recycling operations has been identified and the proposed measures to be taken for mitigation of the impact have been described.

Lee et al. (2014) have reviewed previous research work on preliminary layout design methods for shipbuilding yards. They have attempted to carry out validation for the shipyard layout design proposed by Song and Woo (2013) using computer simulation technology with the help of actual production planning data.

Richard Muther (Muther and Hales 2015) has published a universal layout planning approach termed as Systematic Layout Planning (SLP) in the year 1960, which consists of a specific set of procedures to be followed for layout planning of facilities. They have claimed that the SLP has a logical approach, sound techniques of analysis, a simple set of conventions, and a pattern of procedures which is both straightforward and easy to follow. It does not require algorithms or computer software to obtain results; but needs input from personnel who have practical knowledge about the areas being planned. The procedure has undergone refinement over the last fifty years and makes use of electronic spreadsheets. SLP has been described as consisting of a framework of phases for each layout project, a pattern of procedures for step-by-step planning, and a set of conventions for identifying and rating various activities and relationships involved in a layout design project. They have also claimed that the SLP method has been widely adopted for various industrial and commercial applications. They have given a detailed description of the SLP procedure and have presented illustrations from a wide range of actual projects for which SLP was applied.

Francis et al. (2015) have given a brief account of the quantitative methods for layout design of facilities and have given a description of the layout design process, considering it as an optimisation problem. They have described the significant layout procedures which are used to facilitate the design of facility layouts. They have reported that the SLP procedure, which was developed by Muther, is the most popular approach used for plant layout design and that it has been applied to many fields including production, transportation, storage, and supporting services.

Tompkins et al. (2015) have considered facilities planning as a strategy for navigating a competitive global economy. They have mentioned that material handling constitutes between 20 and 50 per cent of total operating expenses in a manufacturing facility and that these costs can be brought down by 10 to 30 per cent through effective planning of the facility. Proper design of a facility must accomplish increase in productivity and reduction in cost by reducing or eliminating the unnecessary or wasteful activities. They have listed the objectives of facilities planning and have described the engineering design process for executing appropriate facilities planning. They have described various types of layouts and their applicability to various industries. They have dealt with the requirements related to facilities planning such as product design, process design, flow systems, activity relationships, space requirements, and personal requirements and have presented a systematic approach for material handling systems design. They have given a description of layout procedures based on some of the original approaches to the layout problems and of algorithmic approaches for the purposes of improvement of layouts and evaluation of layout alternatives. It was pointed out that the computer based algorithms that are currently available can not replace human experience and judgment and that the qualitative characteristics of a layout have not been captured by them. However, the productivity of the designer and the quality of the final solution can be enhanced by them by faster generation and evaluation of a large number of layout alternatives. Many of the commercial packages for facility layout design are intended for either presentation purposes of the layouts or for evaluations of given layouts. They have noticed that the processes involved in the SLP procedure are straightforward; however, the process of converting space relationship diagram into the layout alternatives requires experience, intuition, and judgement.

Sunaryo and Pahalatua (2015) have presented a brief outline of the layout and the proposed facilities of a green SRY as a pilot project in Indonesia. This study has selected the method of docking of the ship as using slipway and the maximum handling capacity of the yard as a ship of 30000 tonnes deadweight.

Hiremath et al. (2016) have reported that the ship recycling activities in Alang have been conducted primarily in four zones: ship, intertidal zone, primary zone, and secondary zone. This study has also indicated that most of the yards have a width of 60 m and have long work areas of length ranging from 100 to 125 m between high tide line and exit gates. A schematic diagram of a typical yard in Alang along with notional boundaries has also been presented in this paper.

Shipbreaking Code (Revised), 2013 published by Government of India (Ministry of Shipping, 2017) has stipulated the rules and regulations for recycling of ships in India. It has also given the requirements to be complied by a ship recycling facility and has specified the information to be included as part of a Ship Recycling Facility Management Plan (SRFMP).

JICA (2017) has proposed measures for improvement of facilities of an existing SRY and of a Treatment, Storage, and Disposal Facility (TSDF) in India, mainly focussing on the prevention of environmental pollution in ship recycling activities in the intertidal zone, in order to make them compliant with the HKC. A demand forecast of the global ship recycling volume and a description on the regulatory framework has been made as part of this report. Comparison of four types of ship breaking methods was made in order to analyse the most suitable solution for the ASSRY. This report has proposed a basic layout for the concrete paved areas of the yards to be improved.

2.5 CRITICAL REVIEW OF THE LITERATURE

Prevailing regulations concerning recycling of ships may differ between countries. In addition, some of the stake holders involved in recycling of ships, such as regulatory authorities and the promotional bodies differ one another depending on the administrative divisions and the ship recycling industrial structure of each country. It is observed that the stakeholders, except a few, who are involved in the global ship recycling scenario based on the present practice of ship recycling have already been documented. However, only six studies have been published on the required roles and responsibilities of the stakeholders during each of the stages of ship recycling. In addition, a lack of documentation has been noticed regarding the systematic plans for monitoring of the required interactions between stakeholders in the ship recycling industry. Therefore, a need is felt **to develop a strategic guidance plan which clearly identifies and assigns the stakeholders who are required to be involved during each stage of ship recycling and shows the interactions between stakeholders** during various stages of ship recycling.

As per the recommendations of IMO (IMO 2011), ship recycling plan for a particular ship needs to include both the steps of the recycling process and their sequence over the entire process. However, the guidelines given by various agencies including IMO do not give a clear methodology to prepare a ship recycling plan. A number of publications have presented information on various steps of the ship recycling process as well as their sequence based on the present practice. However, most of these studies have limited their scope only to the main processes and they have not gone into the detailed level of subprocesses. Only two studies (Tilwankar et al. 2010; Hiremath et al. 2015) have gone into a little more detailed level by considering a division of the whole ship recycling activities into twelve work activities. Another study (Hiremath et al. 2016) has presented further work division of three of the work activities from the twelve work activities mentioned above.

There are a number of important and critical processes which may be carried out during more than one stage of ship recycling due to various reasons. These processes are to be incorporated into the ship recycling plan. There is a definite need **to develop a detailed guidance plan which shows a systematic arrangement of various processes and subprocesses of ship recycling in a sequential order**. Such a detailed plan can improve the understanding of the processes and subprocesses and thereby generate safe practices for their execution.

Among the literature presented in this report, only three studies (McKenney 1994a, 1994b; Wijngaarden 2005) have reported on the application of disassembly concept to structural dismantling of ship’s hull. The studies by McKenney (1994a, 1994b) were limited to proposing a concept of disassembling hull together with the internal outfit items into a number of larger blocks whereas the study by Wijngaarden (2005) has considered splitting the ship into just two parts. The above studies have not investigated the aspects of structural disassembling of hull in a progressive manner into smaller units. In most of the SRYs which practice beaching method, hulls have been dismantled by cutting them into small panels and the major part of disassembling activities usually take place either onboard or just around the ship in intertidal zone. Therefore, a need is felt **to recommend a naval architectural concept for progressive structural disassembling of hull** as part of the guidance plan for ship recycling.

It is noticed that the utilisation of product models in shipping industry has been limited to the design, new construction, and major conversion stages of ships. Much consideration has not been given to the application of product models for the end of life activities of ships. It is also noticed that the recycling aspects have not been catered for while generating product models of ships during their design stage. Published literature on the required features of ship's product model for its utilisation during recycling stage has not been found. A definite need has been felt **to develop guidelines for enrichment of the product models of ships from a ship recycling perspective** and thereby facilitate their utilisation in the recycling stage in order to make the end-of-life ship a transparent product in terms of material content and hazardous nature.

It is observed that the studies on layout of SRYs were limited mainly to the basic block layouts of main operating zones in the case of model facilities or to the block layouts of the workstations in the case of existing ship recycling facilities. Published literature on methodologies using modern scientific techniques for systematic layout design of SRYs has not been found. Therefore, a need is felt **to establish a methodology that would enable generation of an optimal concept layout of a SRY** in a fast and systematic manner from a recycling point of view and with due consideration for the constraints.

CHAPTER 3

SHIP RECYCLING GUIDANCE PLAN

3.1 INTRODUCTION

Only limited number of studies on the roles and responsibilities of some of the stakeholders of ship recycling are available from the published literature. A need is highly felt to develop systematic plans which identify the roles and responsibilities of stakeholders of ship recycling. It is noticed that publications giving a clear methodology to develop detailed systematic plans for recycling of ships is limited. Studies which have been conducted on ship recycling plans have limited their scope to a maximum of twelve main work activities in recycling of ships. There is also a definite need to prepare a detailed ship recycling plan which shows the systematic arrangement of various ship recycling processes in their sequence.

An efficient and practical plan to carry out ship recycling is envisaged by IMO, ILO, and other important world maritime agencies, as part of creating a sustainable global maritime industrial sector (IMO 2009; ILO 2004). Ship recycling processes in general refers to the engineering activities carried out in the recycling industry as part of end of life of a ship. Preparation of a ship for recycling shall begin before it arrives at a SRY. The SRY shall work with the shipowner to determine the extent of such pre-recycling work that is recommended to be carried out onboard the ship.

Having considered the above need of systematic plans for recycling of ships, the present study has introduced the concept of a plan and it has been named ‘Ship Recycling Guidance Plan (SRGP)’. The intention of developing SRGP is to facilitate execution of recycling of ships in an efficient, safe, healthy, environment friendly, and sustainable manner. The SRGP has been developed in the form of a general frame work that consists of two parts. First part, named as Strategic Ship Recycling Guidance Plan (SSRGP), is proposed for the strategic level in recycling of ships whereas the second part, termed as General Ship Recycling Guidance Plan (GSRGP), is intended for the application level or the operational level in ship recycling. Beaching method, which is currently in practice in the major ship recycling nations located in South Asia such as India, Bangladesh, and Pakistan, has been adopted for the development of SSRGP and GSRGP in this thesis. Roles and responsibilities of stakeholders in the global ship recycling industrial sector are indicated in the SSRGP as a system. Steps to be followed in the end of life operation of an obsolete ship for its dismantling, recycling, reusing, and disposal are deliberated in the GSRGP. The SRGP has been proposed from the perspective of SRY. It is recommended that every SRY shall prepare such a plan by taking into consideration various aspects which are related to recycling of specific types of ships. Steps involved in SSRGP and GSRGP have been developed in this thesis and they are presented in the following subsections.

3.2 STRATEGIC SHIP RECYCLING GUIDANCE PLAN

SSRGP has been developed in this study using system approach and represented in the form of systematic line diagrams. Stakeholders required during each phase of ship recycling have been identified and duly assigned to the respective phase in the SSRGP. The plan also shows the interactions between stakeholders during various phases of ship recycling.

3.2.1 Ship Recycling Phases

In the present study, in order to model the complete ship recycling process, the whole ship recycling activity has been divided into three phases viz., preparation for ship recycling, dismantling of ship, and sale of recycled products and disposal.

3.2.1.1 Preparation for Ship Recycling

Decisions on declassification of ship by the Classification Society underwhich the ship is classified and deregistration of the ship by the respective Registering Authority of the Flag State are made during the first phase. Various options for ending up the life of the ship, including recycling, would be explored by the shipowner in this phase. If the decision is to dismantle and recycle the ship, tendering processes are initiated and a broker or a SRY is to be engaged for recycling of the ship.

3.2.1.2 Dismantling of Ship

Physical dismantling of ship’s hull, machinery, fittings etc. into smaller components, their sorting, and temporary storing are the major activities in this phase.

3.2.1.3 Sale of Recycled Products and Disposal

This phase comprises the sale of various products dismantled from the ship and the disposal of various types of wastes which are generated during the recycling process.

3.2.2 Stakeholders in Ship Recycling Phases

Major elements of the system, i.e. the stakeholders who shall participate in each of the phases of ship recycling, have been identified based on the study on both the present functioning of the ship recycling industry in various ship recycling nations and the regulations and reporting requirements set out by the HKC (IMO 2009). For each of the phases, the roles and responsibilities of the stakeholders have been specified and the required interactions between them have been represented in the proposed system model.

The following are the stakeholders who have been identified and included in the proposed system:

i. International Agency for Ship Recycling (IASR)

ii. International Ship Classification Societies

iii. Flag State Maritime Administration (National)

iv. Ship Recycling State Maritime Administration (National)

v. Ship Recycling State Maritime Administration (Regional)

vi. Ship Recycling Promotional Body

vii. Shipowner

viii. Cash Buyer

ix. Ship Recycling Broker

x. Ship Recycler (Ship Recycling Yard)

xi. Ship Recycling Subcontractors

xii. Ship Recycling Workers

xiii. Environmental Agencies (National and Regional)

xiv. Recycled Product Disposal Centre (Facilitator)

xv. Recycled Steel Re-rollers

xvi. Pre-owned Item Brokers (Facilitators)

xvii. Pre-owned Item Seller (Ship Recycling Product Market)

xviii. Pre-owned Item Customer (Ship Recycling Product Market)

International Agency for Ship Recycling (IASR) is a body that is currently not in existence and it has been proposed to be constituted as per this study. From the published literature that has been reviewed in this study, it is noticed that the stakeholders, viz., Ship Recycling State Maritime Administration (Regional), Pre-owned Item Seller, and Pre-owned Item Customer, have not been included as part of the stakeholders by any existing ship recycling system. These stakeholders have been added to the ship recycling system that is proposed in this thesis.

Desired roles and responsibilities of the stakeholders in ship recycling and the mutual interactions between them have been represented in the system diagrams in Fig. 3.1, Fig. 3.2 and Fig. 3.3. Description of the roles and responsibilities of each of the stakeholders are given in the following subsections from 3.2.2.1 to 3.2.2.16.

3.2.2.1 International Agency for Ship Recycling (IASR)

At present, there has been overlapping of responsibilities between IMO, ILO, and Basel Convention with respect to recycling of ships. IMO has been concentrating mainly on the design, construction, operation, and maintenance of ships. Most of rules framed by IMO, which are intended for a ship in operation, are not applicable to an obsolete ship. In the major ship recycling countries in South Asia, the ship recycling industry has been working as a shore based industry and regulated by the ministry of industry or labour. Role of the maritime regulatory authorities has been meagre in regulating the ship recycling industry. In addition, many stakeholders in the shipping sector have no direct role during the recycling stage of ships. Also, many stakeholders in ship recycling industry have no role in the shipping industry.

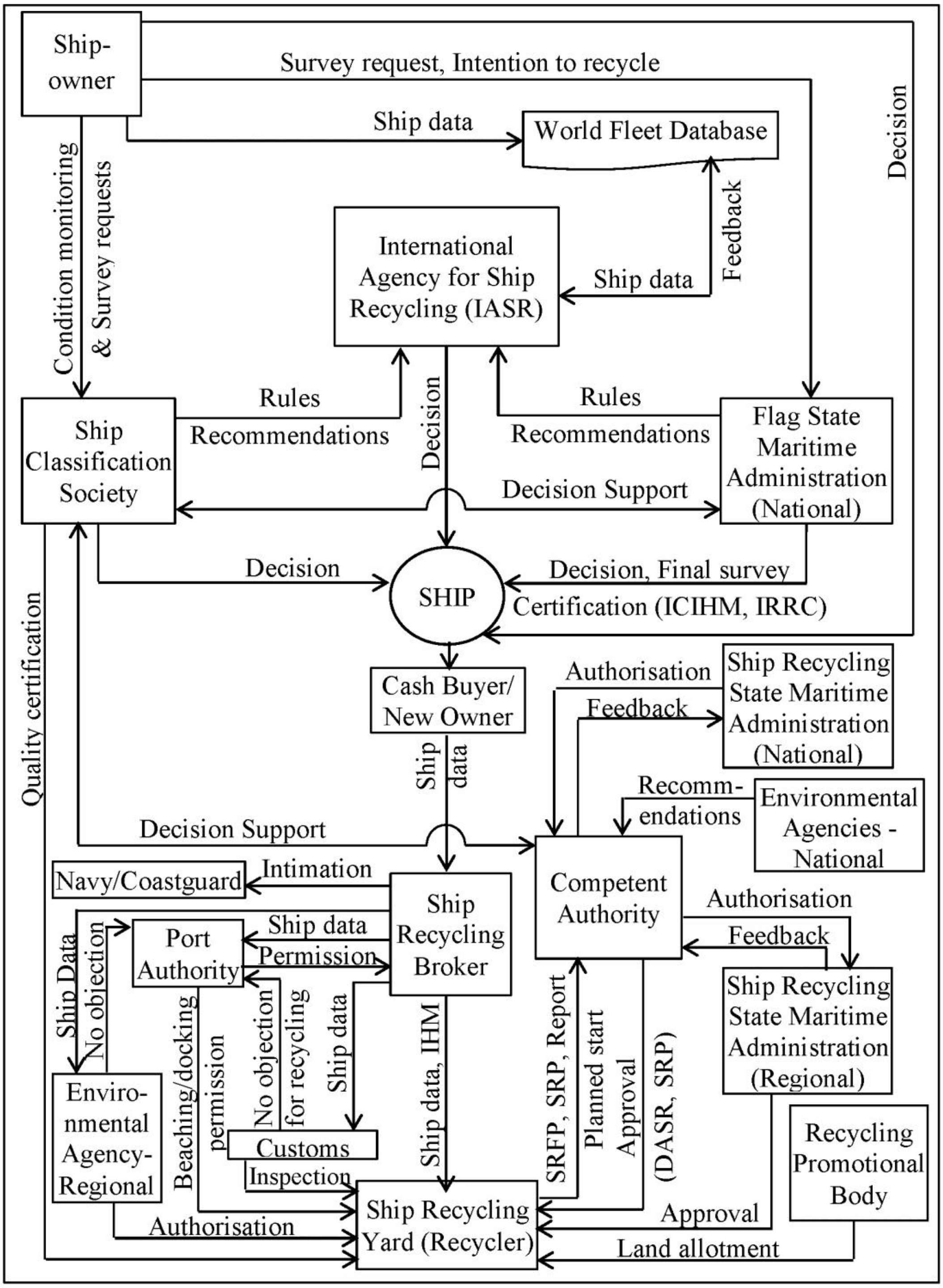

Fig. 3.1 Strategic Ship Recycling Guidance Plan- Phase 1: Preparation for Ship Recycling

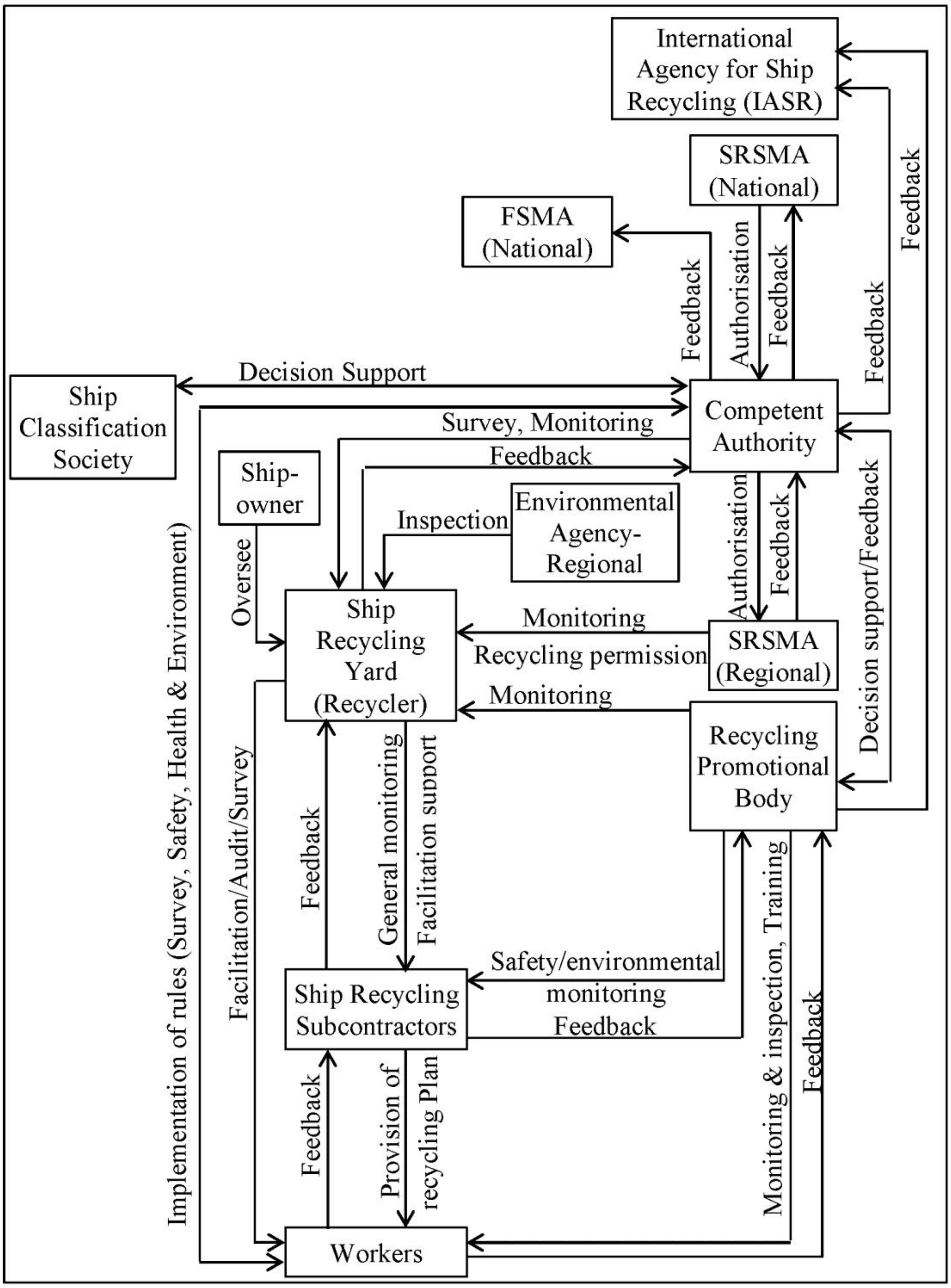

Fig. 3.2 Strategic Ship Recycling Guidance Plan- Phase 2: Dismantling of Ship

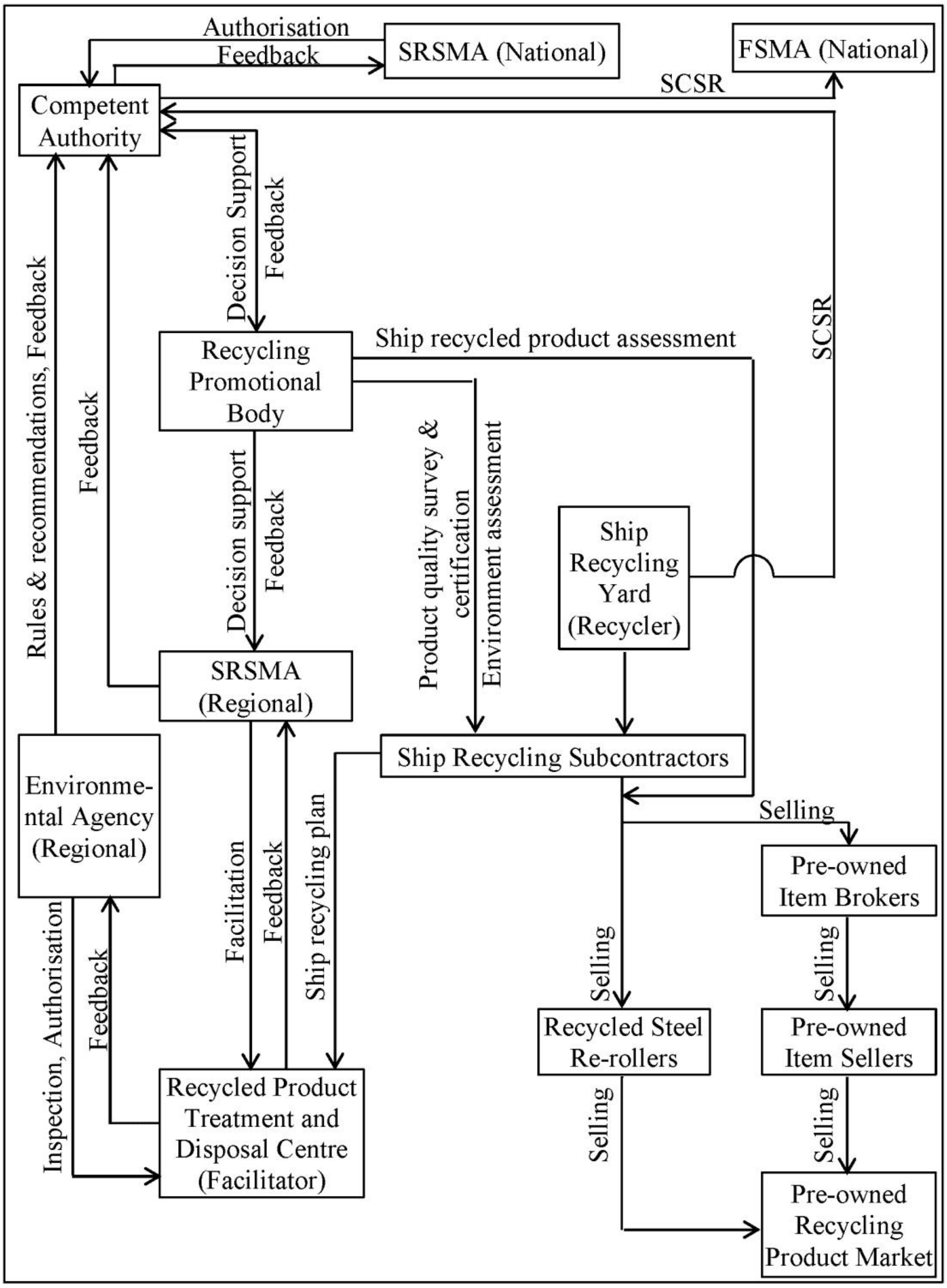

Fig. 3.3 Strategic Ship Recycling Guidance Plan- Phase 3: Sale of Recycled Products and Disposal

Therefore, there is a necessity to constitute an independent agency that is dedicated for looking after the regulations and issues of ship recycling industry worldwide. However, this agency will have to function in close coordination with IMO, ILO, and Basel Convention, and the national and regional regulatory authorities.

IASR is an international body that is proposed in this study to be constituted and added to other elements in the existing ship recycling system. It is intended to look after matters exclusively related to recycling of ships. Its responsibility shall be to regulate and improve the ship recycling scenario. It shall function under the United Nations (UN), and all the member nations of the International Maritime Organisation (IMO) shall be associated with it. The body shall be provided with adequate authority to inspect ship recycling sites anywhere in the world. It shall study and report individual issues related to ship recycling and find solutions for these issues, for implementation by the concerned elements. Recommendations given by IASR shall be implemented by all the member nations of IMO. IASR shall be assisted by Ship Classification Societies, national and regional maritime administrations, and Ship Recycling Promotional Bodies on various matters related to information bank on ships; development of common ship recycling rules; and implementation of quality assurance on safety, environmental, and health issues related to SRYs and facilities. Issues between the States on ship recycling shall be settled by IASR. The IASR has been indicated in both Fig. 3.1 and Fig. 3.2 with arrows showing its interactions with other elements during Phase 1 and Phase 2 respectively.

Organisational structure of IASR shall consist of an Assembly, a Council, and a number of departments. The Assembly shall consist of all Member States of IMO and the countries who have ratified the HKC. The Council shall function as an executive organ of IASR and shall be appointed from the members of the Assembly for a short term. Council shall supervise the regular functioning of IASR, such as coordination with other organisations.

A number of departments shall be formed to independently handle issues related to the development of common ship recycling rules which are applicable to obsolete ships and ship recycling facilities; the development of safe and environmentally sound practices and procedures for ship recycling; the formulation of recommendations on safety, health, and environment related issues to ship recycling facilities; and quality assurance on dismantled materials for implementation by the Member States of IASR. The departments of IASR shall also carry out maintenance of World Fleet Database, inspection of ship recycling sites when necessary, and settlement of issues between the Member States. IMO, ILO, and Secretariat of Basel Convention (SBC) shall have representatives in the Council of IASR. .

By constituting IASR, the ship recycling industry will get the benefits of having an agency to develop rules, regulations, and guidelines specifically for the ship recycling industry; to study, report, and solve individual issues related to ship recycling; to maintain and update database on obsolete ships and SRYs; to conduct awareness programmes on ship recycling for the stakeholders and general public; to implement quality assurance in SRYs; and to settle issues on ship recycling which arise between various States. IASR can be made responsible to formulate the criteria, coordinate the activities, and monitor the performance of stakeholders for the purpose of providing incentives to the stakeholders. This will enable more numbers of players to get involved in the ship recycling industry as stakeholders and thereby improve the competitiveness in the ship recycling industry.

World Fleet Database

A deficiency of having a database, which can act as a source point of information on obsolete ships, is noticed during the review of literature for this research.

It is recommended in this study to generate an information bank named as **World Fleet Database** which is to be maintained by IASR. The data can be collected through feedback from statutory bodies such as Flag State Maritime Administration, Ship Recycling State Maritime Administration/Competent Authorities, Shipowners, Ship Classification Societies, SRYs, and Ship Recycling Promotional Bodies. The proposed World Fleet Database has been shown in Fig. 3.1.

The database shall consist of the following information related to ship recycling:

i. Particulars of ships which have been withdrawn from service; such as ship type, main dimensions, registration details, Classification details, IMO number, material of construction, lightship weight, deadweight, steel weight, machinery weight, number of tiers of superstructure, dimension and weight of superstructure, hazardous material content in terms of weight, numbers and details of machinery, and dates of deregistration and declassification. This information shall be obtained through feedback from Shipowners, Classification Society, Ship Recycling Promotional Bodies, and SRYs.

ii. Particulars of ships which are recycled at various SRYs; such as the date of commencement and date of completion of recycling of each ship, quantity of reusable and recyclable material retrieved from each ship, and percentage of onboard hazardous materials which are removed from ships. This information shall be collected through feedback from Ship Recycling Promotional Bodies and SRYs.

iii. Particulars of SRYs in which ship recycling is carried out and the type of recycling method followed for each ship. This information shall be gathered through feedback from Ship Recycling Promotional Bodies and SRYs.

World Fleet Database can act as a source point of information on sustainable ship recycling for various stakeholders. By establishing a World Fleet Database, accurate information on obsolete ships and material content of the obsolete ships can be obtained through feedback from the ship recycling industry. This information will enable a reliable estimation of SRY layout design parameters such as material flow intensity. The database will also enable IASR to make recommendations based on the hazardous material content of ships for sustainable ship recycling and to verify whether the recycling of ships are carried out only at the authorised facilities.

3.2.2.2 Ship Classification Societies

Currently the Ship Classification Societies are actively involved only during design, construction, and operational stages of a ship. Research on recycling aspects of ships is being carried out by some of the Classification Societies. As proposed in this research work, Ship Classification Societies shall be assigned more responsibilities in the recycling system of ships such as development of rules related to ship recycling, survey of ships destined to be recycled, and taking decision on declassification of ships for recycling. Classification Societies shall advise Shipowners on matters related to ship recycling, especially on the maintenance of records related to hazardous materials onboard, updating of relevant drawings, condition assessment of equipment and hull parts, etc. Classification Societies shall be closely associated with the IASR in the formation of rules and regulations regarding the naval architecture aspects of ship recycling. They shall also work together with other stakeholders, especially statutory authorities, maritime boards, and SRYs, in the interest of sustainable recycling of ships. Ship Classification Societies has been included in Fig. 3.1 and Fig. 3.2.

3.2.2.3 Flag State and Ship Recycling State Maritime Administrations

Statutory bodies such as Flag State Maritime Administration (FSMA) and Ship Recycling State Maritime Administration (SRSMA), both at national and regional level, shall be in the forefront to frame ship recycling rules and regulations which are to be implemented by Shipowners, brokers, SRYs, subcontractors, and vendors in the ship recycling industry. These administrative bodies shall play a major role in framing practical solutions, within the legal frame work of the respective recycling nation, for various recommendations which would be prepared by IASR. A national coordination in maritime sector with respect to sustainable ship recycling shall be an active agenda of these administrative bodies.

An International Certificate on Inventory of Hazardous Materials (ICIHM) shall be issued by FSMA or an agency authorized by it. In addition, such statutory body shall also issue an ‘International Ready for Recycling Certificate’ (IRRC) to ships upon meeting the requirements set out by the HKC and satisfactory completion of the surveys prior to recycling (IMO 2009).

In accordance with the HKC (IMO 2009), SRSMA may designate Competent Authorities who will be responsible for duties related to recycling of ships in their country. It is recommended in this study to form such Competent Authorities also at the regional levels. To enable a smooth conducting of ship recycling in each state or region in the country, it is recommended to form or designate a single agency, such as a regional division of the SRSMA, as the Competent Authority to regulate the recycling of ships within that state and it shall coordinate with the other agencies to enable a smooth conducting of the ship recycling operations. Such an authority at the regional level shall be given the authority to approve Ship Recycling Plan (SRP) and Ship Recycling Facility Plan (SRFP) which are required in accordance with the HKC (IMO 2009). It shall also issue a Document of Authorisation to conduct Ship Recycling (DASR) to SRYs. The Competent Authority at the national level shall forward a copy of the Statement of Completion of Ship Recycling (SCSR) relating to each ship, as required by IMO (IMO 2009), which is received from a SRY through the regional Competent Authority, to the concerned Flag State Administration.

FSMA needs to be involved mainly in the Phase 1 and it has been incorporated in Fig. 3.1 and Fig. 3.3. SRSMA needs to be actively involved in all three phases and it has been shown in Figs. 3.1 to 3.3 accordingly.

3.2.2.4 Ship Recycling Promotional Body

This body shall provide land, infrastructure, consumables, training, expertise, transportation, and logistics support for SRYs and subcontractors. This body shall be the main coordinator for obtaining feedback from the industry. Such feedback will lay foundation for the rules and regulations for clean and safe ship recycling. This body shall remain in constant contact with the statutory bodies, Ship Classification Societies, SRYs, and subcontractors for generation of a knowledge base in ship recycling. This body shall also help the recyclers to ensure the minimum quality standard to be followed in ship recycling sites based on international process quality standards such as ISO 30000. Naval architects and marine engineers shall be made part of this body to ensure good quality of work in ship recycling. Recycling Promotional Body has been indicated in Fig. 3.2 and Fig. 3.3.

3.2.2.5 Shipowner

Shipowner has been assigned more responsibilities and duties in the proposed system. He shall implement an onboard information system that can generate essential outputs to various other stakeholders in the recycling of ships. He shall contribute towards generation of World Fleet Database and its timely updating in order to facilitate an efficient and effective implementation of end of life activities of the ships which are owned by him. IASR guidelines shall be strictly followed by all those who own a ship at any time during its life term irrespective of whether he is the first owner or the last owner just prior to its recycling. In the case of ownership changes, the contracts between the shipowners shall include a commitment from the side of the previous shipowner to transfer all the technical information related to the ship to the new shipowner. Shipowner shall cooperate and coordinate with the respective Ship Classification Societies in order to implement the international and national rules. Shipowner's status has been shown in Fig. 3.1 and Fig. 3.2.

3.2.2.6 Cash Buyer

Cash Buyer as referred in Lloyd's Register (2011) is a person or a firm that buys a ship when it is sold for scrap, assumes all risks of the transactions, and resells it to SRYs. He negotiates with the Shipowner and brokers or SRYs during the ship recycling contract stage. Definition of Shipowner as given by the HKC (IMO 2009) can be considered to encompass also the cash buyer and, therefore, it is necessary to consider the cash buyer to be equally responsible as Shipowner. Cash buyer gets involved only in Phase 1 and it has been indicated in Fig. 3.1.

3.2.2.7 Ship Recycling Brokers

Ship Recycling Brokers are international agents in ship recycling. They participate in tenders of ships which are to be dismantled and take over the ships until their delivery to SRYs. This broker is identified as an important element of the proposed system and is assigned the same roles and responsibilities as that of a Shipowner. They shall maintain and update the knowledge base that is received from previous owner. They shall coordinate with the port authority regarding the anchoring of ship and its entry to the port and they shall intimate Navy and Coast Guard about ship's arrival. They, together with the SRY, shall arrange for inspection and clearance from agencies like customs department, Environmental Agencies, and other relevant regulatory authorities of the country. The broker shall coordinate with the Ship Recycling Promotional Body to implement the SRGP that is proposed in this study. Ship Recycling Broker needs to be involved in only Phase 1 and has been shown in Fig 3.1.

3.2.2.8 Ship Recycling Yard (Ship Recycler)

Ship Recyclers shall provide infrastructure for recycling ships. They shall work in tandem with Promotional Bodies and statutory authorities to ensure safe and environment friendly recycling of ships. They shall be held responsible for any accidents that happen during recycling of ships. In addition to providing land, they shall implement relevant regulations on safety, health, environment, and quality in recycling of ships. They must also ensure that the applicable guidelines on safety and quality are followed by their subcontractors.

Ship Recycler shall issue a statement of completion as required by the HKC (IMO 2009) upon completion of the recycling of each ship at their facility. SRY, in consultation with the Ship Recycling Promotional Body, shall arrange for relevant inspections by various regulatory agencies during the recycling process. Naval architects and marine engineers shall be employed by the Ship Recyclers for ensuring quality and safety in carrying out the ship recycling processes. Ship Recycler is assigned an important role in all the three phases and has been included in Figs. 3.1 to 3.3.

3.2.2.9 Ship Recycling Subcontractors

Necessary manpower and equipment to carry out actual dismantling of ships are supplied by Ship Recycling Subcontractors. Feedback from these stakeholders on the recycling system can be considered to be the fundamental input to develop a sound frame work for rules and regulations in ship recycling. Subcontractors shall be equipped with both skilled manpower and sophisticated equipment to implement safe and clean ship recycling. It is proposed to bring also the subcontractors under the purview of the standards which will be proposed by Ship Recycling Promotional Body in order to improve safety, quality, and productivity in the process. Ship Recycling Subcontractors shall be registered under the Competent Authorities and Ship Classification Societies by declaring their capabilities. Ship Recycling Subcontractor has been indicated in Fig. 3.2 and Fig. 3.3.

3.2.2.10 Ship Recycling Workers

They are the people who physically dismantle ships. They form part of Phase 2 as shown in Fig. 3.2.

3.2.2.11 Environmental Agencies

Environmental Agencies, both at national and regional level, shall ensure proper coordination between the ship recycling activities inside SRY as well as the disposal activities outside the yard premises. Recommendations on sustainable ship recycling shall be given by the national Environmental Agency to the Competent Authority at the national level based on the feedback received by the Environmental Agency from the ship recycling industry. Centres for treatment, disposal and recycling of materials which are dismantled from ship shall be under the purview of these agencies. These agencies shall forward the feedback from these centres, through the Ship Recycling Promotional Body, to the regional, national and international bodies working in the field of sustainable ship recycling. Environmental Agencies shall take a very critical role for the implementation of SRP both inside and outside the yard. Figs. 3.1 to 3.3 show the required interactions between these stakeholders in the proposed ship recycling system.

3.2.2.12 Recycled Product Treatment and Disposal Centre (Facilitator)

Facilitator shall be able to provide both infrastructure and guidance to achieve clean and safe recycling and disposal of dismantled products. They shall also follow the relevant national regulations and guidelines for safe disposal of hazardous items from ships. The Facilitator shall work in close association with the Promotional Body, Environmental Agencies and the regional SRSMA and it has been shown in Fig. 3.3.

3.2.2.13 Recycled Steel Re-rollers

Recycled Steel Re-rollers shall work under the guidance of Ship Recycling Promotional Body. In order to achieve a good quality of re-rolled steel products and ensure a better control on their further use, the re-rollers are recommended to undergo certification process from the Classification Societies or similar agencies which provide accreditation facility. The re-rollers shall give feedback to the Promotional Body regarding reusing or remanufacturing of the products. They shall seek guidance from the promotional body for improvement of the standard of their re-rolled products. They shall also provide all relevant information regarding re-rolled steel to outside market in order to reduce any kind of risk and customer dissatisfaction. Role of Recycled Product Treatment and Disposal Centre and Recycled Steel Re-rollers have been shown in Fig. 3.3.

3.2.2.14 Pre-owned Item Brokers

These brokers are recommended to work as registered business partners with the Ship Recycling Promotional Body. The promotional body shall give directions regarding sale of pre-owned item, emphasizing the risk and environmental impact factors, to the brokers and the customers of the pre-owned market. Such brokers must be made aware of the consequences of reuse and disposal of dismantled products from the obsolete ships.

3.2.2.15 Pre-owned Item Sellers

Pre-owned Item Sellers in the ship recycling product market operate outside the domain of the ship recycling system. Ship Recycling Promotional Bodies may not have any direct control on this element. However, it is recommended that the awareness campaign by various agencies involved in the system must target these elements also. The sellers of the dismantled product shall follow the guidelines actively and sincerely in order to achieve clean and safe ship recycling. It is proposed to also make them a part of the sustainable ship recycling programmes of the State.

3.2.2.16 Pre-owned Item Customers

Without involvement of this sector, sustainable development in ship recycling can not be achieved fully. Pre-owned Item Customers may not strictly follow the principles of ship recycling as envisaged by maritime industrial community. However, continuous efforts specially targeting the ship recycling product market and its customers by the State authorities can bring substantial changes in attitude among the customers. Ship Recycling Promotional Body, State Maritime Administration, maritime industrial community, and Non-Governmental Organisations (NGOs) who work in this area shall contribute to make the market aware of the role to be played by such customers in order to achieve the goals set by the international maritime community regarding recycling of ships. Pre-owned item brokers, sellers, and customers have been shown in Fig. 3.3.

3.2.3 Present Responsibilities versus Proposed Responsibilities of Stakeholders

A tabular explanation of the present responsibilities of the stakeholders in the existing ship recycling system and the recommended responsibilities of the stakeholders as per SSRGP, which has been proposed in this thesis, is given in Table 3.1.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
1	IASR	IASR is presently not in existence.	**It is recommended in the thesis to constitute IASR under UN**. IASR shall look after matters exclusively related to recycling of ships worldwide. These matters on ship recycling include the formulation and implementation of rules and regulations in the ship recycling industry, maintenance of database on obsolete ships, implementation of quality assurance in SRYs and resolution of various other issues of ship recycling industry.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
2	International Ship Classification Societies	Ship Classification Societies are actively involved only during design, construction, and operational stages of a ship. They are involved in taking decision on declassification of ships.	Ship Classification Societies shall be assigned responsibilities in development of rules related to ship recycling and survey of ships destined to be recycled. They shall advise Shipowners on matters related to ship recycling, especially on the maintenance of records related to hazardous materials onboard, updating of relevant drawings, condition assessment of equipment and hull parts, etc. Classification Societies shall be closely associated with the IASR in the development of rules and regulations. They shall also work together with other stakeholders; especially statutory authorities, maritime boards, and SRYs; in the interest of sustainable recycling of ships.
3	FSMA (National)	FSMA is not actively involved in the recycling of ships. As per HKC, FSMA is responsible for issuing ICIHM and IRRC to ships in accordance with the IMO regulations.	FSMA shall assist IASR to develop ship recycling rules and regulations. FSMA shall assist in framing practical solutions for various recommendations which would be prepared by IASR. A national coordination in maritime sector with respect to sustainable ship recycling shall be an active agenda of FSMA.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
4	SRSMA (National)	Some of the countries have developed ship recycling rules and regulations which are to be implemented by SRYs. In the major Ship Recycling States, there has been overlapping of responsibilities between various departments on regulating the recycling activities of ships. As per HKC, SRSMA may designate Competent Authorities who will be responsible for duties related to recycling of ships in their country. The Competent Authority shall forward a copy of the SCSR relating to each ship, which is received from SRY, to the concerned FSMA.	SRSMA shall be in the forefront to frame ship recycling rules and regulations which are to be implemented by all stakeholders such as shipowners, brokers, SRYs, subcontractors, and vendors in the ship recycling industry. SRSMA shall play a major role in framing practical solutions, within the legal frame work of the respective recycling nation, for various recommendations which would be prepared by IASR. A national coordination in maritime sector with respect to sustainable ship recycling shall be an active agenda of SRSMA. It is recommended to form Competent Authorities also at regional levels.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
5	SRSMA (Regional)	SRSMA (Regional) has not been included as part of the stakeholders by any existing ship recycling system.	**SRSMA (Regional) has been added as a stakeholder of the ship recycling system in the thesis**. It is recommended to designate SRSMA (Regional) as the Competent Authority to regulate the recycling of ships within a region or state of a country. SRSMA (Regional) shall coordinate with the other agencies to enable a smooth conducting of the ship recycling operations. It shall be given the authority to approve SRP and SRFP which are required in accordance with the HKC. It shall also issue a DASR to SRYs.
6	Ship Recycling Promotional Body	Ship Recycling Promotional Body provides land, infrastructure, consumables, training, expertise, transportation, and logistics support for SRYs and subcontractors.	Ship Recycling Promotional Body shall be the main coordinator for obtaining feedback from the industry. This body shall remain in constant contact with the statutory bodies, Ship Classification Societies, SRYs and subcontractors for generation of a knowledge base in ship recycling. This body shall also help the SRYs to ensure the minimum quality standard to be followed in SRYs based on international process quality standards such as ISO 30000. Naval architects and marine engineers shall be made part of this body to ensure good quality of work in ship recycling.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stake-holder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
7	Shipowner	Shipowner coordinates the activities with the Classification Society and FSMA for declassification and deregistration, respectively, of his ship. Shipowner sells his ship to Cash Buyers, brokers, or SRYs for the purpose of recycling the ship. Most of the shipowners are not involved in the recycling stage of their ships.	Shipowner shall implement an onboard information system that can generate essential outputs to various other stakeholders in the recycling of ships. He shall contribute towards generation of World Fleet Database and its timely updating with respect to information on end of life activities of the ships owned by him. In the case of ownership changes, the contracts between shipowners shall include a commitment from the side of the previous shipowner to transfer all technical information related to the ship to the new shipowner. IASR guidelines shall be strictly followed by Shipowners.
8	Cash Buyer	Cash Buyer buys a ship when it is sold for scrap, assumes all risks of the transactions, and resells it to SRYs. He negotiates with the shipowner and brokers or SRYs during the ship recycling contract stage. Cash Buyer is not actively involved in recycling operations of ships after handing over of the ships to SRYs.	It is recommended to consider the Cash Buyer to be equally responsible as Shipowner.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	**Stakeholder**	**Present condition/ responsibilities of stakeholders in ship recycling**	**Recommended conditions/ responsibilities of stakeholders as per SSRGP**
9	Ship Recycling Broker	Ship Recycling Brokers participate in tenders of ships which are to be dismantled and take over the ships until their delivery to SRYs. They coordinate with the port authority regarding the anchoring of ship and its entry to the port and they intimate Navy and Coast Guard about ship's arrival. They, together with the SRY, arrange for inspection and clearance from agencies like customs department, Environmental Agencies, and other relevant regulatory authorities of the country. Ship Recycling Broker is not actively involved in recycling operations of ships after commencement of recycling activities in SRYs.	Ship Recycling Broker is assigned the same roles and responsibilities as that of Shipowner. They shall maintain and update the knowledge base that is received from previous owner. The broker shall coordinate with the Ship Recycling Promotional Body to implement the Ship Recycling Guidance Plan that is proposed in this study.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
10	SRY	SRYs provide infrastructure for recycling ships. SRYs work in tandem with Promotional Bodies and statutory authorities for implementation of national rules on recycling of ships and for relevant inspections by various regulatory agencies during the recycling process. SRYs in South Asian countries comply only partly with the safety requirements on recycling of ships. HKC requires SRY to issue a statement of completion upon completion of the recycling of each ship at their facility.	SRYs shall work in tandem with Promotional Bodies and statutory authorities to ensure safe and environment friendly recycling of ships. They shall be held responsible for any accidents that happen during recycling of ships. SRYs implement relevant regulations on safety, health, environment, and quality in recycling of ships. They shall also ensure that the applicable guidelines on safety and quality are followed by their subcontractors. Naval architects and marine engineers shall be employed by the SRYs for ensuring quality and safety in carrying out the ship recycling processes.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
11	Ship Recycling Subcontractors	Necessary manpower and equipment to carry out actual dismantling of ships are supplied by Ship Recycling Subcontractors.	Feedback on the recycling system shall be obtained from these stakeholders and this feedback can be considered to be the fundamental input to develop a sound frame work for rules and regulations in ship recycling. Subcontractors shall be equipped with both skilled manpower and sophisticated equipment to implement safe and clean ship recycling. It is proposed to bring the subcontractors under the purview of the standards which will be proposed by Ship Recycling Promotional Body in order to improve safety, quality, and productivity in the process. Ship Recycling Subcontractors shall be registered under the Competent Authorities and Ship Classification Societies by declaring their capabilities.
12	Ship Recycling Workers	These workers carry out the physical dismantling of ships.	No additional responsibilities with respect to interaction of workers with other stakeholders have been proposed.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stakeholder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
13	Environmental Agencies (National and Regional)	Centres for treatment, disposal, and recycling of materials which are dismantled from ship are under the purview of these agencies.	Environmental Agencies, both at national and regional level, shall ensure proper coordination between the ship recycling activities inside SRY as well as the disposal activities outside the yard premises. Environmental Agencies shall take a very critical role for the implementation of SRP both inside and outside the yard. Recommendations for sustainable ship recycling shall be given by the national Environmental Agency to the Competent Authority at the national level based on the feedback received from the ship recycling industry. These agencies shall forward the feedback from the centres for treatment, disposal, and recycling of materials, through the Ship Recycling Promotional Body, to the bodies working in the field of sustainable ship recycling.
14	Recycled Product Disposal Centre (Facilitator)	Facilitator provides infrastructure for disposal of dismantled products.	Facilitator shall be able to provide both infrastructure and guidance to achieve clean and safe recycling and disposal of dismantled products. They shall follow the relevant national regulations and guidelines for safe disposal of hazardous items from ships. Facilitator shall work in close association with the Promotional Body, Environmental Agencies and the regional SRSMA

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	Stake-holder	Present condition/ responsibilities of stakeholders in ship recycling	Recommended conditions/ responsibilities of stakeholders as per SSRGP
15	Recycled Steel Re-rollers	Recycled Steel Re-rollers carry out processing of the steel materials received from SRYs. They are presently not under the purview of regulations of FSMA or SRSMA.	Recycled Steel Re-rollers shall work under the guidance of Ship Recycling Promotional Body for improvement of the standard of their re-rolled products. In order to achieve a good quality of re-rolled steel products and ensure a better control on their further use, the re-rollers are recommended to undergo certification process from the Classification Societies or similar agencies which provide accreditation facility. The re-rollers shall give feedback to the Promotional Body regarding reusing or remanufacturing of the products. They shall also provide all relevant information regarding re-rolled steel to outside market in order to reduce any kind of risk and customer dissatisfaction.
16	Pre-owned Item Brokers	Pre-owned Item Brokers act as agents for sale of dismantled items from SRY to the pre-owned market. They are not under the purview of regulations of FSMA or SRSMA.	These brokers are recommended to work as registered business partners with the ship recycling promotional body. The promotional body shall give directions regarding sale of pre-owned item, emphasizing the risk and environmental impact factors, to the brokers and the customers of the pre-owned market. Such brokers must be made aware of the consequences of reuse and disposal of dismantled products from the obsolete ships.

Table 3.1 Present Responsibilities versus Recommended Responsibilities of Stakeholders in Ship Recycling- CONT'D

Sl. No.	**Stake-holder**	**Present condition/ responsibilities of stakeholders in ship recycling**	**Recommended conditions/ responsibilities of stakeholders as per SSRGP**
17	Pre-owned Item Seller	Pre-owned Item Seller has not been considered as part of the stakeholders by any existing ship recycling system. Pre-owned item sellers operate outside the domain of the ship recycling system. Ship Recycling Promotional Bodies do not have any direct control on this element.	**Pre-owned Item Seller has been added as a stakeholder of the ship recycling system in the thesis**. Regulatory authorities in the ship recycling industry shall take initiatives to make this stakeholder as part of sustainable recycling programmes of the State. Awareness campaign by various agencies involved in the system must target these elements also. The sellers of the dismantled product shall follow the guidelines in order to achieve clean and safe ship recycling.
18	Pre-owned Item Customer	Pre-owned Item Seller has not been considered as part of the stakeholders by any existing ship recycling system. Pre-owned Item Customers may not strictly follow the principles of ship recycling as envisaged by maritime industrial community. Ship Recycling Promotional Bodies do not have any direct control on this element.	**Pre-owned Item Customer has been added as a stakeholder of the ship recycling system in the thesis**. Regulatory authorities in the ship recycling industry shall take initiatives to make this stakeholder as part of sustainable recycling programmes of the State. Ship Recycling Promotional Body, SRSMA, maritime industrial community, and NGOs who work in this area shall contribute to make the pre-owned market aware of the role to be played by the Pre-owned Item Customer in order to achieve sustainable recycling of ships.

The above section has elaborated the roles of responsibilities of various stakeholders the required interactions between them to carry out recycling of ships efficiently. The following section will describe various processes and subprocesses involved in physical dismantling of ship.

3.3 DEVELOPMENT OF GENERAL SHIP RECYCLING GUIDANCE PLAN

General Ship Recycling Guidance Plan (GSRGP), which has been proposed in the present study, targets the operational level in ship recycling. GSRGP has been presented in the form of flow charts. It represents a detailed guidance plan which shows a systematic arrangement of the processes and subprocesses to be carried out in sequence as well as in parallel during each of the stages in ship recycling. The proposed plan also indicates a number of processes which may be carried out during more than one stage of ship recycling. GSRGP has been developed by taking into consideration the safe and sustainable aspects of the existing practices of ship recycling industry and other factors which can help to improve the quality, productivity, safety, and environmental friendliness of the ship recycling industry and to achieve objectives of sustainable recycling. GSRGP gives a systematic arrangement of various processes in recycling of ships and describes subdivision of the recycling processes at a more detailed level than that is required as per the guidelines of IMO or that is described in the published literature.

It is also in compliance with the requirements set out by the HKC and the guidelines provided by various international agencies. GSRGP also includes a set of instructions to be implemented for various processes in the actual recycling of an obsolete ship. Beaching method has been adopted for the development of GSRGP. A method of progressive disassembling of ship's structure has also been proposed as part of the present study and has been incorporated into the GSRGP.

3.3.1 Disassembly Concept

Advanced outfitting and assembling methods have been successfully implemented in shipbuilding industry. Ship recycling process can be considered as reverse shipbuilding with respect to structural disassembling of both hull and superstructure. Ship recycling can be executed in a safe and effective manner by introducing various disassembly levels in the dismantling operations of hull, analogous to the assembly levels in shipbuilding. A method of progressive disassembling of ship structure at three disassembling levels, viz., primary, secondary, and tertiary; has been proposed as part of the GSRGP.

Disassembling ship into larger units and then transferring them to locations clear of the ship can facilitate better accessibility for structural disassembling operations by man and machine, better containment of hazardous substances, and better control over environmental pollution. In addition, it can reduce cost by reducing the utilisation of auxiliary services such as cranes, ventilation, scaffolding, etc.

For the purpose of this study, structural disassembly concept refers to disassembling of main hull or superstructure into smaller sized structural units, analogous to the assembly concept in shipbuilding. Concept of a three level disassembling, consisting of primary disassembling, secondary disassembling, and tertiary disassembling, has been proposed in this thesis for the structural disassembling of the hull. Terminologies and their definitions which are in practice in shipbuilding and ship recycling and are adopted for explaining the disassembly concept has been given in Table 3.2. Table 3.3 shows the terminologies and their definitions which have been introduced as part of this research.

Table 3.2 Terminologies and Definitions in Maritime Industry

Sl. No	Terminology	Definition
1	Ring units	Hull structural subdivisions that extend from keel to upper deck, and extend over full breadth of ship
2	Blocks	Hull structural subdivisions that extend from keel to upper deck, and extend over half breadth of ship, on port or starboard side
3	Primary disassembling	Process of disassembling of main hull into ring units or blocks. Also the process of disassembling of superstructure into smaller units
4	Secondary disassembling	Process of disassembling of ring structural units or blocks into disassemblies or units. Also the process of further disassembling of such disassemblies or units into either subdisassemblies or panels

Table 3.3 Proposed Terminologies and Definitions in Ship Recycling

Sl. No	Terminology	Definition
1	Primary disassembly	Ring unit of hull (e.g. bow structure, and stern structure); or block of hull (e.g. cargo hold structures on either port or starboard side consisting of keel plate, double bottom, shell plates, deck plates together with internal stiffening arrangement); or structural unit consisting of one or more tiers of superstructure. The primary disassemblies result from the primary disassembling operations.
2	Disassembly	Three dimensional structural unit that consists of a number of nonplanar plates together with stiffeners, but smaller than a block. (eg. double bottom structure and wing tank structure). The disassemblies result from the secondary disassembling operations.
3:	Subdisassembly	Structural panel which is mainly a two dimensional plate with a number of stiffeners attached to it. (eg. main deck structure and planar bulkhead structure. The subdisassemblies result from the secondary disassembling operations.
4	Tertiary disassembling	Process of disassembling of either subdisassemblies or panels into minor subdisassemblies, and the process of further disassembling of such minor subdisassemblies into plates and stiffeners.

3.3.1.1 Cutting Lines for Disassembling Obsolete Ship Hull

Cutting lines are lines along which a ship’s structure is to be cut for dismantling it from ship. It is suggested in this study to decide the locations of cutting lines in such a way that the resulting primary disassemblies are of manageable sizes with respect to yard’s handling and transportation capacities. Cutting plan is a drawing that shows general arrangement of a ship on which locations of cutting lines for each primary disassembling operation are marked. Both vertical and horizontal cutting lines between various primary disassemblies are to be marked on the cutting plan. It is proposed that the longitudinal cutting lines on main hull blocks should be close to the centreline and the transverse ones should be at locations just forward or aft of transverse watertight bulkheads. For superstructure, the cutting lines on shell or exposed bulkheads are recommended to be slightly above each superstructure deck. Size of the ring units or blocks shall be decided based on the maximum weight that can be lifted using cranes and the maximum length that can be accommodated on the transportation equipment that is used in the yard.

3.3.2 General Ship Recycling Guidance Plan

For the development of the GSRGP, it has been considered to divide the ship recycling activities into the four stages based on the major locations of the activities (Sivaprasad 2010). The four stages are ‘In Offshore Location’, ‘In Intertidal Zone’, ‘In Beach’, and ‘In Land’.

In Stage 1, activities such as sale of the ship for recycling, transportation of the ship to the recycling facility under its own power and preparation of it for dismantling have been included. In Stage 2, beaching process of the ship followed by various processes such as decontamination of compartments; primary disassembling of its hull and superstructure into large blocks; and dismantling of main machinery, auxiliary machinery, deck fittings, etc. from ship and transferring these to sorting/ storage area, which are carried out while ship is in the intertidal zone have been covered. The activities included in Stage 3 are secondary disassembling of hull and superstructure blocks into smaller units; tertiary disassembling of the units into panels and further smaller components of suitable sizes; disassembling of various systems including piping, electrical, and ventilation; and disassembling of machinery into components and temporary storage of these items. In Stage 4, sorting of the dismantled components, separation of the materials, storage in the yard, and finally transportation of the materials to the resale market or to the remanufacturing/recycling/disposal centres have been encompassed.

Flow chart for Stage 1 has been shown in Fig. 3.4. Flow chart for Stage 2 has been divided into four parts for convenience of demonstration and has been presented in Figs. 3.5 to 3.8. Flow charts for Stages 3 and 4 have been shown in Fig. 3.9.

Shipowner has to ensure that his ship has acquired IRRC as required by IMO (IMO 2009) from concerned authorities prior to its handing over to a SRY. It is recommended to ensure that the basic requirements for ship recycling are fulfilled and a GSRGP is prepared. Preparation of the plan pertaining to one type of ship is to be led by a competent person having thorough understanding of safe practices and procedures adapted to dismantle that particular type. Drawings showing general arrangement of the ship, locations of safety equipment, cargo handling equipment, cargo holds, tanks and other compartments, accommodation outfits, piping systems, and ventilation and air conditioning systems; log books of tank substances; stability and hydrostatic data; etc. must be given due consideration while preparing the GSRGP. The flow charts presented in Figs 3.4 to 3.9 shows the general aspects of the GSRGP. Since each type of ship would have a number of special items onboard to suit her function, the plan has to be adapted for individual types and further elaborated upon acquiring more information for the specific ship to be dismantled. For special types of ships, input from experts shall be sought as necessary during development of the plan. It is recommended that the yard should further make their own standards for safe practices to be followed for each of the processes.

3.3.3 Ship Recycling Processes

Processes and sub-processes which have been indicated in the flow charts for the four stages are described below. Out of these, some activities may extend over two stages or even more depending on various factors such as the ease of access to the job location by personnel and handling equipment, requirement of removal of components for access to the work location, ease of carrying out the work, availability of time for job completion, and incompatibility with other ongoing activities.

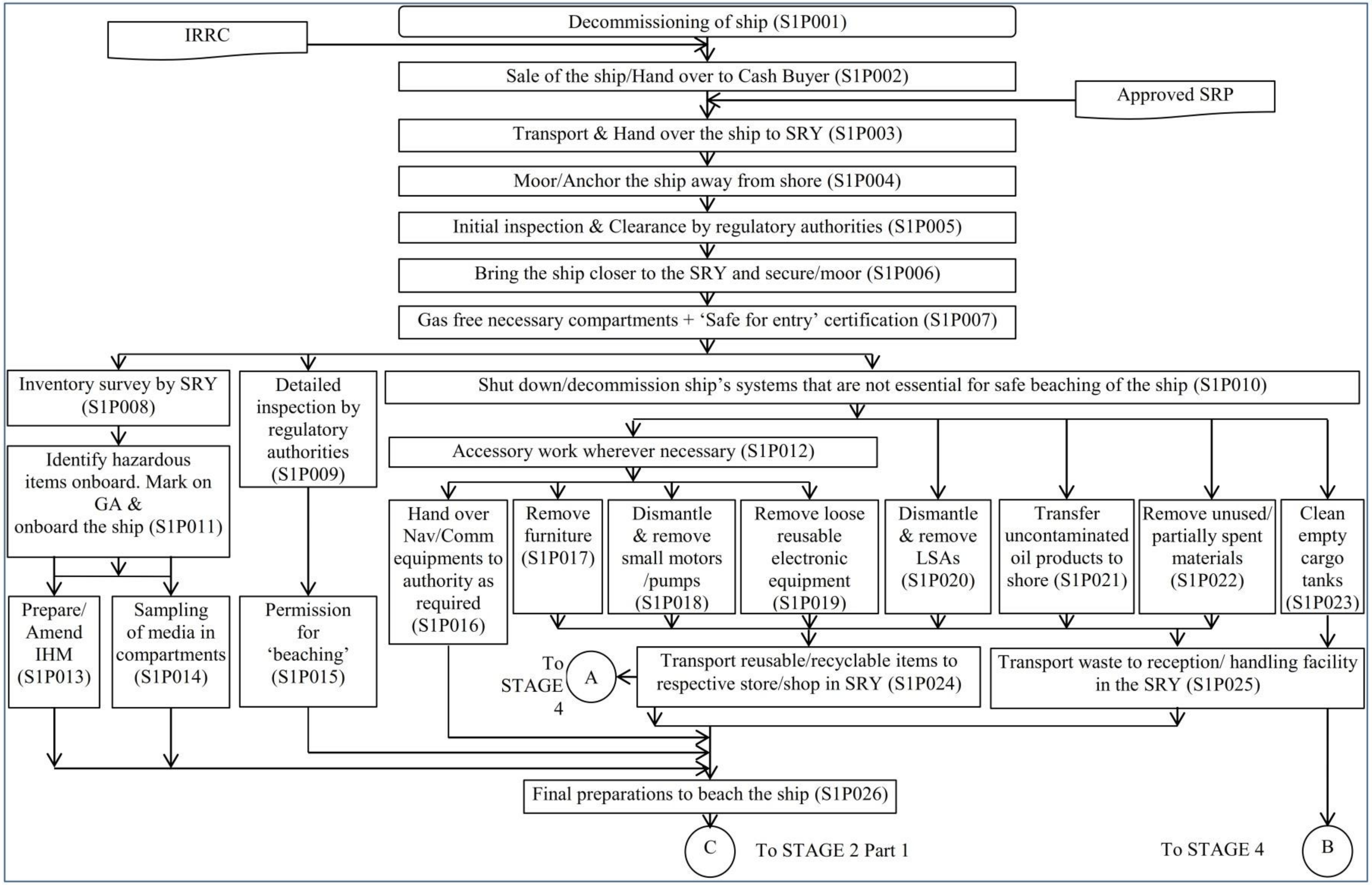

Fig. 3.4 General Ship Recycling Guidance Plan- Stage 1: In Offshore Location

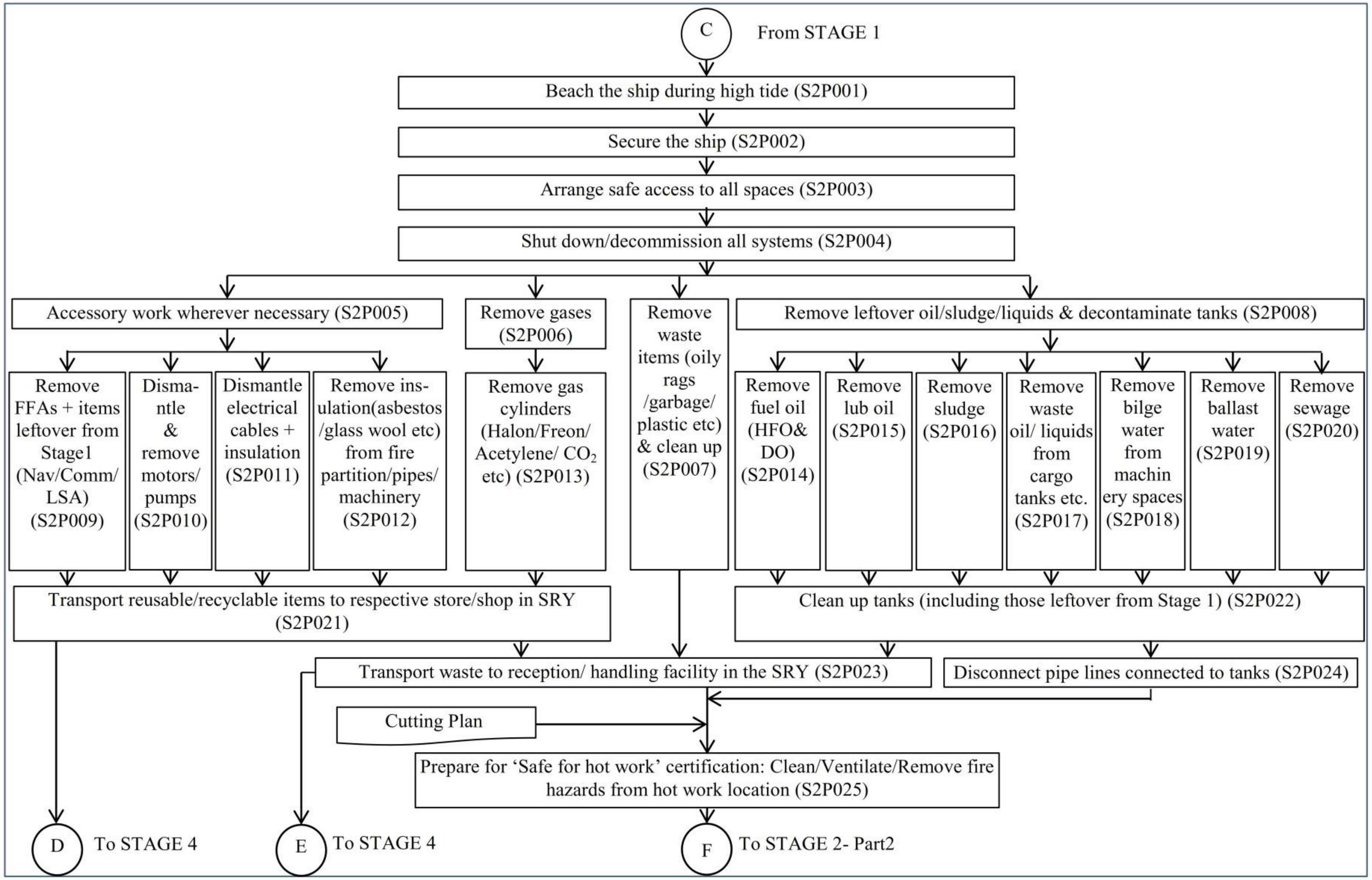

Fig. 3.5 General Ship Recycling Guidance Plan- Stage 2: In Intertidal Zone (Part 1)

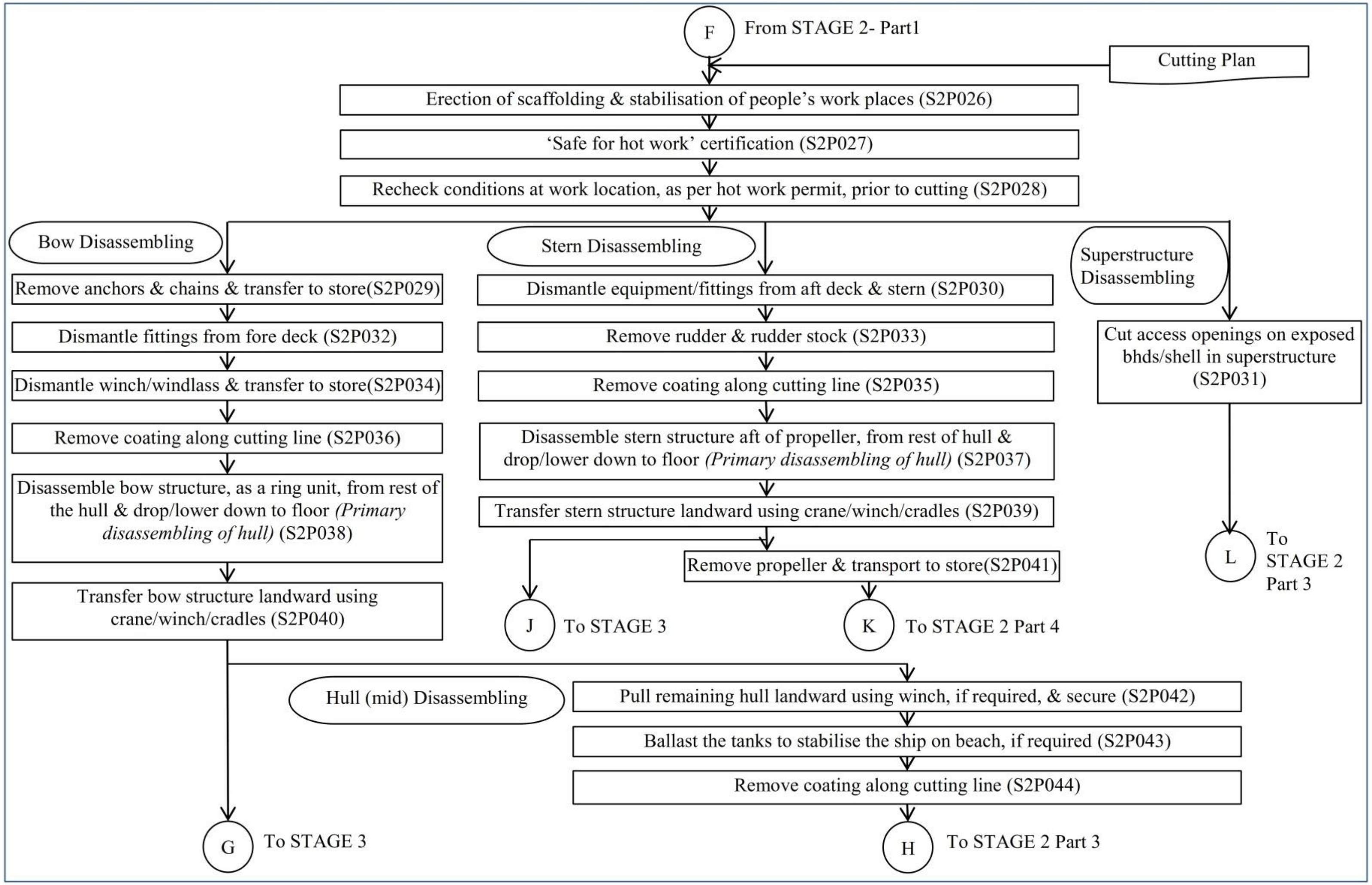

Fig. 3.6 General Ship Recycling Guidance Plan- Stage 2: In Intertidal Zone (Part 2)

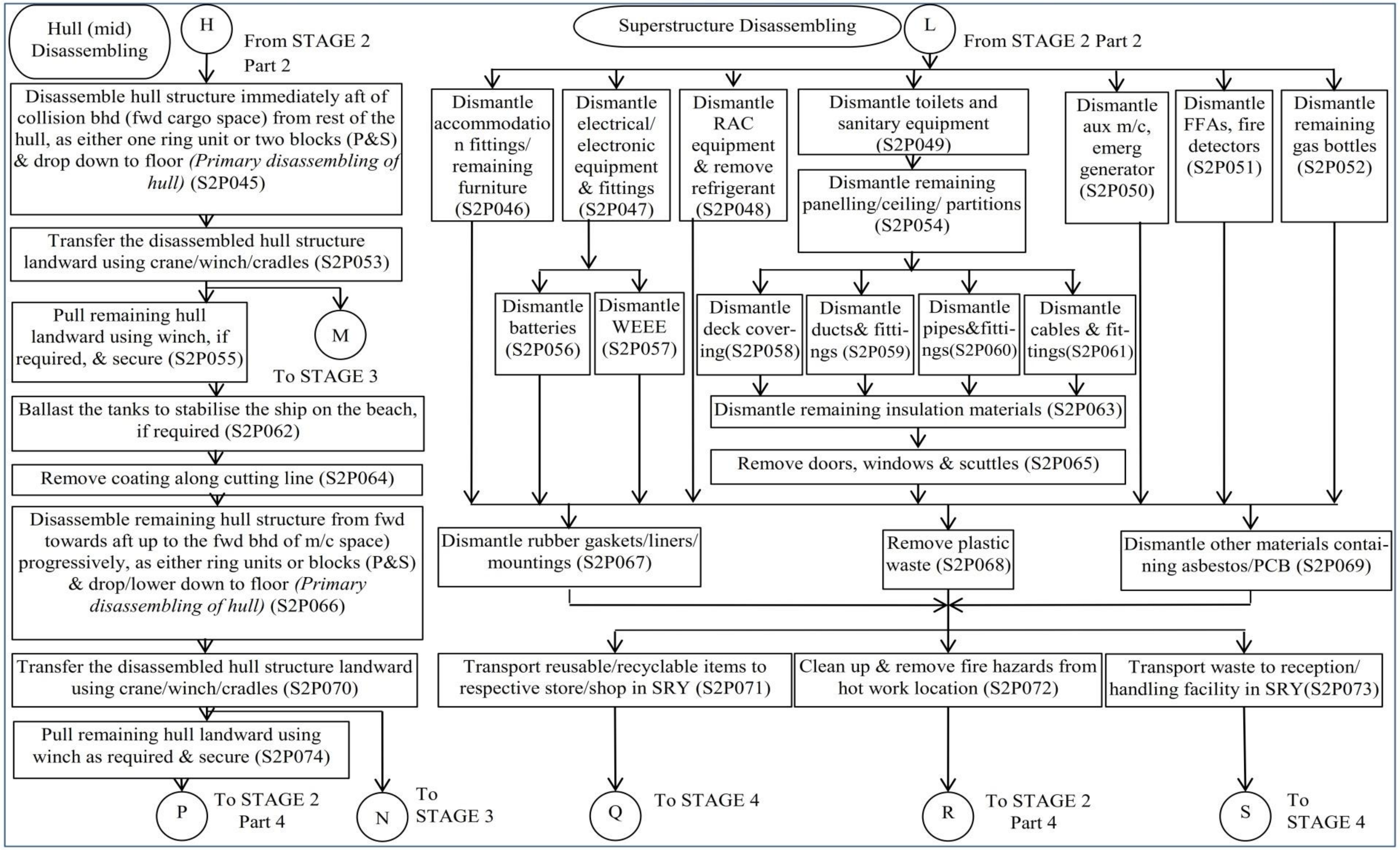

Fig. 3.7 General Ship Recycling Guidance Plan- Stage 2: In Intertidal Zone (Part 3)

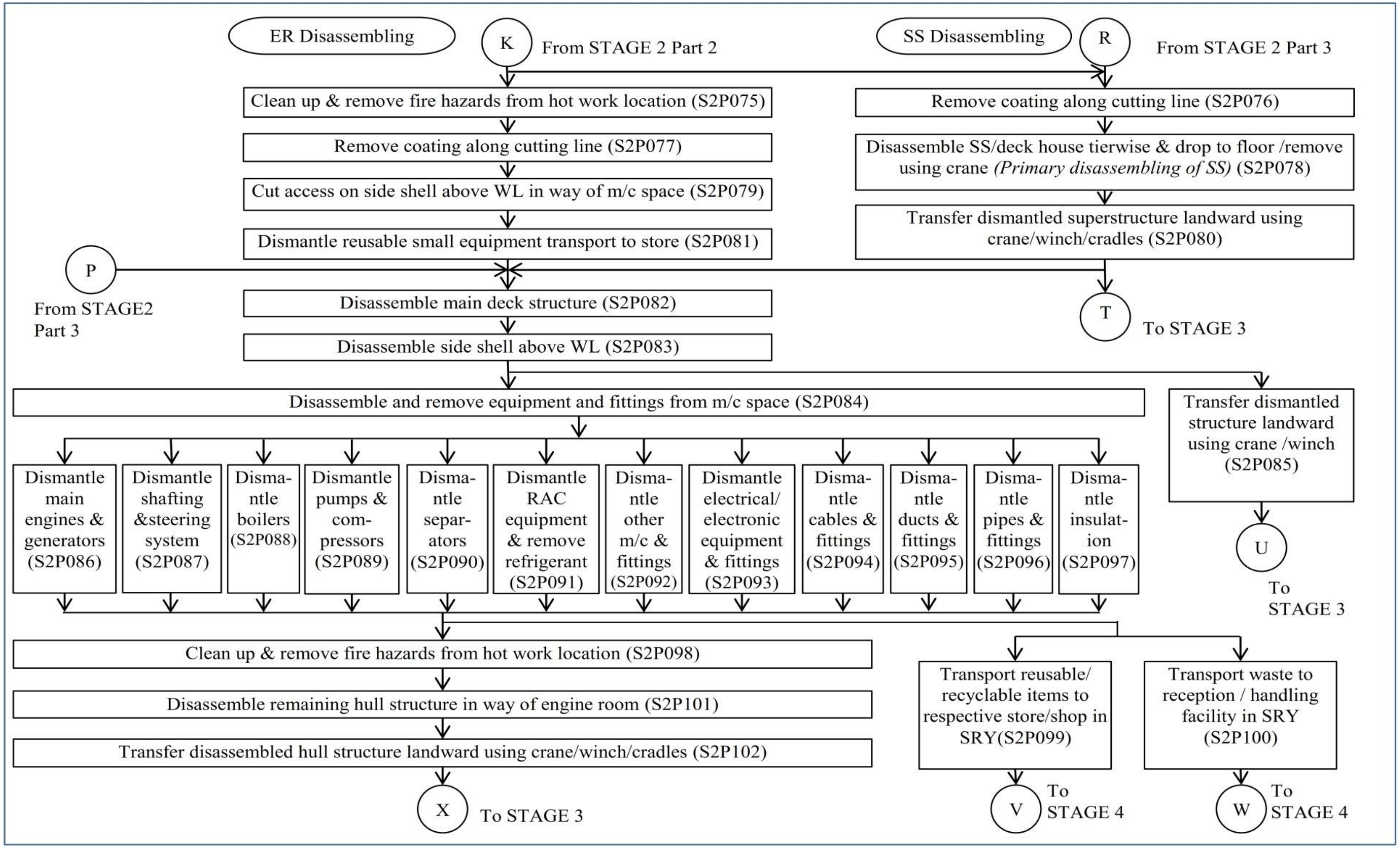

Fig. 3.8 General Ship Recycling Guidance Plan- Stage 2: In Intertidal Zone (Part 4)

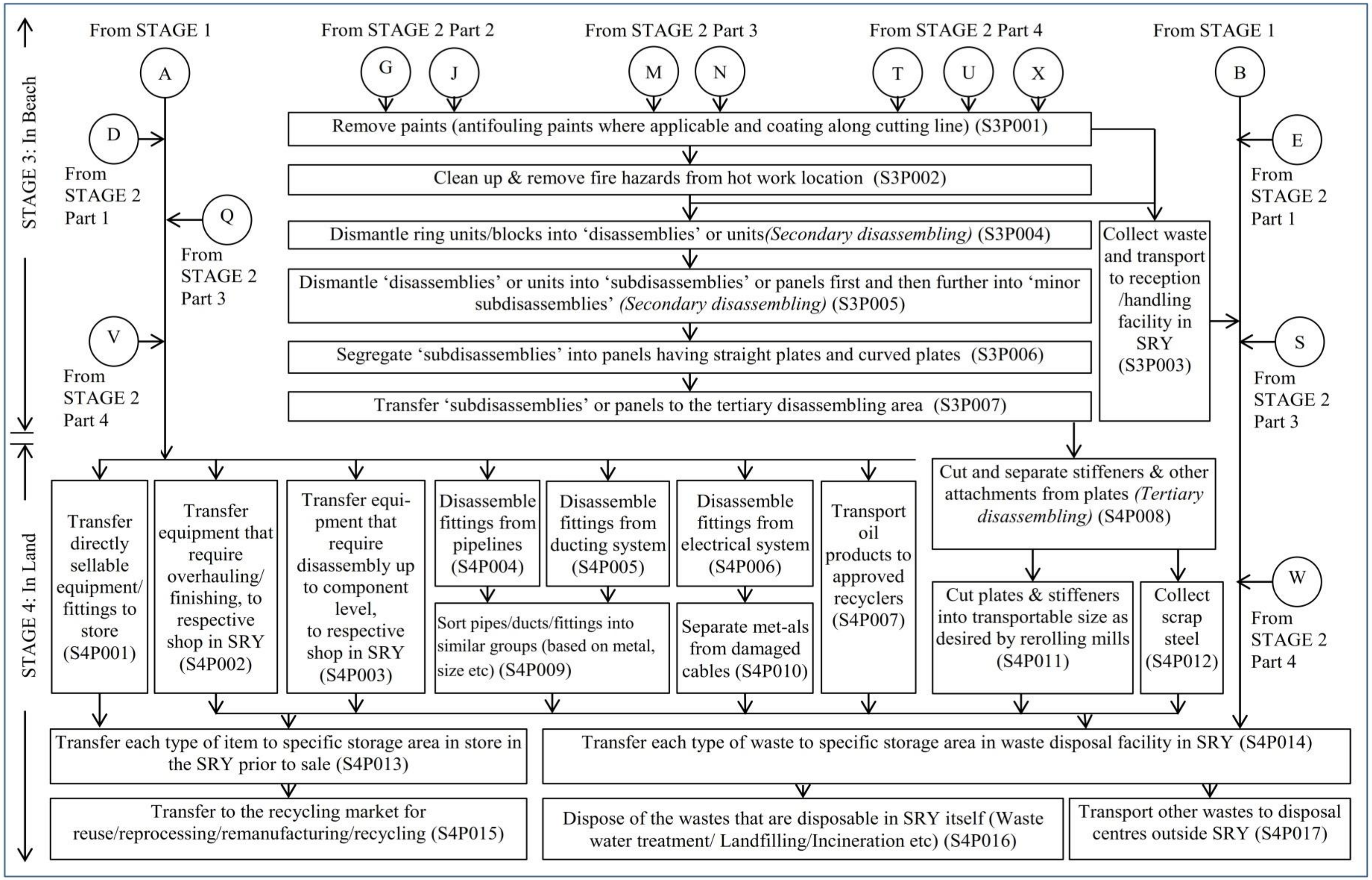

Fig. 3.9 General Ship Recycling Guidance Plan- Stage 3 and 4: In Beach and In Land

Depending on factors such as layout of the ship, facilities in the SRY, and availability of manpower the method of execution of recycling processes may vary between various types of ships and also between various SRYs. Such processes under each of the stages must be clearly indicated while preparing the GSRGP for a particular ship. It is recommended that the yard must make their own standards for the safe practices to be followed for each of the processes described in sections 3.3.3.1 to 3.3.3.4 below. Few images taken from the documentation, which has been used for studying the recycling processes of a ship, are presented in the following subsections along with the description of the process.

A coding has been proposed for each process and subprocess in the ship recycling activity. The coding has been done based on a numbering for the Stage and the process and it is of the format ‘SxPy’ where ‘S’ represents Stage, ‘x’ is a single digit number which stands for the stage number, ‘P’ represents Process, and y is a three digit number which is unique for each process and subprocess. Values of x are 1, 2, 3, and 4 for ‘In Offshore Location, ‘In Intertidal Zone’, ‘In Beach’, and ‘In Land’ respectively. Values of ‘y’ for each process has been incorporated in Figs. 3.4 to 3.9 corresponding to the GSRGP for each ship recycling stage.

3.3.3.1 In Offshore Location (Stage 1)

Decommissioning of ship

If a shipowner decides to permanently withdraw his ship from service due to various factors including ship’s age and market constraints, necessary procedures for its declassification from the Classification Society shall be followed. The shipowner shall inform this decision to IASR for incorporating in the World Fleet Database. If the shipowner opts to recycle the ship, he has to initiate tender processes to finalise a SRY, either directly or through brokers or cash buyers. The shipowner must forward necessary documents; including updated IHM, drawings, and ship stability data; to enable the SRY to generate a safe SRP. Upon completion of preparation of the plan, the owner shall arrange for a final survey by the Flag State Authority for issuing the IRRC. It is recommended that the preparation of the ship for recycling; which includes removal of hazardous substances, cleaning of compartments, removal of residues, and arranging safe conditions for entry; should be carried out to the maximum possible extent during this stage for facilitating a safe and smooth recycling of the ship.

Sale of the ship / Hand over to cash buyer

After getting clearance from the Flag State, the ship can be sold to the cash buyer together with the documents such as IHM, IRRC, and the ship's drawings.

Approval of ship recycling plan (SRP)

As required by IMO (IMO 2009), approval of SRP, which is prepared by the SRY, shall be obtained from the SRSMA or the Competent Authority assigned by the administration prior to commencement of any operations related to recycling of a ship.

Transport and hand over the ship to SRY

It is preferred that the ship be transported by its own propulsion power to the recycling site. However, if the condition of the ship does not permit this, it is to be towed using tugs. The necessary approvals, permissions and certifications are to be obtained from Flag State, Classification Societies, and Port State, and Recycling State authorities prior to this voyage or towing and safe practices are to be followed for this operation.

Moor/Anchor the ship away from shore

The ship may be anchored or moored to the buoys away from shore, until clearance is obtained from the concerned authorities of the Recycling State.

Initial inspection and clearance by regulatory authorities

An initial inspection of the ship is carried out at the anchorage or moored position by the Customs, Port State and Recycling State Maritime Administrations and pollution control authorities to verify its general condition and the documents onboard. An inventory of navigational and communication equipment is prepared during this inspection.

Bring the ship closer to the SRY and secure or moor

Upon satisfactory completion of the initial inspection and obtaining permission from the authorities, ship can be brought closer to the yard and moored alongside a pier or quay.

Gas free necessary compartments and ‘safe for entry’ certification

Tanks and other spaces in which inspection or work is to be carried out before beaching are to be well ventilated and gas freed so that the ambient conditions in these spaces are safe for entry. ‘Safe for entry’ certificates shall be obtained from the concerned authority and displayed at the entrance of such spaces.

Inventory survey by the SRY

The yard shall conduct an inventory survey onboard the ship, with the help of IHM if available, in order to identify, locate and quantify various components containing hazardous materials such as PolyChlorinated Biphenyl (PCB), asbestos, oils, paints, TriButyl Tin (TBT), heavy metals, chemicals, radioactive isotopes, freon or ChloroFluoroCarbons (CFCs), halons and other wastes. Services of specialists may be sought if the yard does not have the expertise to conduct such a survey. The information obtained from the survey shall be indicated on a General Arrangement drawing of the ship. It is recommended to prepare an IHM if it is not made available by the previous owner of the ship. Suitable markings shall be made onboard at the location of the hazardous materials for awareness of the people working around. Any deviations from the IHM, if found during the survey, shall be noted and the IHM shall be amended accordingly. Sampling of media in the compartments requiring hot work shall be conducted in order to identify its content and composition. Inventory survey of useful items onboard can also be carried out during this stage.

Detailed inspection by regulatory authorities

A detailed inspection shall be carried out by the regulatory authorities or their representatives to check the safety, strength, stability and environmental aspects of the ship for beaching operation. Condition of bottom structure is to be thoroughly checked to eliminate chances of a structural failure during the beaching operation. Permission for beaching will be issued for the ship only after obtaining clearance from the authorities.

Shut down/decommission ship's systems that are not essential for safe beaching of the ship

Some of the auxiliary systems in the ship, such as hydraulic system, domestic water system, and incinerators which are not essential to carry out safe beaching of the ship may be shut down and decommissioned while the ship is near the SRY.

Accessory work

This involves removal of items, such as panelling, insulation, cables, furniture, and fixtures for making access to the equipment or fitting to enabling their removal.

Hand over navigational and communication equipment to authority

Navigational and communication equipment such as Very High Frequency (VHF) radio and walkie talkie sets, shall be handed over to the concerned government authority as per the regulations of the recycling state.

Remove furniture

Majority of the furniture onboard the ship may be reusable. Only smaller size furniture that is removable through ship's doors shall be dismantled at this stage and transported to the store. They shall be carefully handled to avoid any damage. Since no hot work will be permitted at this stage, the lugs at their base for connection to the deck shall be removed only by cold work.

Dismantle and remove small motors and pumps

Equipment including small pumps and motors which are not essential for the beaching operation or other recycling related operations onboard the ship may be dismantled and transported to the store in this stage. Depending on the conditions of the equipment, they can be categorised as reusable or recyclable. If these had been utilised for handling hazardous substances onboard, necessary safety precautions shall be taken for dismantling them from the connections and for proper containment of the hazardous substances. Any dismantling requiring hot work shall be carried out only after obtaining hot work permit and it is to be planned for the next stage.

Remove loose reusable electronic equipment

Electronic equipment such as printers, scanners, radios, music systems, televisions, and computers which are easily detachable and reusable shall be removed carefully and transported to the store for resale.

Dismantle and remove LifeSaving Appliances (LSAs)

LSAs including life jackets, survival suits, life buoys, life rafts, life boats, and rescue boats shall be removed from the ship, lifted ashore, and transported to the store. Resale of these for direct reuse is to be based on the assessment of their conditions and clearance by the regulatory authority. Any dismantling requiring hot work shall be planned for the second stage. Removal of Rescue Boat from the obsolete ship is shown in Fig. 3.10.

Fig. 3.10 Removal of Rescue Boat

Transfer uncontaminated oil products to shore

The uncontaminated oil products may include heavy fuel oil, marine diesel oil, lub oil, and hydraulic oil. If these are inside the ship's tanks, transfer to the shore can be made with the assistance of ship's own systems. If the oil is inside the drums or barrels which are unused, it may be carefully lifted to shore.

Remove unused and partially spent materials

These materials include various gas cylinders, chemicals, batteries, paints, grease, ropes, provisions, etc. These shall be safely transported to the store in the yard.

Clean up the empty cargo tanks

Any small amount of cargo residues leftover in the cargo tanks or holds shall be drained or emptied and the tanks shall be washed. Waste water and the solvents that are used for tank washing shall be properly contained and treated either onboard or in the yard in accordance with the requirements of International Convention for the Prevention of Pollution from Ships (MARPOL) or the national regulations.

Transport reusable or recyclable items to respective store or shop in SRY

Items removed from ship during this stage shall be transferred to a barge alongside and then to the store or the workshop in the yard depending on whether it is reusable or recyclable. Safe removal of as many items as possible from the ship will help to make the ship lighter and thereby help to move the ship as landward as possible.

Transport waste to reception or handling facility in the SRY

Any waste generated during the activities carried out in Stage 1 shall be transferred to the reception facility in the yard with the help of a barge without any spillage to sea.

Final preparations to beach the ship

Parameters such as stability of the ship during the afloat and beached conditions, hydrostatic particulars of the ship including draft and trim, condition of propulsion system, ship's speed, condition of beach, and tide levels shall be analysed to achieve a safe beaching of the ship. A suitable schedule for beaching shall be prepared after clearance is obtained from the concerned authorities.

3.3.3.2 In Intertidal Zone (Stage 2)

Beach the ship during high tide

Ship will normally be beached by its own propulsion power during high tide with bow facing the land and stern towards the sea. It will be moved as landward as possible so that it can be stable on the beach during low tide. If the ship is beached with the assistance of tugs, it may not be practically possible to make the ship sit in a dry condition during low tide. It is recommended to have an impermeable bottom of concrete at the site, where dismantling activities take place, along with a drainage system which can ensure containment of hazardous substances in the yard. To the extent practicable, ship shall be moved up to the level of such an impermeable floor during beaching operation. This could also help to reduce chaffing action of ship's bottom with beach sand. Direct contact of ship's hull with beach can cause deposits of antifouling paint in the sediments, which may get transported to the water and cause environmental pollution. It is recommended to use air bags for beaching or hauling up the ship in order to reduce the extent of pollution due to the chaffing action mentioned above. Image showing beaching operation of the ship is given in Fig. 3.11.

Fig. 3.11 Beaching of Ship

Secure the ship

The ship is to be well secured in position to reduce unwanted movements that can adversely affect the performance of the workers during high tide. This can be ensured by mooring using wire ropes connected to shore and to winches and by ballasting some of the tanks as necessary to increase weight of the ship. The securing arrangements need continuous monitoring and alteration with progress in disassembling operations of the hull and superstructure. Securing of the ship is shown in Fig. 3.12.

Fig. 3.12 Securing of Ship

Arrange safe access to all spaces

‘Safe for entry’ permits shall be obtained both for the compartments; including tanks, cargo spaces, void spaces, other confined spaces and enclosed spaces; in which the actual work will be carried out and for the adjacent compartments that may get affected by the work. Adequate forced ventilation shall be provided to keep the oxygen and flammable gases contents inside the compartments within permissible limits as specified by regulations such as ILO. Entries to such spaces are to be made free of obstructions and preferably, sloping rigid ladders shall be provided where necessary and practical. No access shall be provided through areas subject to falling hazards. Unprotected areas shall be suitably barricaded. Scaffoldings shall be provided wherever necessary. Lighting arrangement shall be provided inside the spaces.

Shut down and decommission all systems

At this stage, all ship systems can be decommissioned as the ship is not waterborne any more. Such systems include cargo oil system, fuel oil system, lub oil system, cooling system, hydraulic system, bilge and ballast system, pneumatic/compressed air system, ventilation system, refrigeration and air conditioning systems, firefighting system, fire detection and alarm system, control systems, oil water separator system, exhaust system, sanitary discharge system (black water and grey water), stabilising system, electrical systems, boilers, air filling and sounding systems, and any other systems, such as domestic fresh water and domestic sea water, which might be leftover from shutting down during Stage 1. All machinery and fittings shall also be shut down and decontaminated before commencement of actual dismantling of the ship. If necessary, operation manuals of the machinery shall be referred to before stopping the systems.

Remove FireFighting Appliances (FFAs) and other items leftover from Stage 1 including navigational and communication equipment and LSA

FFAs such as portable fire extinguishers and fixed fire extinguishing systems can be removed from the ship at this stage except for those which require hot work for removal. Removal of the fittings, which require hot work to be carried out, shall be done after the hot work permit is obtained. Fire detectors can also be removed at this stage. Necessary care shall be taken and safe practices shall be followed in handling hazardous substances that form part of the above items. Image of fire extinguishers which were removed from the obsolete ship is shown in Fig. 3.13.

Dismantle and remove motors and pumps

Pumps, motors, and other auxiliary equipment which can be unbolted from their foundations as well as their pipe connections, shall be dismantled during this stage and shifted to designated locations onboard. The equipment and surrounding area shall be decontaminated and the pipe connections shall be blanked to prevent any pollution due to spillage. Markings shall be made on the pipe end connections to identify them later for further dismantling. Necessary permits shall be obtained and safety precautions shall be taken while handling any equipment that has been used for handling dangerous and hazardous substances. The equipment shall be lifted ashore after access openings are cut on the shell or decks later on. Temporary storage of motors and pumps in designated locations onboard is shown in Fig. 3.14.

Fig. 3.13 Removed Fire Extinguishers

Dismantle electrical cables and insulation

This activity involves removal of electrical cables and their insulation from the open areas and accessible areas such as engine room, bare bulkheads and decks, and exposed areas. This does not include areas in way of accommodation and wheel house. An inspection shall be conducted to locate end connections and junctions of the cables. These shall be safely detached from equipment such as alternators, batteries, switch boards, and panels. Dismantling of cables shall be done in sections or parts and the cables can be wound directly on reels or drums during their removal itself. The drums shall be transferred to designated areas on each deck and lifted ashore at a later stage. Lagging and insulation of the cables shall be detached following the recognized safe practices and with proper containment. Cable trays can be left on the attached structure and can be removed along with the structure as a unit during disassembling.

Remove insulation (asbestos/glass wool etc.) from fire partition, pipes, or machinery

This activity consists of removal of lagging and insulation on pipe lines, such as exhaust systems and hot water systems, and on machinery such as boilers and engines. Removal of fire partitions consisting of insulation together with ceiling and panelling or cladding located in accommodation areas is also included in this activity.

Fig. 3.14 Designated Locations Onboard for Motors

Remove gases

Cylinders containing hazardous items, such as acetylene, Freon, and halon, together with other gases, such as oxygen and CO_2, which were leftover from Stage 1 shall be dismantled from their securing arrangements and safely stored at segregated locations onboard with temporary securing arrangements. These shall be lifted ashore later.

Transport reusable and recyclable items to respective store/shop in the SRY

During dismantling and removal of equipment, it is recommended that it should be segregated onboard as either reusable and recyclable or scrap, and then it shall be marked and temporarily stored at designated locations prior to lifting it to the shore. This can help to avoid their intermixing and thereby save time at the land during their transportation either to store for sale or to shops for further processing.

Remove leftover oil, sludge, and liquids and decontaminate tanks

Liquids such as Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO), lub oil, sludge, dirty oil, cargo tank residues, other waste oil, bilge water, ballast water, and sewage which might remain in the tanks and bilge areas in machinery spaces shall be transferred into drums without any spillage or pumped directly to the individual reception facilities in the SRY for treatment and disposal in accordance with the regulations. Pumps available in the SRY shall be utilized to completely empty the tanks as the ship's systems might have already been decommissioned. Bilge water needs to be removed on a continual basis since water will be used for various cleaning operations and fire control measures in various compartments throughout the recycling operation. Permits for removal of the liquids and cleaning shall be obtained prior to commencement of the above operations.

Clean up tanks (including those leftover from Stage 1)

After removal of the contents, the tanks or compartments together with the pipe connections shall be cleaned mechanically or chemically and decontaminated. Waste generated during cleaning and the waste water or solvents shall be transferred to the reception facilities in the yard for further treatment.

Disconnect pipe lines which are connected to tanks

All suction, discharge, air, and sounding pipe connections shall be suitably blanked to prevent any further contamination of the tanks

Remove waste items (oily rags, garbage, plastic etc.) and clean up

Waste generated due to the ship's operations and due to the dismantling operations including oily rags, garbage, plastic, drums, and paint chips shall be collected, properly contained, and transferred to the disposal facility in the yard. Cleaning up of spills and residues as well as removal of debris in and around the ship shall be carried out on a continual basis in order to ensure pollution free and hazard free environment. Proper housekeeping shall also be done throughout the recycling process.

Cutting Plan

Cutting plan can be used as a document to show progress of work, position of safety measures, location of hazardous items onboard, and proposed location for disassembled items. This is in addition to its functions specified in section 3.3.1.2.

Primary disassembling will result in ring units or blocks. For superstructure, the cutting lines on the shell or exposed bulkheads may be slightly above each superstructure deck subject to their weight not exceeding the limits set by the yard with respect to lifting or transportation. Size of the ring units or blocks shall be decided based on the maximum weight that can be lifted using cranes and the maximum length that can be accommodated on the transportation equipment in the SRY.

Prepare for 'safe for hot work' certification

Necessary preparations to comply with the conditions for 'safe for hot work' certification shall be done for all the compartments requiring hot work. Individual certification will usually be required for each compartment. Therefore, the preparations shall be done in a sequential order as per the cutting plan. Adequate ventilation shall be maintained in the compartments and the inside atmosphere shall be maintained within the permissible limits for hot work.

Erection of scaffolding and stabilisation of people's work places

Tower scaffolding or hanging scaffolding shall be erected as necessary for carrying out work at heights. It is to be ensured that the workplaces of the people are stable and are not subject to any type of hazards including falling hazard. .

'Safe for hot work' certification

Upon ensuring compliance with the safety requirements, requests shall be made for 'safe for hot work' certification for locations as per the SRP.

Recheck conditions at work location, as per hot work permit, prior to cutting

Even if 'safe for hot work' permit is available, checks shall be made prior to commencement of any hot work in order to prevent incompatible activities within the vicinity of the hot work. These incompatible activities include cleaning of oil tanks, removal of paints, and handling of other combustible materials such as paint drums and acetylene cylinders. Persons for functioning as fire watch shall be positioned at designated locations during the hot work.

Bow disassembling

Primary disassembling' of hull is usually commenced with bow structure since it is the closest part of the hull to the yard. Initially bitter end connection is to be released, and anchors and chains shall be lowered in a controlled manner to the ground. This shall be followed by removal of deck machinery including windlass, winches, capstans, and davits; and deck fittings such as bollards, rollers, forward navigation mast, hatch covers, and manhole covers. Hot work is employed to dismantle these from their foundations. Access openings may be cut on the side shell for ventilation as well as removal of items. Reusable equipment such as hand pumps, emergency fire pumps, and ventilation fans and items such as ropes, which are left over from Stage 1, shall be removed in this stage carefully, without causing any damage to it. If ship is fitted with bow thrusters, the propellers and the drive shall be dismantled and transported to shore. It may be necessary to cut and remove the bow thruster tunnel together with the propeller without weakening the bow structure.

Once the above activities are completed, cutting line shall be marked on the hull and paint coating on the surface along the cutting lines shall be removed and cleaned up. As forepeak tank may be narrower in many locations, especially if it is a bulbous bow, structural members such as shell plates may need to be cut and removed as panels to ensure proper access and ventilation. Bow structure up to the forecastle deck may be removed as a single ring structural unit. After rechecking the surrounding locations, disassembling of the bow structure from rest of the hull can be commenced. It is recommended to lift and remove the bow structure in a controlled manner using crane during its dismantling. If the wire ropes used to secure the ship are connected in way of the bow structure, these shall be shifted to the hull part aft of the bow structure prior to the commencement of cutting operations on the bow structure. Partly disassembled bow of the obsolete ship is shown in Fig. 3.15.

After detaching bow structure from hull, it shall be transferred to the ‘Secondary Disassembling Area’ in the SRY using a crane, winch and/or cradles. If the bow structure is too large to be transported using crane and trailers, especially due to its curved shape, it may be further disassembled into blocks or units prior to the transportation. This is to be carried out quickly in order to avoid obstruction to other activities, including disassembling of remaining hull and transportation of items, which will also be carried out at the same location. Any debris created such as scrap, paint chips and waste from the structure inside shall be quickly collected, properly contained and transferred to designated areas in the yard in order to prevent contamination of the sand.

Fig. 3.15 Bow Disassembling

Stern disassembling

Depending on proximity of stern portion to the land and accessibility of handling equipment, the stern disassembling can be commenced as a parallel activity with bow disassembling. Initially the deck machinery, such as winches and capstans, and deck fittings including hatch covers, manhole covers, mooring fittings, and ventilators shall be dismantled. Access openings may be cut on the transom or side shell as necessary for ventilation and removal of items. Control panels and equipment in way the stern structure shall also be dismantled and the connections of pipes, electrical cables, and ventilation ducts shall be detached. Reusable equipment such as hand pumps, ventilation fans, and fittings shall be removed carefully. Rudders, followed by rudder stocks, shall be dismantled from the steering gear if the rudder trunk is much above the water level during high tide. It shall be carefully lowered to the floor or to a platform and transported to the yard using a crane. Upon completion of these activities, cutting lines shall be marked on the hull and the paint coating on the cutting surface along the cutting lines shall be removed.

Stern structure aft of propellers shall be removed either as a single ring unit or as two blocks, one each port and starboard. In order to prevent any pollution, it is recommended to make the blocks oil-free prior to their disassembling from the hull. The stern structure shall be lowered in a controlled manner using cranes and transported to ‘Secondary Disassembling Area’ in the SRY using a crane or winch. Propellers can be removed at this stage and transported using crane to the store.

Scrap, paint chips, grease, and waste created due to dismantling operation shall be collected, contained, and transferred to designated areas in the SRY in order to prevent contamination on the beach.

Superstructure disassembling

Disassembling of superstructure can also be started simultaneously with that of the bow and stern structures as mentioned above. The actual ‘primary disassembling’ of the structural part of superstructure can start after equipment and fittings are dismantled and removed from the ship. Necessary permits for work, including hot work, cleaning, and removal of hazardous substances, shall be obtained prior to commencement of each work in each space.

Cut access openings on exposed bulkheads and shell in superstructure

Necessary access openings shall be cut on the external bulkheads or side shell to ensure adequate ventilation and to remove the equipment, fittings, and waste to shore. However, it shall be ensured that this will not result in weakening of the structure.

Dismantle accommodation fittings and remaining furniture

Accommodation fittings including furniture that remain in the ship shall be dismantled at this stage. Many of these items are reusable and, therefore, shall be removed with utmost care. Hot work may be employed to remove the securing arrangements of these from the structure only where it is necessary. These fittings may be transported independently to the store in the SRY.

Dismantle electrical and electronic equipment and fittings

Electrical equipment in the galley, accommodation, and other areas shall be removed from the ship and transported to the respective locations in the yard. These may include both reusable and waste items. There will also be a large number of electronic equipment related to navigational system, communication system, and operational control of the ship inside wheel house and other control rooms. Reusable items from these shall be transferred to the store. Necessary precautions shall be taken and safe practices shall be followed while handling Waste Electrical and Electronic Equipment (WEEE) as they may contain hazardous substances such as PCB and heavy metals. Navigational equipment onboard the obsolete ship is shown in Fig. 3.16.

Fig. 3.16 Navigational Equipment

Dismantle refrigeration and air conditioning equipment and remove refrigerant

Refrigeration equipment, including evaporators inside cold rooms, and air conditioning equipment, such as Air Handling Units (AHU) for central air conditioning system and indoor and outdoor units for split air conditioning system, are normally located inside the superstructure or deckhouses. They shall be dismantled from their foundations and connections, such as pipe, electrical, and ducts, and transported to the shore. Any refrigerant contained in the machinery shall be stripped off and properly collected as per the safe practices.

Dismantle toilets and sanitary equipment

If the toilets are of the module type, each of them can be removed and lifted as a module from various decks in accommodation area. Otherwise, the sanitary and toilet equipment shall be removed individually. These may need accessory work like removal of tiles and cementing and the disconnection of pipe lines.

Dismantle remaining panelling, ceiling, and partitions

There might be partitions, lining, panelling, and ceiling which act as fire boundaries or just as cabin separators in the ship. The fire partitions may contain asbestos or other hazardous materials. Some of these may be covering up the thermal or fire insulation materials. Depending on the types of materials, safe practices shall be followed for their dismantling and safe containment prior to transportation to the concerned section in the yard. Dismantling of panelling in the obsolete ship is shown in Fig. 3.17.

Fig. 3.17 Dismantling of Panelling

Dismantle auxiliary machinery, emergency generator

Auxiliary machinery such as emergency generator together with the distribution boards, diesel oil tank, and batteries are normally installed inside superstructure. These shall be dismantled and lifted ashore.

Dismantle remaining FFAs/fire detectors

FFAs which were not removed earlier and those requiring hot work for removal of their fixtures shall be dismantled during this stage. Fixed fire extinguishing systems will need to be disconnected from pipelines. Fire detectors may contain radioactive isotopes and extinguishers may contain halons. Safe practices shall be followed while handling these items.

Dismantle remaining gas bottles

Superstructure generally encloses a CO_2 room containing cylinders for fighting fire in the machinery spaces. Gas bottles may also be found inside the galley, hospitals, workshops, etc. Gas bottles which were not removed during earlier stages shall be dismantled and safely transported to the store.

Dismantle deck covering

Flooring inside cabins and accommodation spaces normally consists of linoleum or vinyl flooring. Sanitary spaces may be with cementing and ceramic tiles. These shall be removed before commencement of hot work on the decks. Tiles and cementing may need to be cut or broken and removed as waste material.

Dismantle ducts and fittings

There would be separate ducting system inside the superstructure for air conditioning system and mechanical ventilation system. Ducts inside the accommodation would get exposed only after removal of ceiling and panelling. These ducts can be unbolted at the joints and transported together to the shore. Fittings on the ducts such as dampers and regulators shall also be removed along with this. Removal of insulations on the ducts needs to be carried out carefully in segregated locations onboard without making the insulation particles airborne.

Dismantle pipes and fittings

Pipes and fittings on various systems including fire system, domestic seawater and freshwater system, hot water system, cooling system, and sanitary system will need to be dismantled. Like ducts, most of the pipes inside accommodation would be running behind panelling or ceiling. Insulation of the pipes may contain glass wool or asbestos and these needs to be separated from pipes in segregated locations with adequate precautions. Pipes can be dismantled at their flanged joints and can be stored temporarily on each deck at designated locations prior to lifting them ashore. Pipe supports need not be removed at this stage as these can be dismantled later as part of the structural blocks on superstructure.

Dismantle cables and fittings

This activity involves the removal of electrical cables and their insulation from areas covered by the panelling and ceiling inside the superstructure and those which are left over from the previous stage. Cables shall be disconnected from the joints and junctions of the cables and shall be stored directly on reels during the time of removal. These reels shall be transferred to designated areas on each deck and lifted ashore later. Insulated cables shall be transferred to designated areas where the removed insulations can be properly contained without causing air pollution. Cable trays along with supports may be left on the attached structure and can be removed along with the structure during disassembling. Temporary storage of cables in the SRY is shown in Fig. 3.18.

Fig. 3.18 Temporary Storage of Cables

Dismantle remaining insulation materials

Majority of the exposed areas of the superstructure in way of accommodation would be having thermal insulation made of materials such as glass wool or asbestos in case of old ships. Some of them may be fitted with thermocol. Fire partitions will be insulated with materials such as asbestos or rock wool. The fibrous insulation material shall be carefully removed by trained persons having adequate Personal Protective Equipment (PPE) without causing any dispersion into the air.

Remove doors, windows and scuttles

Doors in the superstructure may be made of various materials such as steel, aluminium, Fibre Reinforced Plastic (FRP), and wood. Some of these doors and windows in way of bare bulkheads can be dismantled in the initial phase of Stage 1. However, those which are associated with panelling and insulation can be dismantled only after removal of such covering. Reusable items, especially those with glass panels, shall be removed with care. Steel frames welded to the structure may be left as part of the structure. Fire doors would need special consideration in handling their insulation.

Dismantle rubber gaskets, liners, and mountings

Rubber used as gaskets on closing appliances such as doors, hatch covers, manhole covers, tank lids, windows and scuttles, and as mountings of machinery and deckhouse shall be collected and stored temporarily onboard clear of the hot work locations prior to their transport to store.

Remove plastic waste

Plastic wastes may include pipes, trays, bottles, containers, office items, covering materials, and other fittings inside the accommodation. Some of these may need removal by cold work or mechanical cutting. These shall be transported as waste to the disposal facility in the yard unless they are having a resale value. If they have a resale value, it shall be sold to the outside market.

Dismantle other materials containing asbestos or PCB

Asbestos is mainly found on thermal insulation and surfacing materials in old ships, especially in laggings on pipelines, in ceiling, floors, and partitions in way of accommodation. PCB are normally found, both in solid and liquid form, in materials such as cable insulations, transformers, capacitors, hydraulic oil, and paints. Dismantling of items containing these hazardous substances shall be done by specially trained people in segregated covered locations onboard or in the yard. These materials shall be packed in safe containers and marked with warning signs.

Transport reusable and recyclable items to respective store or shop in SRY

Reusable and recyclable items dismantled from the superstructure shall be segregated and stored at temporary storage locations onboard at each deck and transported progressively to concerned locations in the yard using cranes.

Clean up and remove fire hazards from hot work location

Cleaning up shall be carried out on a regular basis inside the superstructure to reduce the extent of hazards and pollution. Upon completion of the dismantling of various equipment and fittings as mentioned above, all the fire hazards shall be removed from the superstructure. An inspection shall be conducted to check the compliance with the conditions on hot work permit prior to structural disassembling of superstructure.

Transport waste to reception or handling facility in SRY

Various types of wastes shall be segregated in accordance with the best practices for each type of waste and safely contained in bags prior to transportation to the reception or handling facility in the yard.

Structural disassembling of superstructure

Once the above activities included under the superstructure disassembling have been completed, cutting line shall be marked on the superstructure and coating along the cutting line shall be removed and cleaned up. Foundations of the already dismantled equipment can now be removed from the decks as necessary. Navigation masts and funnels shall be cropped at the bridge top level and lowered to the floor. Checks shall be made on strength of superstructure and the rigidity loss that may result from structural dismantling. As part of the primary disassembling process, the superstructure and deck houses can be removed as separate blocks, for port and starboard sides, from top down up to the upper deck level. The blocks may consist of one, two, or three tiers depending on the superstructure arrangement as well as the safe working load and reach of the cranes in the yard. The blocks shall be transferred to the 'Secondary Disassembling Area' in the yard using cranes, winch and/or cradles.

Scraps, scales, paint chips; and other wastes created during the dismantling shall be collected and transferred to designated locations in the yard.

Disassembling of remaining hull in way of cargo area or middle body

This activity involves primary disassembling of remaining hull in way of the cargo area commencing from the forward cargo hold. Therefore, it can only be started after the bow structure has been removed and adequate access is obtained from the forward end to the cargo hold. If the collision bulkhead is not removed along with the bow structure, it shall be dismantled as a panel at this stage in order to get a better access to the cargo hold and wing tanks. Remaining hull shall be pulled landward using winches and secured using wire ropes. If necessary, sea water may be filled in the ship's ballast tanks to get stability for the remaining hull on the beach. Fittings or equipment on the decks; such as cranes, accommodation ladder, davits, hatch covers, tank lids, and manhole covers; and inside the passage; such as ventilations fans, electrical panels, and fire detectors; shall be removed first. Pipes connections and electrical connections in way of underdeck passage shall be disconnected from the adjacent blocks. Deck houses, in way of the cargo holds shall be removed prior to disassembling of corresponding hull block.

After the above activities have been completed, cutting line as per the cutting plan shall be marked on the hull and the paint coating on the structure along the cutting line shall be removed and cleaned up. Hull in way of cargo holds may be disassembled and removed as two separate blocks, one on each port and starboard sides, unless the handling capacity in the yard permits its removal as a single ring unit. It shall be lifted and removed using crane in a controlled manner onto the ground.

Wire ropes that are used to secure the ship are to be shifted progressively from the securing points on the block that is going to be removed to new securing points on the remaining hull further aft of it. The disassembled hull blocks shall be transferred to the 'Secondary Disassembling Area' in the yard using a crane, winch and/or cradles. If the disassembled blocks are too large to be handled, it may be further cut into smaller structural units consisting of disassemblies, prior to the transportation. Residues, such as scrap, paint chips, and wastes, which are generated as a result of the dismantling process, shall be immediately removed and transferred to designated areas in the SRY.

The remaining hull may be moved or pulled landward using winches to facilitate further disassembling of the remaining hull with the hull blocks becoming closer to the yard. Similar disassembling operation as stated above shall be continued for the remaining hull structure in way of the cargo holds in a progressive manner from forward towards aft upto the forward bulkhead of the machinery space.

Disassembling of engine room

Disassembling of small equipment inside engine room can be commenced simultaneously with the disassembling of bow structure and superstructure. Chequered floors and bilge areas of engine room need to be cleaned on a regular basis since the disassembling of equipment can cause traces of oil from the disconnected pipelines. Since any work inside engine room of a ship can be highly hazardous, works requiring permits shall be commenced only after obtaining the necessary certification and after taking necessary safety precautions. Dismantling of hull structure being carried out from deck is shown in Fig. 3.19.

Fig. 3.19 Dismantling of Hull Structure

Access openings can be cut on vertical side shell plates in way of machinery spaces at locations above the high tide water level, on both port and starboard sides. In addition to providing ventilation and lighting, these openings can help to remove smaller reusable equipment and fittings through a lower location than the upper deck.

It is suggested that maximum number of reusable equipment and fittings such as pumps, motors, compressors, air bottles, batteries, and valves shall be disconnected, removed through these openings, and transported to the store in the yard. This can help in saving time for the dismantling activities of larger machinery in engine room.

Upon removal of superstructure down to the upper deck level and upon completion of primary disassembling operations of hull in way of the cargo space which is immediately forward of the machinery space, structural disassembling of engine room can be commenced. Cutting lines shall be marked on the decks and side shell prior to cutting and the coatings along the cutting lines shall be removed. Initially the upper deck structure shall be cut and removed as a panel, as per the cutting plan, followed by the cutting and removal of side shell plate panels, on both port and starboard sides, up to a level sufficiently above the high tide water level which will facilitate easy removal of the maximum number of equipment. These disassembled panels shall be lowered to the ground using cranes. The panels shall be transferred to the 'Tertiary Disassembling Area' in the yard after each disassembling operation of the structure.

Dismantling and removal of the remaining equipment and fittings in the machinery space, including the larger ones, can be carried out in this stage. Only skilled people shall be engaged to carry out these operations. A detailed plan shall be made for disassembling each of the major machinery based on its type and size.

Dismantle main engines and generators

Main engines consist of several components and a large number of pipe connections. Factors such as congestion of space in engine room, heaviness of various components of engines, and requirements on minimum headroom for removal of engine shall be considered for this operation. Safety related aspects shall be given first priority. For small engines, it may be possible to be lifted as a single unit to the land. However, for large engines it may be necessary to disassemble into different components prior to transporting it ashore. Initially the main engine shall be disconnected from various pipe connections of systems such as fuel oil, lub oil, cooling, exhaust, and compressed air. Open ends of pipe connections to the engines shall be blanked as necessary in order to eliminate any pollution due to spillage. Then the engine shall be uncoupled from the gearbox and the equipment on the forward power take-off. Gear boxes and other equipment connected to the shafting shall be disconnected from the couplings as well as the connections to the piping and electrical systems. After unbolting from the foundations, the components of the main engine and gearboxes can be lifted ashore. Handling of main engine of the obsolete ship using crane is shown in Fig. 3.20.

Fig. 3.20 Handling of Main Engine

Auxiliary generators can be disassembled into engine and alternators after disconnecting the joints for pipes and cables. With respect to the crane capacity, if the auxiliary generator is too large to be lifted ashore as a single unit, the engine may be disassembled further into components. Handling of the components inside the engine room may be done using chain pulley blocks or cranes.

Dismantle shafting and steering system

Remaining components of the shafting system such as intermediate shafts, plummer blocks, other bearings, and couplings can be removed at this stage. Tail shaft shall also be removed if the stern tube is above the high tide level. Steering gear shall be disconnected from cables and pipelines prior to its removal. Electrical panels and controls inside steering gear compartment shall be dismantled for removal.

Dismantle boilers

Boilers shall be disconnected from pipelines. Boiler is a probable location of asbestos onboard a ship. Insulation on the boiler and pipelines shall be handled as per approved safe practices at the designated handling area.

Dismantle remaining machinery and fittings

Remaining machinery inside the engine room; such as pumps, air compressors, oily water separators, purifiers, heat exchangers, air receivers, and refrigeration machinery; and fittings; such as valves, flanges, gaskets, and flow meters on various systems; shall be disassembled from their connections and lifted ashore. Open ended pipes shall be blanked and the hazardous liquids inside, such as oil and refrigerants as applicable, shall be removed and properly contained.

Dismantle electrical and electronic equipment, cables, and fittings

Main switch boards shall be disconnected from the cables. If the main switch board is too large to be handled, then it shall be disassembled into segments and lifted ashore. Control panels and distribution boards shall also be lifted ashore. Electrical cables inside engine room and the cables which are covered by panelling and ceiling inside machinery control room shall be disconnected from joints and stored directly on reels. These reels shall be transferred separately to designated areas on each deck and lifted ashore later. Insulated cables shall be transferred to designated handling areas where the removed insulations can be properly contained without causing air pollution. Cable supports may be left on the attached structure for their removal along with the attached structure during structural disassembling.

Dismantle ducts and fittings

There would be large sized ducts inside the engine room for mechanical ventilation. These ducts can be disconnected at the joints and can be transported together to the shore. Ventilation fans shall be disconnected and removed separately to store as these may be reusable. Fittings on the ducts such as dampers and regulators shall also be removed along with this. Insulations on the ducts shall be carefully removed in segregated locations onboard without making them dispersed in the air.

Dismantle pipes and fittings

Pipes and fittings on various systems including fuel oil, lub oil, cooling water, steam, fire system, bilge, compressed air, refrigeration, exhaust, and hydraulic oil shall be dismantled. Special care shall be taken to prevent any spillage of liquid inside the pipes, during and after dismantling. Pipes can be dismantled at their joints and can be stored temporarily on each deck at designated locations prior to lifting them ashore. Insulated pipes shall be separated and handled in segregated locations with adequate precautions. Pipe supports need not be removed at this stage as it can be removed as part of the engine room structure

Dismantle insulation

Insulations on engine room ceiling, machinery control room boundaries, and engine casing shall be removed and safely stored in containers to transport to the disposal centre in the yard.

Clean up and remove fire hazards from hot work location

On completion of disassembling of the machinery and fittings, engine room shall be thoroughly cleaned up and wastes and other hazardous items shall be removed prior to commencement of hot work.

Disassemble remaining hull structure in way of engine room

Remaining hull only consists of structure below side shell including double bottom. This can be disassembled to one or two units each port and starboard and transported ashore using a crane or winch.

3.3.3.3 In Beach (Stage 3)

Secondary disassembling shall be carried out in the beach area of the SRY. It is proposed to have an impermeable floor of concrete and a drainage system for the Secondary Disassembling Area in the SRY in order to contain the hazardous substances such as paint, other wastes, and contaminated water.

Remove paints (antifouling paints where applicable and coating along the cutting line)

Underwater portion of hull are normally protected with antifouling paints containing hazardous substances such as TBT. It is recommended to remove these coating using a blasting technique in a segregated area and then collect the blasted media, wastes, and paint chips without contaminating the surroundings. In case the ring units and blocks are too large to be handled in this area, they shall be further disassembled into smaller units and then brought for blasting in this location. Before cutting them, coating along the cutting line on the ring units or blocks must be removed and collected. The wastes shall be sent for treatment and disposal. The blasting is required to ensure that the steel plates going to be reused or recycled in the outside market are without any coating containing hazardous materials.

Clean up and remove fire hazards from hot work location

Since the blocks and units removed from the ship will be brought to the Secondary Disassembling Area for further disassembling by cutting, it is necessary to maintain a fire hazard-free environment in this location. Therefore, this area shall be cleaned up on a regular basis and the wastes shall be transferred to the designated locations.

Dismantle ring structural units or blocks into disassemblies or units (Secondary disassembling)

Ring units and blocks disassembled from the hull are further dismantled into disassemblies or units in the Secondary Disassembling Area by cutting. Cutting lines shall be marked on the plating and the paint on the plate surface in way of the cutting lines shall be removed prior to this disassembling operation. Double bottom disassemblies which were dismantled from the hull are shown in Fig. 3.21.

Dismantle disassemblies or units into subdisassemblies or panels (Secondary disassembling)

The disassemblies or units shall be dismantled further into smaller sized subdisassemblies or panels which are transportable using fork lifts. Sizeable attachments to plate panels, such as foundations of equipment and pipes, shall be removed at this stage and stored separately for transportation to the respective locations.

Fig. 3.21 Disassemblies

Segregate subdisassemblies into panels having straight plates and curved plates

Subdisassemblies consisting of straight plates, such as decks and bulkheads, shall be segregated from that having curved plates, such as side shell and bottom shell, in the Secondary Disassembling Area. The curved ones may be cut further into smaller sizes, if necessary, for ease of transportation.

Transport subdisassemblies or panels to the Tertiary Disassembling Area using cranes or fork lifts

Straight and curved subdisassemblies or panels shall be transported, using fork lifts or mobile cranes, to designated locations in the Tertiary Disassembling Area where they will be dismantled further into plates and stiffeners.

Collect waste and transport to reception or handling facility in the SRY

Any scrap or waste generated during secondary disassembling shall also be collected and transferred to the designated locations in the SRY.

3.3.3.4 In Land (Stage 4)

Cut and separate stiffeners and other attachments from plates (Tertiary disassembling)

Tertiary disassembling shall be carried out in the land area of the yard. An impermeable floor of concrete shall also be provided in this area. All the attachments to the plated structure including stiffeners and brackets shall be removed at this stage. After removal, both the plates and stiffeners shall be cut to the required size that is preferred by the re-rolling mills and is suitable for transportation. Then these shall be segregated and stored according to their sizes and grades in the storage area. Scrap steel that are generated during the cutting operation shall be segregated according to their grade and stored separately for transportation to recycling market. Transportation of plate parts of the obsolete ship is shown in Fig. 3.22 and sorting of plates in the SRY is shown in Fig. 3.23.

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Fig. 3.22 Transportation of Plates

Transfer directly sellable equipment and fittings to store

Directly reusable items; such as machinery, fittings, furniture, electrical appliances, kitchen equipment, workshop equipment, and electronic devices; which do not require any further processing shall be transferred to the specific area in the store for immediate sale.

Fig. 3.23 Sorting of Plates

Transfer equipment which requires overhauling or finishing to respective shop in SRY

Some of the equipment; such as pumps, compressors, ventilation fans and purifiers; and fittings; such as valves, strainers, dampers, and eductors; may require repair or overhauling in order to improve their condition and to give a better finishing prior to the sale. These shall be transferred to the concerned workshops and then to the store upon completion of the refurbishment.

Transfer equipment that requires disassembly up to the component level to the respective shop in SRY

Machinery such as the main engines, auxiliary engines, generators, and gearboxes which are reusable, but can not be removed as a single unit from the ship, may be disassembled into transportable units as per the dismantling plan given by the manufacturer. If these are not reusable as a single unit in the present condition and are considered to be scrap, then these shall be disassembled into the component level as per the manufacturer's recommendations.

Disassemble fittings from pipe lines

Pipelines together with fittings shall be segregated into pipes and fittings. The pipes shall be sorted according to the metal type first and then based on the size such as diameter and thickness. The fittings such as valves shall be sorted according to the material, type, and size. These shall be transferred to the store if directly reusable. Valves and fittings requiring overhauling shall be sent to the respective workshop prior to their sale. Welded pipes may be cut into transportable sizes if necessary.

Disassemble fittings from ducting system

Ducting systems with fittings shall be segregated into ducts and fittings. Rectangular ducts may be cut into sheets and sorted based on the thickness. Spiral type ducts shall be sorted according to the metal type first and then based on the size. Built-in ventilation fans in the ducts shall be removed and transferred for direct sale or sent for overhauling based on its condition.

Disassemble fittings from electrical system

Electrical fittings shall be separated and sorted for resale or scrapping. Cables shall be segregated according to their type. Cables containing hazardous materials such as PCB shall be separated from others. Metal content shall be removed from damaged cables using the approved procedures and the remaining waste materials shall be transferred to the designated locations for disposal.

Transport oil products to approved recyclers

Waste oil products shall be collected and transported to the approved recyclers for further separation, processing, and disposal.

Transfer each type of item to specific storage area in store in the SRY and sell to the outside market

Reusable items and components which are obtained by dismantling various equipment, machinery, and fittings in the workshop shall be transferred to the store. They shall then be sold and transported to the outside market for sale, reprocessing, remanufacturing or recycling.

Transfer each type of waste to specific storage area in waste disposal facility in SRY and dispose of

Various types of wastes generated during the dismantling processes shall be transported to the temporary storage in the disposal facility in the yard and segregated based on their type in a progressive manner. Wastes that are disposable in the yard shall be disposed of on a regular basis by various means according to the type of the waste. These methods may include waste water treatment, landfilling, and incineration based on the approval obtained by the concerned authorities. Wastes which are not permitted to be disposed of inside the yard shall be safely transported to the approved disposal centres outside the yard.

3.4 ADVANTAGES OF GENERAL SHIP RECYCLING GUIDANCE PLAN

The following are the advantages that a SRY can get by preparing and utilising GSRGP for each ship to be recycled in their yard:

i. Since the GSRGP gives a systematic arrangement of the processes which are to be carried out in parallel and in sequence, it helps to improve the understanding of the processes and thereby to generate information on safe practices to be followed for reducing risks involved in ship recycling.

ii. Detailed subdivisions of processes at various phases of ship recycling are given in the GSRGP. Therefore, it provides information that helps to estimate time and manpower requirements for recycling a ship and assists to estimate ship recycling cost.

iii. GSRGP shows the ship recycling processes which are planned to be carried out in each phase of recycling. It also takes into account the technologies practised in the yard. Therefore, GSRGP acts as a document that demonstrates the technological expertise and accountability of SRY.

iv. GSRGP described the activities to be carried out prior to its arrival at the SRY. Therefore, it helps to prepare a ship to the maximum possible extent prior to its arrival at the SRY.

v. GSRGP shows a systematic arrangement of the recycling processes according to the sequence of the operations. Therefore, it can act as a reference document for the SRY to carry out ship recycling systematically.

The descriptions given under section 3.3.3 for various ship recycling processes as part of GSRGP have been taken into consideration while arriving at suitable decision on SRY layout. The coding of some of the processes have been specified against the corresponding workstation, in the proposed list of activity areas in a SRY in Table 5.8 in Chapter 5, in which the process is to be carried out

CHAPTER 4

ENRICHMENT OF PRODUCT MODELS OF SHIPS FROM A RECYCLING PERSPECTIVE

4.1 INTRODUCTION

Computer based product modelling techniques are in an advanced stage of development and are widely used in most of the industries including automotive, shipbuilding, aeronautical, space technology, and other mechanical engineering and civil engineering fields. These techniques have been widely used only during the initial stages of product life cycle such as design and production. It has been reported that product models have been utilised also for disassembly, but only in the case of standardised products. Like any other mechanical engineering product, life cycle of ships also consists of four major stages such as design, construction, operation, and recycling. In the present scenario, major utilisation of the product models of ships gets over by the completion of design and building stages. Utilisation of product models of ships for the post commissioning stages has been limited (Whitfield et al. 2003).

The present study has investigated the need to extend product modelling concepts to the recycling stages of ships. *Product Modelling for Ship Recycling* (PMSR) can be defined as modelling concepts and activities which are to be followed for the development, updating, and enrichment of product model of a ship from a recycling perspective, during various other life cycle stages of the ship. It is intended to facilitate utilisation of the product model for safe, economical, and sustainable recycling of ship.

A set of proposals containing PMSR has been developed in this thesis for applying '*modelling for*' concept in ship recycling engineering. In order to facilitate enrichment of product model of ship from a recycling perspective and thereby facilitate product model's utilisation in recycling stage, the concept of PMSR has been presented as a set of guidelines in this thesis. These guidelines indicate the aspects to be considered for enrichment of ship product model during each life cycle stage of a ship. These guidelines have also specified various stakeholders and their roles in facilitating enrichment of the model during each life cycle stage of ships. Following the proposed guidelines, it would be possible to create a ship very close to a real ‘Transparent Ship’. Once a ‘Transparent Ship’ is created with the help of the proposed 3D model concepts, it would act as an efficient information platform for developing a digital twin of ships.

Ship product model enhanced with the features proposed in this thesis can also function as a ‘Ship Construction File-Specific Document’ that contain recycling related information specified by IMO (IMO 2010), which is introduced as part of the Goal Based Ship Construction Standards. Few 2D views of various onboard parts of a typical bulk carrier developed following the proposed guidelines of PMSR are depicted in this chapter. These 2D views show the presentation of the textual content of the proposed PMSR.

4.2 UTILISATION OF PRODUCT MODELS IN LIFE CYCLE STAGES OF SHIPS

4.2.1 Stages and Substages in Life Cycle of a Ship

The major life cycle stages such as design, production, and operation can be further divided into substages (Sivaprasad 2010; Alkaner et al. 2006b). Design can be subdivided into basic design and detail design of ships (Taggart 1980). Production stage consists of substages such as fabrication, assembly, erection, launching, outfitting and machinery installation, commissioning, and trials. Many of the design and production activities may be done in parallel, like the manufacturing of one part of a ship and the detailed design of another part (Johansson 1996).

Operation stage includes routine operations of ship to generate revenue. Maintenance and repair, which are required for maintaining the ship fit for service, are also considered to be part of this stage. When a ship becomes either unfit or uneconomical for service in its operating conditions, shipowner may consider altering the features of the ship or converting it into a different type of ship altogether depending on condition of its hull, operational requirements of the ship, or the emerging global or national shipping market scenario. Depending on the extent of work, the conversion may include a number of substages such as design, construction, installation, and commissioning of the modified systems (Sivaprasad 2010). If the owner feels that it is not economical to convert the ship, he may decide to end up its life. There are various options for this fourth and the final stage including conversion into floating museums or artificial reefs and recycling to recover the materials from ships (Thomas 2006).

4.2.2 Utilisation of Product Models in Life Cycle Stages of Ships

CAD systems facilitate generation of sophisticated types of product descriptions such as models that can act as substitutes for the real product. Due to complexity of product realisation cycle for products in the mechanical engineering field, various models of the product are made for use in various activities that contribute towards the overall process. Such models would consist of both geometric and nongeometric information about the products (Pratt 1995).

A ship product model can be defined as a 3D product model of a ship containing its geometric as well as nongeometric information. Geometric information consists of the dimensions, shape, and form of both hull and superstructure. Nongeometric information includes materials used for its construction, their physical and chemical properties, etc. (Johansson 1996; Baum and Ramakrishnan 1997). 3D product model system of a ship supports the analysis and informational needs for engineering, design, construction, and maintenance of a ship (Ross and Abal 2001). Shipbuilding industry has been employing a large number of software tools to develop 3D models (Briggs et al. 2006; Kim et al. 2007). For most of the modern ships, a 3D model has been generated as part of design and construction process (Johansson 1996). Such a model usually contains information about ship structure, equipment, outfitting, and various other systems. Sivaprasad (2010) has envisaged PMSR as one of the key features that would add to the effect of Best Practices in ship recycling.

Product models have been used to support the activities related to ships in the design and production stages. Product Models are utilised to find answers to various questions about an actual ship and to find solutions to critical problems that are faced during the life cycle stages. Since the nature of problems may differ between stages, requirement on capability or information content of the product model for each stage may also be different.

4.2.2.1 Product Model in Preliminary Design

Questions during initial stages of basic design may be about speed; capacity; deadweight; and compliance with restrictions such as gross tonnage, air draught, and water draught. For the above listed ship design requirements, geometrical parameters of the product model may be the deciding factors. Design process aims to shorten the time for design development of a product at the same time the process would also aim at ensuring a high quality product and low cost for production. In the case of ships, naval architects and ship designers have to face conflicting requirements on deadweight, speed, fuel and cargo capacity, safety, building cost, and operating costs. Design process involves successive refinements at various levels. Iterations on main dimensions and other geometrical parameters of the hull form are carried out to finalise the optimal hull form that satisfies the requirements of shipowner and regulatory authorities. Once the main dimensions are finalised, preparation of lines plan and fairing are done using 3D model during the basic design stage. Ship product models are then used to get better estimates of the parameters including main engine power, speed, deadweight, capacity, stability, and trim.

4.2.2.2 Product Model in Detail Design

It may be required to conduct a number of analyses, including structural analysis and hydrodynamic analysis to check various functional requirements and performance, and simulation for the proposed design. This is followed by the structural modelling of the ship and the concurrent engineering activities (Pratt 1995; Baum and Ramakrishnan 1997). Any interference between machinery, fittings, and structural components can be crosschecked on the 3D product model and can be corrected much before the commencement of production. During the detail design stage, detailed production drawings are created to construct the components and assemblies of the ship structure, outfitting, and other systems. Perspective or isometric sketches as well as 3D drawings can be generated from the model (Barry et al. 1998).

4.2.2.3 Product Model in Ship Construction and Repair

During construction, the importance is usually given to sizing, shaping, and nesting of the steel plates; sizing of units and blocks; routing and end connections of piping systems, ventilation and air conditioning systems, electrical systems, etc. Type of product model required during this stage is dependent on the type of construction method that is going to be employed in the shipbuilding yard. Product models can be utilised by the yards to provide data for automated manufacturing processes, planning, construction-specific drawings, and exchange of data with contractors (Baum and Ramakrishnan 1997). 3D models can generate document files for CNC cutting machines (Johansson 1996). Ship product model technology has been applied for conversions of ships in a practical manner and can also be extended to ship repair (Ross and Garcia 1998).

4.2.2.4 Benefits of Product Model and Recent Developments

Benefits in using 3D product modelling technology in ship design and production include decreased design hours; early detection as well as elimination of component interferences; increase of the dimensional accuracy of design data; reduction in design rework related to inadequate visualization, engineering changes, and manual data recreation; improved productivity in product design; reduced lead time; increased productivity in the yard; increased competitiveness of the yard; reduction on the number of skilled workers; and cost reduction (Johansson 1996; Baum and Ramakrishnan 1997; Ross and Abal 2001; Okumoto et al., 2006).

Analogous to '*design for X*' methodologies especially for manufacturing, analysis, etc., 'modelling for X' concepts have been proposed for the automotive industries (Contero et al. 2002). Similar 'modelling for' concepts such as 'modelling for construction', 'modelling for engineering support', 'modelling for production support,' and 'modelling for life cycle support' have been applied in product modelling of ships in order to decide on the scope of modelling effort required for various applications during design, production, operations, and maintenance (Oetter and Cahill 2006).

Initiatives are being taken towards applying the 'digital twin concept,' which involves having one exact digital replica of an individual ship, to life cycle stages of ships from design to operations (Smogeli 2017, Morais 2018).

In shipping industry, extent of utilisation of product models is limited in the postcommissioning stages as compared to the precommissioning stages, such as design and new construction, and major conversion stages of ships (Ross and Abal 2001; Whitfield et al. 2003). Roles of ship product models in the post commissioning stages include comparisons of various data of ships with the measured values; preparation of the stability booklet using the results from inclining experiment; and integration of the model with the ship's navigational software for assessment of parameters such as tank sounding, stability, trim, and loading conditions.

Initiatives have also been taken regarding the extension of product data models for life cycle support of ships, especially for ship operation, damage control, maintenance, and repair (Briggs et al. 2006). However, only a few technical papers on application of product models of ships have been reported for the repair, conversion, and recycling stage. Recommendations have been noted from the literature regarding generation of a ship product model representing the as-is condition of ship for its recycling application (Sivaprasad 2010) taking into account 'design for ship recycling' concept (Sivaprasad 2010; Sivaprasad and Nandakumar 2012a) and regarding use of the model as a pre-processor for generating input to the expert systems that are going to be used in the ship recycling industry (Sivaprasad 2010; Sivaprasad and Nandakumar 2012b). A missing link between the recycling stage and other stages in ship's life cycle has been clearly noticed and a necessity to integrate major ship life cycle stages such as design, production, operation, conversion, and recycling stages of ships has been highlighted in the published literature (Jain et al. 2015).

4.3 NECESSITY FOR ENRICHMENT OF SHIP PRODUCT MODELS FROM A RECYCLING PERSPECTIVE

This study has firstly identified some of the major reasons why importance was not given to the incorporation of product models in the recycling stage of existing ships. The major reasons include requirement of additional cost for either generation or enrichment of product models, lack of ship's data especially for older ships, absence of guidelines from IMO or regulatory bodies regarding utilisation of ship product model for recycling application, lack of expertise in utilising product models at the present worker/supervisory levels in ship dismantling yards, and nature of ownership change of ships during its life span resulting in a loss of valuable information about the ship. Need for protection of the 'intellectual property rights' on the design of ships by designers/shipyards, which prevent them from passing the product models or design documents to the recycling yard, and the conflict of interest between the yard building a ship and the firm to which the contract for its design is directly awarded by the owner are identified as some of the additional reasons.

Due to the above reasons, initiatives have not been adopted by concerned stakeholders to generate 3D product models of ships for recycling application. Even if a product model has been generated initially, further initiatives might not be taken by the stakeholders to continually update a model for the changes made on the ship during its life span. Shipowners would have been compelled to make necessary updating of the 3D models only when the modifications were of serious nature.

For the ships which are presently in their design stage, a recycling perspective is not being considered by majority of designers while generating product models. This could be because of the following reasons: Firstly, neither the owner nor the shipbuilding yard is made accountable by the present regulations for ensuring safe and sustainable recycling of ships. Secondly, there could be other constraints related to the cost and time aspects. Thirdly, '*design for*' philosophies applied to ships such as '*design for dismantling*,' '*design for disassembly,*' '*design for recycling*,' (Dilok et al. 2008; Papanikolaou et al. 2009) and '*design for ship recycling*' (Sivaprasad 2010) are still in a stage of research and development and the shipbuilding industry is yet to start implementing these during the design stage of ships.

Knowledge base of various onboard systems, equipment, dismantling processes, material characteristics, safety standards, SRP, relevant rules and regulations and yard based specific instructions are essential to develop best practices in ship recycling. If all these information can be incorporated in a single 3D model, the knowledge base will be more accessible and efficient.

Product models can be efficient tools for improving productivity, quality, safety, and ecofriendliness in ship recycling and for simplifying the complex nature of dismantling activity. Product model can assist to plan the recycling work in advance, even before a ship physically reaches a recycling facility. With the assistance of a product model, several dismantling activities can be planned for carrying out simultaneously in a better and safer way and thereby reducing the total duration of the dismantling activities. Product model can act as a single source of all data about the ship to be dismantled. Various departments in the SRY can utilise the same product model database.

Generating a product model for a ship during its design stage and updating the model continually with the changes on the ship during each life cycle stage, are to be made as strategies to be adopted by every shipowner. Utilising a product model, which is enriched with recycling aspects, shall be made a strategy to be adopted by every SRY together with the shipowner.

4.3.1 Transparent Ship

In this research context, 'transparent ship' is defined as a ship for which there is complete transparency or clarity about the whole ship and its individual components with respect to their conditions and the material content including those of hazardous nature. Product model of a 'transparent ship' will enable an accurate estimation of reusable and recyclable material content of the ship and give increased and efficient accessibility options about the risks associated with recycling of such a ship.

Implementing the guidelines proposed under PMSR concept that is proposed in this study would enable the designers to make the ship closer to a 'transparent ship.' By enriching ship product model based on the proposed aspects from a recycling perspective, during each life cycle stage of a ship, the transparent ship model will be made more useful for PLM.

4.3.2 Digital Twin Concept

'Digital twin' is a digital representation of a ship, which combines various information and digital models of the ship, throughout the ship's life cycle (Smogeli 2017). The digital version shall get updated for any modifications done to the ship or its components (Morais 2018). By implementing the guidelines for PMSR concept, it would be possible to make the product model of a ship closer to a 'digital twin.'

4.3.3 Ship Construction File (SCF)

IMO has specified the 'International Goal-based Ship Construction Standards' and the functional requirements to be met as part of it (IMO 2010). Ship Construction File (SCF) shall contain specific information on how the functional requirements of the Goal-based Ship Construction Standards have been applied in the ship design and construction. SCF shall be provided upon delivery of ships, kept onboard and/or ashore, and updated as appropriate throughout a ship's life in order to facilitate safe operation, maintenance, survey, repair, and emergency measures. IMO has given guidelines on the list of information to be included in the SCF (IMO 2010). One of the functional requirements of the Goal-based Ship Construction Standards corresponds to recycling considerations for ships. With respect to the recycling considerations, IMO has specified that the SCF should include information related to identification of all materials that were used in construction and that might need special handling due to environmental and safety concerns.

A ship product model that has been enhanced with the recycling related aspects proposed in this research can be treated as an extended SCF-Specific Document that contains the recycling related information specified by IMO as well as other important and relevant information.

4.3.4 Shipowner's Obligations in Recycling and Product Model Enrichment

HKC (IMO 2009) requires the ships destined to be recycled to carry out their recycling in ship recycling facilities that are authorised in accordance with the HKC; to conduct operations in the period prior to entering the ship recycling facility in order to minimize the amount of cargo residues, remaining fuel oil, and wastes remaining on board; and to provide all relevant information relating to the ship for the development of SRP.

European Union (EU 2013) requires the Shipowners to ensure that their ships destined to be recycled are only recycled at ship recycling facilities that are included in the European List and to provide the ship recycling facility all ship-relevant information necessary to develop SRP. European Union (EU 2013) also requires the Shipowners to conduct operations, prior to the ship entering the ship recycling facility, in order to minimise the amount of cargo residues, remaining fuel oil, and ship generated wastes.

Based on the above, it is clear that the European Union directly and IMO indirectly require the Shipowners to be well associated with the recycling of their ships. Ship's product model, which has been enriched with the recycling related aspects proposed in this thesis, can act as a source of the above ship-relevant information, specified by European Union and IMO, for the development of SRP.

It shall be part of the social commitment of the Shipowners, who have been the main beneficiaries of the revenue from the ships, to facilitate sustainable recycling of their ships. A few Shipowners, like Maersk Line, have been involved in the recycling activities of their ships by collaborating with SRYs and by monitoring the recycling activities of their ships in the SRYs.

The cost of development and maintenance of product models of ships should be evaluated with respect to their benefits also at the recycling stage. Eventhough the initial development of the product model as well as the enhancement of it with various changes on the ship and recycling related aspects are going to be at an additional cost, shipowner can get an economical advantage at the time of its selling or demolition due to its better competitiveness as being closer to a 'transparent ship.' Such an economical advantage is achieved by means of attracting more number of prospective buyers and by obtaining a higher market price.

It has been recommended in this thesis in the section 4.3.3 to consider a ship's product model, which has been enriched with the recycling related aspects, as an extended Ship Construction File Specific Document that is mandatory as per IMO. Therefore, enriched product model of ship will also enable the Shipowner to comply with the functional requirements of the Goal-based Ship Construction Standards of IMO with respect to recycling.

4.4 PRODUCT MODELLING FOR SHIP RECYCLING (PMSR)

Analogous to '*design for ship recycling*' concept, this study has introduced a concept termed '*Product Modelling for Ship Recycling* (PMSR).' This concept is intended to give guidelines for extending '*modelling for*' concept to ship recycling application. The proposed guidelines specify the essential features of a ship product model for recycling application.

The following subsections describe the guidelines which have been proposed as part of this study in order to implement the PMSR concept. These guidelines indicate both the characteristics to be enriched on the product model during each life cycle stage of a ship and the stakeholders to whom the responsibility of enrichment shall be assigned.

4.4.1 Generation of Product Model from a Recycling Perspective

This subsection describes the proposed guidelines for facilitating the generation of product models for new ships and existing ships from a ship recycling perspective. As the requirements for modelling of information is different for a ship that is going to be built and an existing ship, set of different guidelines are to be prepared. Section 4.4.1.1 discusses the development of guidelines for ships to be built. Section 4.4.1.2 describes the proposed guidelines for existing ships.

4.4.1.1 PMSR for Ships to be Built

Capability and features of ship product model would be limited if that is developed by a stakeholder whose purpose of the model is only spanning over a few substages of the life cycle of a ship. The stakeholders may try to restrict capabilities of the model to a level that is just sufficient enough to support the execution of their work or the associated activities of other stakeholders during that particular substage.

Considering the overall responsibility of a shipbuilding yard in the activities including design, construction, commissioning, and delivery of a newly built ship, it is suggested that the shipbuilding yard should take the initiative to develop a model that can support satisfactory completion of these activities until the delivery of the ship.

In some of the shipbuilding projects, shipowner may appoint a designer to carry out the basic design of the ship. For such cases, it is proposed that the responsibility of generating the original product model and incorporating the amendments during basic design stage should be assigned to the designer. If the above mentioned designer is also assigned the contract for detail design, then the responsibility of upgrading and amending the product model during the detail design stage shall also be assigned to the designer. If the yard is going to carry out the detail design, then it is recommended that the designer should hand over the model to the yard for incorporation of the information generated during the detail design.

During basic design and detail design stages, it is suggested to utilise the product model to store the original intentions of the designer and the other relevant information that will be useful at recycling stage. An example of this is the *design for disassembly* concept considered for a particular component such as soft patches on deck plates and lifting eyes for handling disassembled items. If transmitted properly, this information would be useful for the recycling yard at the time of its dismantling. In this way, product models can be considered to be a medium for transfer of later life cycle stage application oriented information between stakeholders. It is also proposed that the as-fitted information of the ship; such as materials of construction, location of weld seams and butts on the plates and stiffeners, scantlings of structural members, details of piping systems and electrical systems, and details of outfit items; which are modified from the original design should be incorporated into the product model by the shipbuilding yard. The above information shall also include the block and unit structural divisions on both hull and super structures.

Information related to equipment and machinery including type of hazardous materials used, their quantity, and locations onboard shall be incorporated by the shipyard into the 3D product model. It is recommended that the electronic copy of manuals of machinery onboard the ship should be either added to the model or made accessible by adding necessary links. Such manuals shall contain information, which are furnished by the respective manufacturer, about the disassembling and handling of the machinery.

It is recommended that ship product model should be included as part of deliverables to the owner, along with the other documents at the time of delivery of a ship. The product model shall be of convertible type which is accessible in all standard file formats. This can be achieved using STEP (STandard for the Exchange of Product model data) which has become ISO 10303 (Kassel and Briggs 2008). STEP defines a vendor independent neutral format for exchange of product models between users or companies using various systems (Johansson 1996).

It is suggested to include the updated ship product model as one of the documents forming part of the SCF which has been made mandatory by IMO as part of the Goal Based Ship Construction Standards (IMO 2010). After a ship starts her operations, there could be variations in the hull form from that of the original hull as generated in the model due to deformations caused by various loads which act on the hull during the operation. It could still be possible to use the model as a reference for recycling application since such variations are usually going to have only minor influence on the disassembling operations.

In the shipbuilding industry, the intellectual property rights of the documents on ships are owned by the concerned shipbuilding yards. The rights are partially given to the shipowner along with the Ship Construction File (SCF). These documents are stored in the database of Classification Society on condition that the Class will not misuse it or reveal it to third party. For the updated product model mentioned above, it is proposed to have a tripartite copyright agreement between shipbuilding yard, shipowner, and Classification Society. Classification Society can store the updated product model in their database.

Updating of product model on a regular basis as mentioned in the guidelines given above will form the initial steps towards achieving a product model that is closer to a 'Digital Twin.' The information on the model about the ship can be further enhanced by installing sensors onboard the ship and updating real time information about the ship obtained through the sensors (Smogeli 2017; Morais 2018).

A flow chart that summarises the proposed guidelines for a ship to be built has been shown in Fig. 4.1. It shows information related to the enrichment of information content of ship product model and the responsibilities of stakeholders. Ship product modelling aspects from a recycling perspective have been shown in italics in the flow chart.

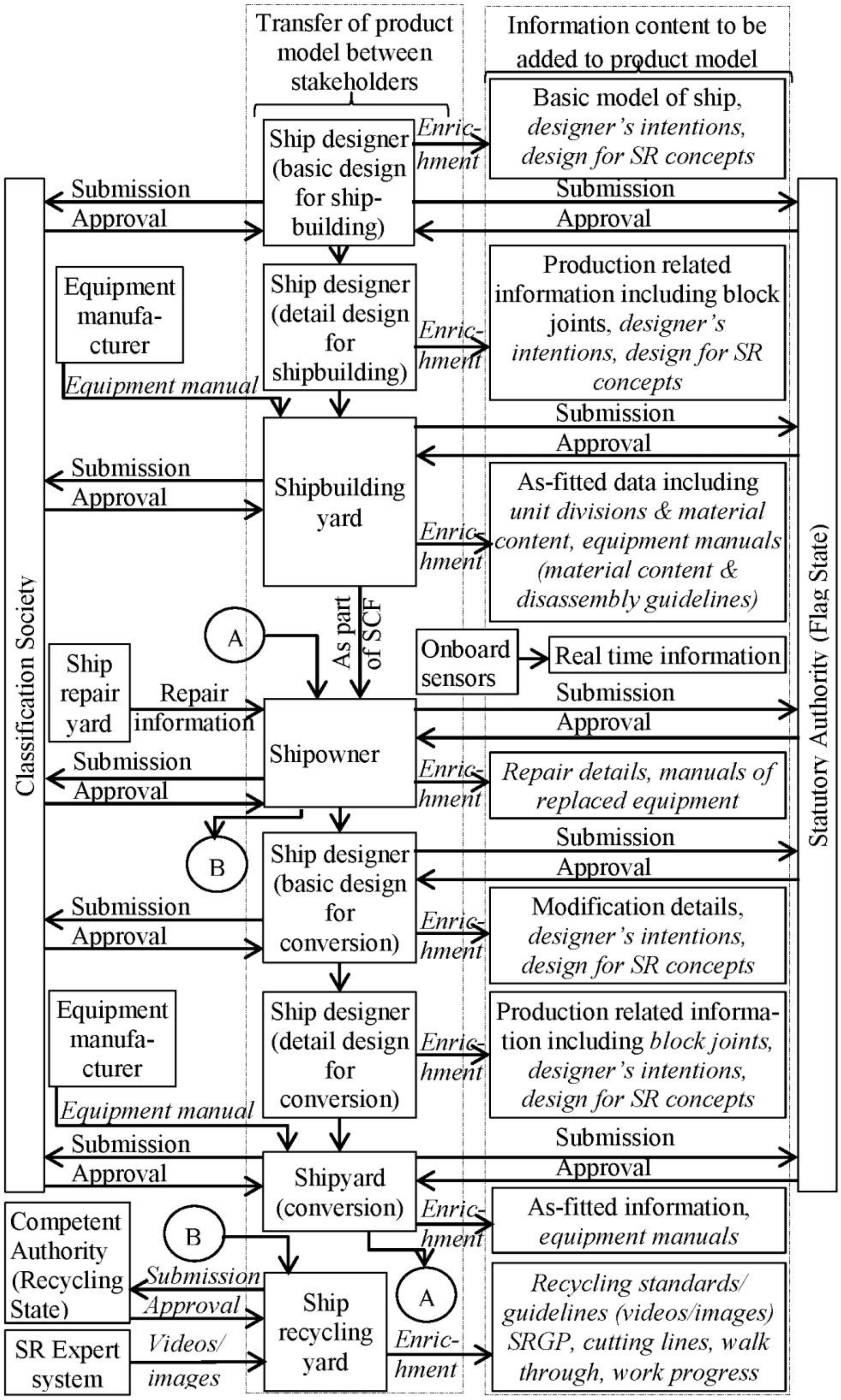


Fig. 4.1 Flow Chart for the Enrichment Process of Product Model in the Case of a Ship to be Built

4.4.1.2 PMSR for Existing Ships

PMSR for new ships have been described in section 4.4.1.1. However, for an existing ship that is not having a product model, it will be a difficult task to develop a model that represents the ship in its entirety and a compromise is, therefore, necessary on the capability of the model. The capability shall suffice the requirements for the remaining life cycle stages of the ship without much of an additional cost.

It is suggested that the responsibility to generate product model for an existing ship must lie with the shipowners who has been the custodians of the ship for the longest period of its life, i.e. from delivery until recycling, and the main beneficiaries of its revenue. For generation of the product model in such a case, it is proposed to gather information from the ship's drawings, manuals, and IHM and also by inspections onboard. Any inventory software tool (Gramann 2006), if already being used for the ship, may also be utilised as a source of information. It is recommended to utilise advanced digital photogrammetric measuring techniques, which are presently being utilised for shipbuilding and ship repair (Goldan and Kroon 2003), to capture the as-is condition of the ship to be recycled.

Ship design software such as Ship Constructor or general purpose CAD software such as AutoCAD could be used to generate model for hull and superstructure of the ship. This can be combined with independent third party product modelling software such as Autodesk Navisworks for generating a ship product model for the recycling stage.

4.4.2 Updating of Product Model from a Recycling Perspective during Life Cycle Stages

This subsection describes the proposed guidelines for updating of a ship product model from a recycling perspective. It is recommended that the information relating to minor modifications, which are carried out on the ship while in service, should be incorporated into the model by the shipowner. These modifications include replacement of equipment, fittings, and structural members with corresponding items having different sizes or specifications; and minor modification of structure, machinery, or materials onboard.

Shipowner shall take necessary steps to update the product model by incorporating additional information about renewals of structural and outfit items, which are incorporated into 2D drawings as part of the Classification requirements. In the case of major repair and conversion projects, it is recommended that the shipowner shall obtain information from shipyard about the changes from that of the original design which were made at site. The owner may also show active interest in incorporating these changes into the model so that the product model becomes more close to a Transparent Ship or a Digital Twin.

If the ship conversion yard is going to carry out basic design and detail design for the conversion work themselves, then it is suggested to assign the responsibility of updating of the model to this yard. Upon completion of the conversion work, the ship conversion yard shall incorporate the as-fitted information into the model and hand it over to the owner. Therefore, in the case of major repair/conversion of ships, shipowner will have to arrange for providing the product model to ship repair yard/ship conversion yard for updating the product model. In order to protect the intellectual property rights of ship's product model, which has been mentioned in section 4.4.1.1, it is recommended to make copyright agreements between shipowner and ship repair yards/ship conversion yards.

If the conversion involves substantial changes on the characteristics of a ship, it might be difficult to modify the original product model. Such cases may necessitate the generation of a new product model that has been incorporated with the modifications.

4.4.3 Enrichment of Product Model during Recycling Stage

This subsection describes the proposed guidelines for facilitating the enrichment of ship product model during recycling stage. Once a ship reaches recycling stage, it is recommended that the shipowner should hand over the product model to SRY prior to delivery of the ship to the SRY. Agreements shall be made between shipowner and SRY for protecting the intellectual property rights of ship's product model that has been mentioned in section 4.4.1.1.

Prior to the ship's arrival, availability of accurate information about the ship through the product model will help the SRY to facilitate an early preparation of the

SRP and advance planning of recycling activities. As compared to 2D drawings which are presently being used in SRY as reference document for ship dismantling, availability of a model having 3D aspects will reduce the necessity of interpretations by the yard personnel.

It is recommended that the SRY, either directly or through its consultant, should add important information as per the GSRGP as supporting text to the equipment or items which are incorporated as graphical objects in the product model. The description of ship recycling processes given in section 3.3.3 of Chapter 3 can be considered as the preliminary inputs to the textual description of ship recycling processes for incorporating in the product model.

Another important information is the location and sequence of ‘cutting lines’ as specified in section 3.3.1.1 of Chapter 3. Original product model of ship would contain the locations of joints where blocks or ring units were assembled together during construction. The product model, if updated with respect to the repairs and conversions carried out on the ship, would contain information about modified locations of seams and butts on the structural members. It is proposed that the SRY should use such information to specify the cutting lines. Original joints of the blocks, which were followed during shipbuilding, might be considered to be the cutting lines if the available facilities in the SRY can handle the resulting primary disassemblies, such as blocks and ring units. If the handling capacity of the yard with respect to the hull structural blocks is smaller, it is suggested that additional cutting lines must be incorporated into the model. Criteria for deciding this shall be based on parameters which lead to ‘minimum effort for dismantling’ and the ‘maximum utilisation of the cut plates and sections.’

It is suggested that SRY must arrange for incorporating their standards, guidelines, and videos and images demonstrating the best practices related to ship recycling into the model. It is proposed to assign this responsibility to the SRY since they would have a better knowledge about the recycling procedures than the other stakeholders. If SRY can generate and standardise the database of safe practices for dismantling of various machinery, outfits, ventilation and air conditioning systems, piping systems, and electrical systems, it can then be used as a common library for enrichment of product models of other ships which have similar kind of such items onboard. Capability to generate product model, based on information from shipowner, can improve the marketability of SRY. If the SRY does not have the expertise and infrastructure to carry out enrichment of the product model in a timely manner, then the above information shall be incorporated into the model by a consultant who has thorough understanding of safe and good practices to be followed in dismantling of various types of ships.

The videos of ship recycling processes can either be that of real recycling activities or be animated simulations showing safe practices of disassembling or recycling. For some of the equipment and components, it might be possible to adopt the videos and images from database of expert systems related to ship recycling and accepted by the industry. However, it may still be necessary to develop a detailed database for a number of equipment or components onboard, considering the variety of equipment in a ship for its specialized operations.

SRY shall also arrange to generate a 3D walk-through model in order to support the SRY personnel for ship recycling activities. Simplicity of the walk-through model enables its utilisation by naval architects and other engineers. At present, many SRYs have started employing naval architects and other engineers to carry out supervision of recycling of ships. Utilisation of product models in the recycling stage would get improved if a naval architect joins the ship product model development team. PMSR can support visualisation by the supervisors in order to plan the work in advance, understand the work area, assess the hazards, take necessary precautions against the risks of exposure to hazardous materials, and execute the job in a safe manner. Good practices can be effectively conveyed down to the worker level by utilisation of a product model with added features, such as videos and images about the activity to be done and about the safe working practices.

Adding textual information in the product model is possible using software such as the Autodesk Navisworks. For each equipment or compartment, SRY can assign a number corresponding to the stage in which the equipment is going to be dismantled or the compartment which is going to be removed as a block, respectively, based on the GSRGP mentioned in Chapter 3.

There shall be a provision for updating the information; regarding the compartments which are safe for entry, locations which are safe for hot work, and locations of access openings which have been cut on various boundaries; in the product model during the disassembling process of a ship. Utilisation of an enriched product model along with its regular updating during the recycling stage will enable the management of the SRY to have a better control of the recycling activities. It will enable to shorten the lead time for ship recycling through better information flow and planning, and thereby enable execution of more number of recycling orders of ships.

4.4.4 Advantages of Utilising Enriched Product Model for Ship Recycling

Advantages of enriching a product model of a ship for the utilisation during the recycling stage are as follows:

i. Product model will enable an accurate estimation of reusable and recyclable material content of the ship. This can improve the accuracy on estimation of its demolition price. It can also improve competitiveness of the ship for recycling, against other end-of-life ships that are not supplemented with product models.

ii. Risks associated with recycling the ship will be more clearly defined. This can ensure participation of more number of SRYs for the tendering processes to recycle the ship. Yards will be in a better position to quote for recycling a ship for which the hazardous material content is precisely known since they can make a better assessment of the dismantling operation using the facilities available in their yard

iii. It can ensure a better price to the owner for his ship.

iv. Availability of accurate information about the ship through the product model will enable an early planning of recycling activities by the SRY prior to the ship's arrival in the yard. This includes scheduling the visits of the specialists based on the information in the model about the specialized equipment onboard.

v. It will enable an early preparation of the SRP based on the information about the material content and layout of the ship from its product model.

vi. It will assist to make a better planning and coordination of the work at the supervisory level. Product model can support visualisation by the supervisors in order to plan the work in advance, assess the hazards, take necessary precautions against the risks of exposure to hazardous materials and execute the job in a safe manner. A better understanding of the work area and its surrounding areas using the model can help the supervisors to improve the monitoring of safety at work.

vii. Good practices can be effectively conveyed down to the worker level by utilisation of a product model with added features such as videos and images about the activity to be done and about the safe working practices. This will improve the awareness of the working level personnel about the safety standards to be followed in dismantling of ships.

viii. Based on the information from the model, better quotes can be obtained from pre-owned item brokers for major machinery, even before the ship's arrival in the yard.

ix. It will enable the SRY management to have a better control of the recycling activities.

x. It can be used to convince the regulatory authorities about the materials contained in the ship and thereby expedite clearances from them.

xi. Capability to generate product models, based on the information from the owner, can improve the marketability of SRY

xii. It can shorten the lead time for ship recycling due to better information flow and planning, and thereby enable execution of more number of dismantling orders of ships.

xiii. Information in the model about disassembly of equipment can form the basis of input information to expert systems for ship recycling.

xiv. 2D drawings require interpretations to obtain the 3D aspect of a part it represents. In addition, the true dimensions of the part will have to be obtained by interpolation between a number of drawings. Since a product models represents the actual 3D aspects of the part in a single data base, such information can be directly derived from it. 3D product model also eliminates inconsistency of information since data are stored in only one location and it is not repeated in other files.

4.5 SAMPLE VIEWS OF ENRICHED PRODUCT MODEL

It is recommended that the shipowners, SRY, and the other stakeholders must implement the guidelines and play their assigned role for developing a product model in order to support the activities during recycling stage of ships. This section gives a brief outline of a 3D product model representing part of a 90 metre bulk carrier that has been developed as part of this study. Figs. 4.3 to 4.9 show 2D views of parts of the 3D model. These views have been shown in order to highlight the way by which the information related to recycling aspects of a ship should be presented in its product model.

Computer based visual graphics have been used in order to ensure a better utilisation and accessibility of the model by the users. Ship Constructor software has been used to model the ship including its systems. General arrangement of the ship has been incorporated into the model. For demonstrating the concept proposed in this research, geometric and nongeometric information have been incorporated into the model for the structural components and some of the onboard systems and equipment in the compartments, viz., the engine room and a cabin in the accommodation area of the superstructure. It is possible to obtain the bill of materials or properties of any part of ship that has been included in the above model.

The above concept is to be extended to entire onboard systems and equipment in the ship by incorporating the information related to the recycling aspects for every component using the exhaustive and extensive database generated as part of design stage of a ship. The model can then be made as a practical product model of ship for recycling. This will also enable to get the bill of materials for the entire ship from the

3D model which has been generated using any ship design software. After completing development of the 3D model using the Ship Constructor software or similar ship design software, it can be exported to the Autodesk Navisworks software for creating a walk-through model. Screenshots of a walk-through model that has been generated from the above 3D product model is presented in Appendix A.

Fig. 4.2 shows the General Arrangement of the ship for which part of a product model has been developed. Fig. 4.3 shows perspective view of the bulk carrier from the model. By clicking the button on the menu at the top right corner, which contains a list of decks or compartments, it shall be possible to navigate to the location of the respective compartment in the model. Fig. 4.4 demonstrates the 2D view of the engine room from the 3D model along with the machinery and the piping systems. By clicking the home button near the menu button on top right corner, navigation back to the home page shall be possible. By clicking the objects in the view, it shall be possible to get the particulars of the object, material content of the components, information related to their disassembly, and the method of handling or lifting for removal from the engine room.

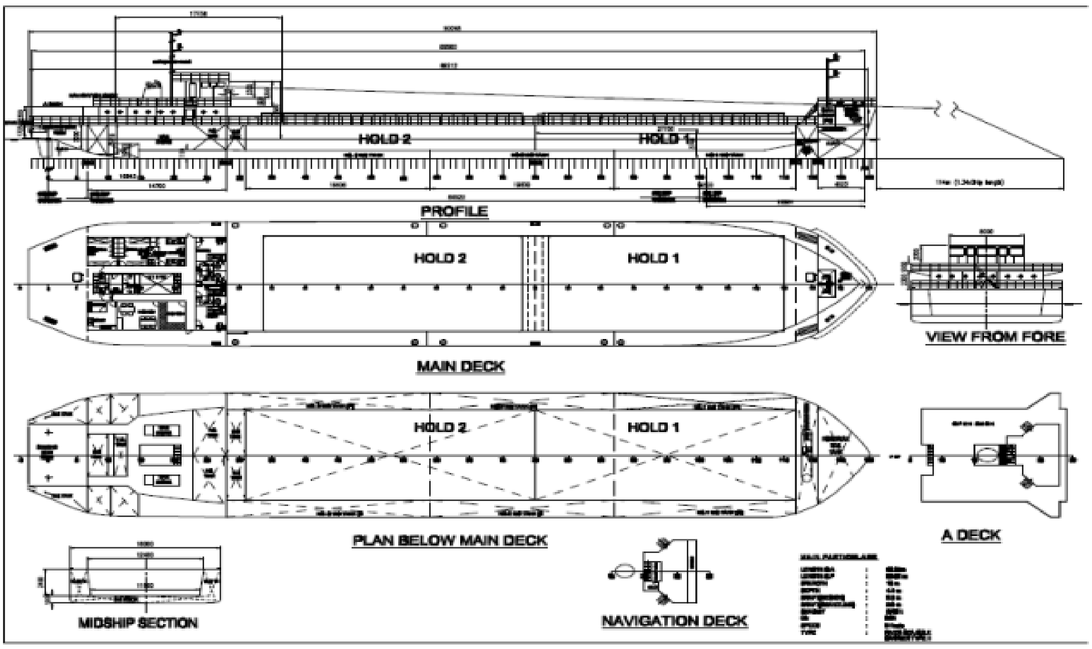
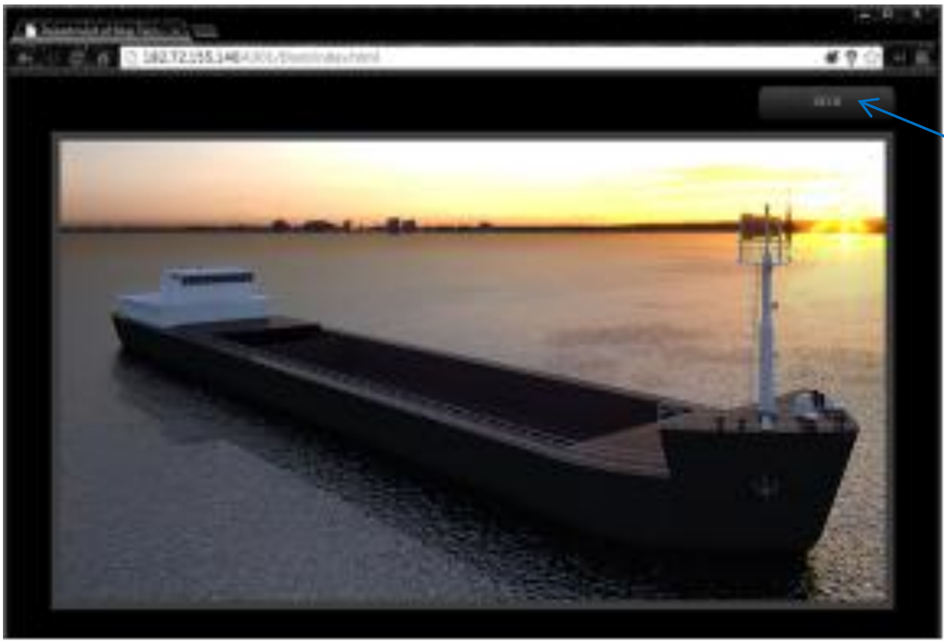


Fig. 4.2 General Arrangement of 90 m Bulk Carrier

Fig. 4.5 shows a popup window which shall appear upon clicking the main engine in the model as shown in Fig. 4.4. The popup window shall show information related to handling of the main engine. On clicking the video icon on the right side at the middle of the screen, video or animated simulations showing the sequence of operations required for dismantling of the main engine such as unbolting, rigging, and lifting out of the engine room shall be displayed. Similarly, on clicking the image icon on the right side, an image gallery displaying information about safe handling practices shall be displayed.



Main menu to navigate between decks.

Fig. 4.3 Perspective View of the 90 m Bulk Carrier

Fig. 4.6 demonstrates 2D view of cabins from the 3D model along with the interior fittings, which shall be displayed on clicking the accommodation deck level in the menu of the model as shown in Fig. 4.3. As mentioned earlier, by clicking the objects in the view, it shall be possible to get their particulars, material content of their components, guidelines related to their disassembly, and method of handling or lifting for removal from the ship.

Fig. 4.7 shows a popup window, which shall appear upon clicking a bunk in the model as shown in Fig. 4.6. The popup window shall show information related to the disassembly guidelines for the bunk which includes the sequence of operations. The functions of the video icon and image icon shall be similar to those described for Fig. 4.5.

Fig. 4.4 2D View of Engine Room from the 3D Model

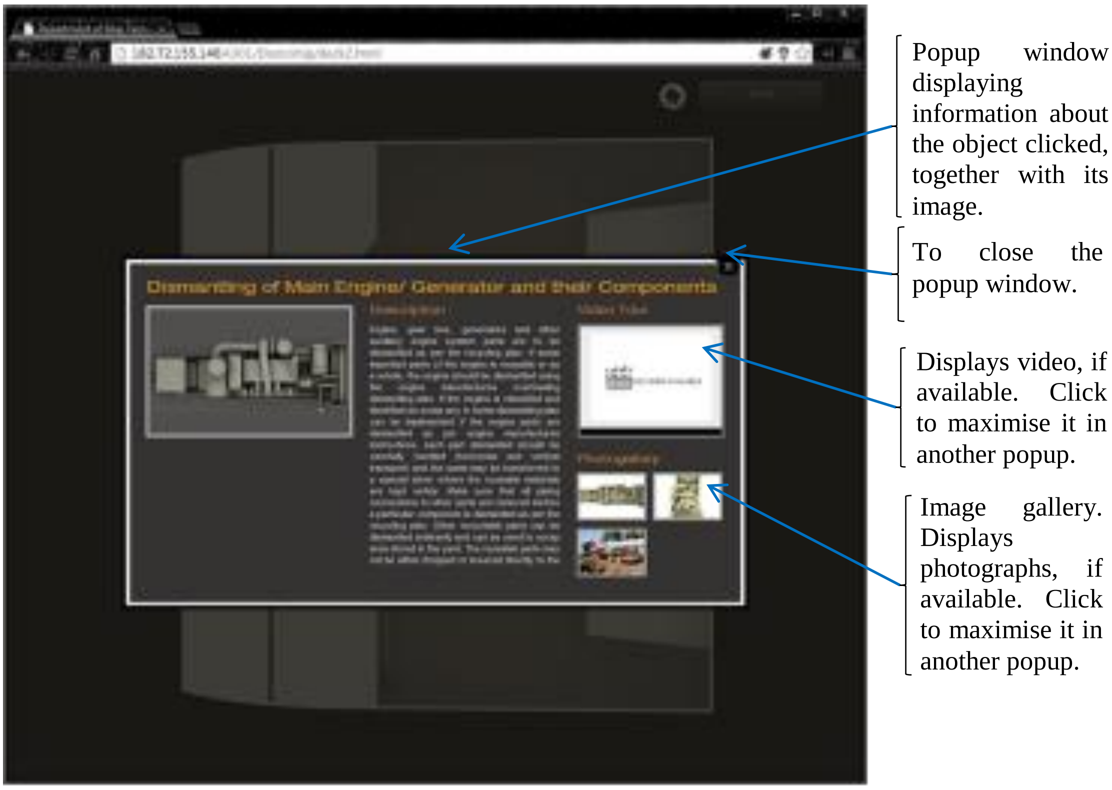


Fig. 4.5 Popup Window Showing Handling Information related to Main Engine

Fig. 4.6 2D View of Cabins from the 3D Model

Fig. 4.7 Popup Window Showing Disassembly Guidelines for Bunk

CHAPTER 5

METHODOLOGY FOR LAYOUT DESIGN OF SHIP RECYCLING YARDS

5.1 GENERAL

Planning of facilities is a part of strategic ship recycling. This important activity shall be considered as an integral part of the overall corporate strategy (Tompkins et al. 2015). Demand for environment friendly solutions for the final life cycle stage of ships necessitates the utilisation of advanced technology and improved design of ship recycling facilities as well as the recycling processes. Layout design of a SRY is to be considered as strategically important since the finally chosen layout will have a major role in deciding the flexibility and efficiency of the SRY. Methodology adopted for designing a SRY shall consider the ship type, quantity of ship recycled per unit time, and final qualities of the recycled products.

It is noticed from the review of literature that due importance has not been given for layout design of SRYs. Layouts of most of the yards or facilities which are used exclusively for ship recycling, especially in the major ship recycling countries, are found to be developed without a well planned design. In other countries, most of the existing SRYs are basically converted facilities from ship repair yards, shipbuilding yards, piers, or harbours.

In 2012, the global capacity of green ship recycling per annum was only 780,000 Light Displacement Tonnes (LDT) as compared to the annual global amount of 11 million LDT of the ships recycled (Abdulla et al. 2013; Robin des Bois 2012). Considering the fact that many of the existing SRYs do not comply with the requirements of HKC, the numbers of yards which are going to be built exclusively for ship recycling applications are likely to increase due to strict HKC guidelines under implementation.

Only Alkaner et al. (2006a) has touched on layout design of SRYs. They have used SLP method and have focused only on the primary and secondary dismantling zones. Others have either proposed indicative general layouts of SRYs as part of the guidelines or have simply presented the layouts of the prevailing SRYs. An organised layout was also found missing in the SRY in Azheekkal, Kannur, Kerala for which the study was conducted using visual documentation as mentioned in section 1.3. Therefore, a definite need is felt to develop a layout design methodology for new SRYs.

This study has focused on the development of a methodology for generating optimal concept layouts for SRYs. Facilities in SRYs are to be selected based on the recycling processes described as part of the GSRGP which has been presented in Chapter 3, and also according to the type of ships to be recycled.

A methodology in the form of steps to be followed for generation of concept layouts of SRYs has been developed in this study. List of activity areas in SRY, a method of estimation of quantitative values of flow intensities, a procedure for estimating the space requirements workstations in SRY, and the relative closeness ratings between various activity areas in SRY have been presented in this thesis. Drawings showing two layout alternatives for a SRY have been generated as a case study using the proposed methodology for layout design of SRYs and these two layouts have been presented in this chapter as sketches.

5.2 TYPES OF LAYOUTS

Layouts of industrial facilities can be classified into four basic types: fixed position layout, product layout, process layout, and group layout.

5.2.1 Fixed Position Layout

In this type of layout, the product is very large, heavy, or bulky, or it has a fixed position. Workers, raw materials, and equipment are to be brought to the product site according to a time schedule in order to facilitate better utilisation of the available space (Bedi 2013). Workstations in a fixed position layout are to be located around the product based on the sequence of processes to be carried out. Considerable logistics are involved to ensure that right processes are brought to the product at the right times and the process areas are located in right places. Personnel and equipment movement are more with this type of layout than the other types since the product remains stationary (Francis et al. 2015). Examples of fixed position layout are construction of an aircraft, dam, or a ship, and drilling of offshore oil drilling unit (Bedi 2013).

5.2.2 Product Layout or Production-Line Layout

Product Layout involves arrangement of machines or workstations based on the sequence of operations (Muther and Hales 2015). Flow of materials takes place from one workstation directly to the other. This type of layout is used for high volume production conditions (Francis et al. 2015). This layout is suitable for a product which is having standard features and is to be produced in large volumes. Production process comprises repetitive tasks to be performed on items which are arranged in a sequence. Specialised machines are arranged in the sequential order required in the production process and thereby forming a production line (Bedi 2013). Examples of processes using this type of layout include quick car washing line and automobile assembly line (Muther and Hales 2015).

5.2.3 Process Layout

All processes of similar type are grouped together and performed in one area and the material is moved through various process areas in this type of layout (Muther and Hales 2015). General purpose machines are arranged without any particular sequence in this type of layout since the sequence and the processing requirements are different for the various products to be manufactured (Bedi 2013). It is opted if the products are low-volume and are dissimilar. It is used when neither product layout nor group layout are feasible. In this type of layout, there are high degrees of interdepartmental flow as compared to group layout (Francis et al. 2015). Examples of processes using this type of layout include normal machine shop work, assembling sheet metals by welding (Muther and Hales 2015), and car service station (Bedi 2013).

5.2.4 Group Layout, Cellular Layout or Group Technology Layout

Group layout is a combination of process layout and product layout. In this type, most of the manufacturing cells produce a family of parts or similar items which share a common sequence of operations and production equipment (Muther and Hales 2015). Group layout is selected if the production volumes for individual products are not sufficient to justify product layouts, however by grouping products into logical product families, a product layout can be justified for the family. Since the groups of processes are called as cells, the group layout is also termed as cellular layout. Group layout is characterised by a high degree of intradepartmental flow and is a compromise between process layout and product layout. The group layout is also termed as group technology layout (Francis et al. 2015).

5.3 LAYOUTS OF SHIP RECYCLING YARDS

Layouts of almost all industries are planned based on the assembly concept. However in the case of layouts of ship recycling industry the focus is on disassembly of products. Therefore, layouts of SRY shall be designed and developed based on disassembly concept keeping in mind the fact that ship's parts and materials which are processed in SRY are not initially designed and developed for the end of life activities of the ship. High levels of risk faced during ship dismantling operations can be mitigated by proper designing of the facilities at an early stage.

Layout of a SRY shall satisfy the following requirements in an optimal manner:

i. Facilitate recycling of ships
ii. Maximise recycling capacity of the SRY
iii. Minimise material handling efforts (Muther and Hales 2015)
iv. Enable effective utilisation of floor space and labour (Muther and Hales 2015)
v. Comply with requirements on safety, health, and environment.
vi. Minimise investment in equipment (Muther and Hales 2015) and infrastructure
vii. Eliminate bottlenecks during handling and marshalling
viii. Have flexibility to adapt to different types of ships
ix. Have possibilities of future expansion
x. Minimise overall recycling time

xi. Provide for employee convenience, comfort, and safety (Francis et al. 2015; Muther and Hales 2015)

xii. Minimise variation in material handling equipment types (Francis et al. 2015)

xiii. Facilitate the organisational structure (Francis et al. 2015)

Recycling of a ship can be considered as a complex engineering process which requires adoption of a combination type of layout. Ships which are going to be recycled at a time in a particular SRY are usually small in number. SRYs usually prefer to dismantle ships which are more or less similar from a recycling perspective. Therefore, the number of ships and ship types which are to be dismantled at a time will be less in any SRY. Due to the reasons cited above, it is not possible to go for either a product layout or a process layout for SRYs.

Layout type to be selected for individual workstations within SRY would vary according to the kind of recycling process carried out in the workstations. For example, large size of a ship necessitates a fixed position layout for the recycling operations during initial stages such as primary disassembling of hull, removal of various items and machinery from ship, and onboard cleaning operations. A process layout is more suitable for operations such as secondary disassembling of hull and overhaul of machinery. Product layout is appropriate for operations like cutting of plates and sections into standard sizes and disassembling of pipes and cables.

Considering the above mentioned reasons, it is recommended to go for a general layout which is a combination of various layout types and is suitable for recycling of different types of ships. During detailed design of the activity areas, individual facilities shall be laid out according to the type of process carried out and the product handled in that facility. For the purpose of layout development, a systematic breakdown of both sequential and parallel disassembling activities based on the GSRGP, which has been presented in Chapter 3, is to be considered. The layout shall incorporate mechanical support for various operations and it shall aim to minimise environmentally unfriendly and unsafe operations.

5.3.1 Need for Efficient Layouts for Ship Recycling Yards

Any engineering proposal for implementation of an efficient layout for a SRY is quite challenging due to the inherent characteristics of the industry and the restrictions imposed by the prevailing national coastal zone management regulations. However a feasible solution has to be found that is bounded by the needs of sustainability of ship recycling industry and the restrictions imposed by the State on the industry.

IMO requires ship recycling facilities to be designed, constructed, and operated in a safe as well as environmentally sound manner according to the HKC regulations (IMO 2009). Competent Authority of the Ship Recycling State certifies the capability of SRY based on the documentation submitted by the SRY and the verification of the facilities in the SRY. Capability of SRY is specified in terms of the maximum size of ship that can be recycled. This information will be incorporated in the DASR (IMO 2009).

Authorisation of the ship recycling facilities by the Competent Authorities will be as per the SRFP (IMO 2012a). An SRFP, following IMO, shall include a detailed drawing or map of the ship recycling facility along with the information regarding the area where recycling will be carried out and a clear description of the details of the facility such as facility layout, accessibility, water depth, maintenance, and dredging (IMO 2012a). The SRFP shall also provide description of the estimated ship recycling capacity; production throughput of recyclables; permanent and temporary buildings for carrying out various processes including storage and offices; details about access routes; and details of main operational equipment (IMO 2012a).

Secretariat of the Basel Convention has recommended that the new ship recycling facilities, which are going to be established, must comply with the model facility standards given in their guidelines (SBC 2003). The guidelines by Basel Convention include recommendations on procedures, processes, and practices in ship recycling to attain environmentally sound management in the new facilities. Basel Convention guidelines have specified the zones, consisting of the required facilities, into which the ship recycling facility must be divided.

ILO has given guidelines for continual improvement in occupational safety and health performance of ship recycling facilities. As a part of the recommendations for safe ship recycling operations, ILO has suggested subdivision of the ship recycling areas into various zones (ILO 2004).

The above requirements necessitate preparation of a detailed layout of the ship recycling facility. Prior to development of any such detailed layout, it is necessary to develop a preliminary layout that takes into account the fundamental requirements related to ship recycling such as recycling capacity, relative locations and orientations of activity areas that will facilitate a cost effective process, and compliance with the relevant rules and guidelines of the regulatory authorities. A set of systematic guidelines are required for the design and development of concept layout of ship recycling facilities, which is compliant with IMO, Basel Convention, and ILO.

Concept layout design of shipyards are to be carried out using reasonable input data and with the logical methodology since it may be difficult to change majority of the resources and activity areas from their originally installed condition even if there is a need to increase the production capacity (Song and Woo 2013). Locations of ship recycling are often characterised by sea from one side and roads or industrial facilities on the other side. Layouts of SRYs may not be subjected to frequent changes due to the large size of components removed from ships. Once a layout is installed, there may be practical difficulties in the future to implement many of the advanced technologies that will be evolved with time.

Layout design will have a significant impact on the recycling performance of a SRY. An efficient layout is needed for a SRY to improve the industrial performance parameters such as yard productivity, operational safety, and output quality.

5.3.2 Factors Influencing Location Decision of a Ship Recycling Yard

Factors to be considered for determining the location for a new facility are as follows: proximity to customers or markets; good transportation facilities; availability of power supply; basic amenities such as water supply, roads upto factory premises, and sanitary facilities; government policies; environmental and community considerations; proximity to subcontractors; easy availability of cheap land; less construction costs; availability of cheap, skilful, and efficient labour; and residential complexes, schools, hospitals, clubs, etc. (Bedi 2013).

Ideal location of a larger SRY, which is suitable for recycling of larger commercial ships, shall be on the coast near the shipping route. Smaller SRY, which are suitable to recycle smaller ships, can be on the coast or even beyond the estuarine point subject to accessibility of the ships. Ship recycling sites must have access from the sea and the access shall be of sufficient water depth in order to safely bring ships of appropriate sizes. There shall be local road infrastructure or road links to handle heavy truck traffic. There shall be accessibility to a hazardous and nonhazardous waste processing facility directly from a SRY. It will be advantageous to have a rail and sea transport link. It may be specially noted in this context that socio-economic conditions at the site shall be favourable for ship recycling (DEFRA 2007).

Other parameters to be considered in order to decide the location for a SRY are as follows: enforced regulations on environmental pollution (Litehauz 2013), strong demand for steel domestically (IL&FS Ecosmart 2010; Litehauz 2013), proximity of a market for second hand equipment and consumables from ships (IL&FS Ecosmart 2010; Litehauz 2013), and supply of low cost labour to carry out the labour intensive extraction process (IL&FS Ecosmart 2010).

5.3.3 Factors Influencing Size and Layout Decisions of a Ship Recycling Yard

For a SRY to be sustainable, it is necessary to have supply of ships for recycling over a long term. Equally important factor is a consistent demand for the recycled materials. Ship recycling operations involve complexity with respect to the sequence of operations to be followed depending on the type of obsolete ship. In a SRY, the quality and quantity of materials and products which are to be processed are relatively beyond common standards of prediction.

Ship recycling is characterised by large sized dismantled products that require large areas for handling and processing during the initial stages of the recycling process. Size of individual recycling plots in a SRY depends on the size, type, and number of ships that can be recycled in the yard at any point of time; requirements related to occupational safety; and the general working conditions. It shall be sufficient enough to accommodate all the necessary facilities for the ship recycling process in compliance with the requirements related to safety, health, and environment (IL&FS Ecosmart 2010).

Size of a SRY also depends on type of access of ships from sea, availability of space to hold and process the obsolete ships, and the arrangement of the infrastructure at the site (DEFRA 2007). In addition to this, the maximum size and weight of primary disassemblies and secondary disassemblies to be handled also influences the size of a SRY. No fixed guideline can be specified regarding the area required for a SRY, but this can be approximately determined based on the requirements to be met by the SRY and also by comparison with other well established SRY.

Layout of a SRY shall ideally be based on both material flow and the interrelationship of the production workstations with the supporting facilities in the yard. Material of construction of the ships play an important role in the layout since the disassembly operations vary considerably between ships made of different materials such as steel, wood, FRP, and aluminium. Dismantling of only steel ships has been taken into account in this study.

5.3.4 Methods of Docking Ships

Methods which have been employed in different parts of the world for docking the ships for carrying out the recycling are described in the following paragraphs.

Beaching method has been practised by SRYs that are located on coastal areas having significant tidal differences and having gently sloping shores. This enables a ship to be driven far into the beach during spring tides. The obsolete ship gets intentionally grounded on the beach, thereby transferring her weight to the sand. The ship must preferably be under own power; else, tug assistance may become necessary. In this case of tug assisted ship beaching there can be many hurdles in taking the ship right across the beach. Once the ship is in position, the whole dismantling activities take place on the beach. This method has been employed by the major ship recycling countries located in South Asia such as India, Bangladesh, and Pakistan (Hougee 2013; Lloyd’s Register 2011; Sivaprasad 2010; Litehauz 2015).

In dry dock method, a ship is taken to a dry dock or floating dock and the whole dismantling activities take place inside the dock. This may be considered to be the cleanest and the costliest method of ship recycling. This has been practised in some of the European countries (Hougee 2013; Lloyd's Register 2011; Sivaprasad 2010).

Slipway method may be considered to be a modified version of beaching method and dry dock method. It has been practised by SRYs located in areas where very small tidal difference is present. It consists of a slipway (mostly made of concrete) extending to the sea. Ship will be transferred to the land using these slipways and the dismantling is to be carried out on the land. It is practised mainly in Turkey. (Hougee 2013; Lloyd's Register 2011). Recently some SRYs have come up to use air bag method of docking for ship recycling. This involves winching the ship to the land over a slipway consisting of inflatable marine air bags. After reaching the dry land, the ship's weight will be transferred to keel blocks and the air bags will be removed.

In alongside method, major part of the dismantling operations takes place in the afloat condition. Ship may be secured in the sheltered waters alongside a wharf, pier, quay, or a buoy. This method has been employed by yards in China, United States, and European countries (Hougee 2013; Litehauz 2013; Lloyd's Register 2011).

5.4 LAYOUT DESIGN METHODS

The approaches to layout design problems can be classified under two major categories, viz., algorithmic and procedural approaches (Yang et al. 2000).

5.4.1 Procedural Approaches

Procedural approaches are capable of incorporating quantitative and qualitative objectives in the layout design process (Yang et al. 2000). Here again, procedures which have been developed for generating layout alternatives can be classified into two main categories, viz., construction type and improvement type. Former category involves development of a new layout altogether where as the latter comprises development of layout alternatives by considering improvements in an existing layout (Tompkins et al. 2015). For design of plant layout, a number of procedures have been published. Among these, the significant contributions include ‘Ideal Systems Approach’ by Nadler, layout planning steps proposed by Immer, and plant layout procedures proposed by Reed in 1961 and by Apple in 1977 (Francis et al. 2015).

The approach proposed by Nadler is a design philosophy based on a hierarchial approach towards layout design. Immer has proposed three basic steps which can be applied to any type of layout design problem. Apple has proposed a plant layout procedure which is composed of a sequence of twenty steps to design a plant layout. Plant layout procedure developed by Reed consists of a ‘systematic plan of attack’ involving ten steps for planning and preparing the layout. Eventhough there are variations in the degree of specificity of the above procedures, they are similar in their emphasis on the design aspects of layout planning (Francis et al. 2015).

5.4.1.1 Systematic Layout Planning Procedure

‘Systematic Layout Planning’ (SLP) is a layout planning procedure developed by Richard Muther (Muther and Hales 2015) in 1960. Pattern of procedures included in SLP has been shown in Fig. 5.1.

SLP contains four phases in layout planning, viz., location, general overall layout, detailed layout plans, and installation. The first phase involves determining location of facility. In second phase, a general arrangement is to be developed for the layout. Third phase consists of locating every specific piece of equipment in the layout. Fourth phase involves planning of the physical installation of the layout. The second and third phases of SLP contain a pattern of procedures, which consists of five sections.

First section of pattern of procedures includes an assessment of five basic input data (given as notations in the parenthesis) such as product, material, or service (P); quantity or volume (Q); routing or process sequence (R); supporting services (S); and time or timing (T) for layout, which are used in layout planning. The first section also includes assessment of the possible types of layout. Outcome of the first section will be a list of activity areas.

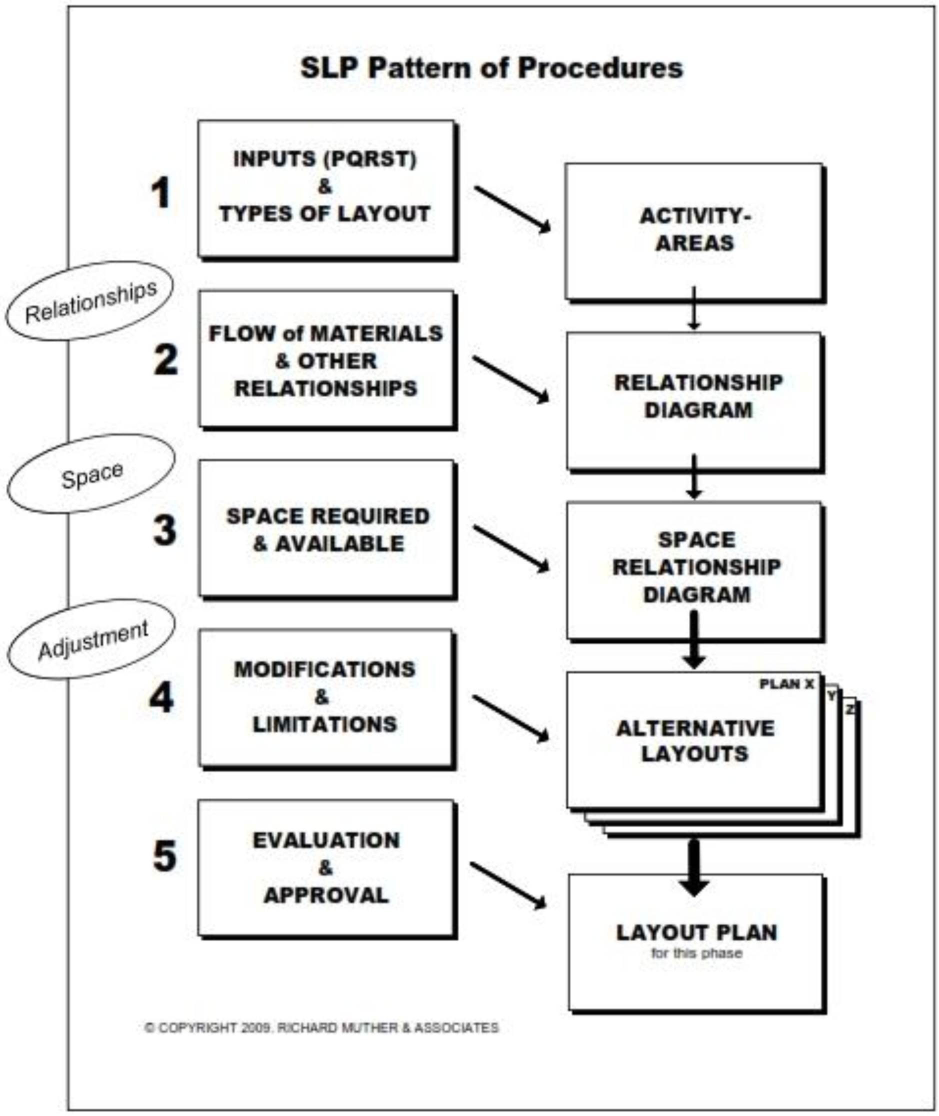


Fig. 5.1 SLP- Pattern of Procedures (Muther and Hales 2015).

In the second section, an analysis of relationships between the activity areas is to be performed based on flow of materials and also based on relationships other-than-flow of materials. The flow of materials will result in a From-To Chart and the other-than-flow relations will result in an Activity Relationship Chart. These investigations are to be then combined into a Relationship Diagram.

Third section is composed of estimating area requirements for the activity areas and balancing them against the available space. Then a Space Relationship Diagram is to be formed by combining the Relationship Diagram and the area values.

In the fourth section, modifying considerations and practical limitations are to be applied to the Space Relationship Diagram in order to generate a number of different layout alternatives. Evaluation of the layout alternatives are to be carried out in the fifth section for choosing the final layout plan. SLP also uses a set of conventions for identifying, visualising, and rating various activities, relationships and alternatives in any layout project (Muther and Hales 2015).

5.4.2 Algorithmic Approaches

Algorithmic approaches use simplified design constraints and objectives (Yang, Sun, and Hsu 2000). These approaches can be used to develop layout alternatives efficiently especially with the help of commercial software (Yang and Kuo 2002). However, the quantitative results obtained using these approaches may not capture all the design objectives (Yang and Kuo 2002).

One of the classifications of layout algorithms is based on the type of input data required by the algorithm. The type of input data required for some of the algorithms is only qualitative flow data such as a Relationship Chart where as for some others it is quantitative flow matrix in the form of a From-To Chart. Second classification is based on the objective function. Some algorithms are with a distance-based objective which aims at minimising the sum of the multiplication product of flow and distances while some others are with an adjacency-based objective which aims at maximising an adjacency score. (Tompkins et al. 2015).

Most of the layout algorithms are best suited for computer implementation (Tompkins et al. 2015). However, computer based algorithms that are currently available for layout design cannot replace human judgment and experience (Tompkins et al. 2015). Most of the software based techniques for layout design of facilities disregard the creativity of a designer who has knowledge about the interaction between material flow and the activity areas (Matulja et al. 2009).

In addition, the qualitative characteristics of a layout are not captured by these algorithms. However, productivity of the layout designer as well as quality of the final solution can be enhanced by the computerised layout algorithms because of their capability to generate and evaluate a large number of layout alternatives in a short time. In addition, commercial versions of algorithms for overall layout design have not been found to be available (Tompkins et al. 2015).

5.4.3 Method Selected for Layout Design of Ship Recycling Yard

Due to lack of published data, sufficient design data may not be available for developing an efficient layout of a SRY. In addition, quantitative results obtained using algorithmic approaches may not capture all the design objectives and further modifications may be necessary to satisfy some of the design requirements including department shapes, material handling systems, and space utilisation. The designer needs to be trained in mathematical modelling techniques in order to use algorithmic approaches for solving layout design problems (Yang et al. 2000).

Layout design problem of a SRY can be considered as a problem having multiple objectives. Algorithmic approaches are usually not adequate in obtaining practical and perfect solutions for multiple objective decision problems (Fafandjel et al. 2009). It is computationally difficult or infeasible to obtain optimal solutions for the layout problems because of multitude of objectives, number of design variables, and the complexity of problems and, therefore, sub-optimal solutions which can be obtained using heuristic methods need to be considered (Alkaner et al. 2006a). However, Yang et al. (2000) have suggested that procedural approaches are capable of incorporating quantitative and qualitative objectives in the layout design process

The process of carrying out layout design using SLP, which is a proven tool, is relatively straightforward (Yang et al. 2000; Tompkins et al. 2015). SLP has already been applied to various fields including transportation, production, storage, supporting services, and office activities (Francis et al. 2015).

SLP technique has been found to be efficient for situations in which the available data are not sufficiently detailed like the case of an early design stage of a project. The activity chart in SLP contemplates qualitative parameters, in lieu of quantitative parameters. This is useful for projects in which detailed quantitative information are not available in the initial design stage (Chabane 2004). From published literature, it has been noticed that SLP has been applied to the layout design of shipbuilding and ship repair yards (Chabane 2004; Fafandjel et al. 2009; Matulja et al. 2009). SLP has also been used for the layout design of primary and secondary dismantling zone of a ship dismantling yard (Alkaner et al. 2006a). In addition, SLP has a specific convention for diagramming negative relationships between activity areas that carry out activities which are incompatible from a safety point of view.

Based on the above considerations, it has been decided to use a sound procedural approach such as SLP as the method for overall layout design of SRY in this study.

5.5 PROPOSED METHODOLOGY FOR LAYOUT DESIGN OF SHIP RECYCLING YARDS

Project cycle of a SRY consists of six main stages: project concept, pre-feasibility, feasibility, design and engineering, implementation, and monitoring and evaluation (IL&FS Ecosmart 2010).

For most of the layout projects of facilities, the extent of savings that can be made in investments and operating costs by putting quality effort in the initial stage of the overall design is more than the corresponding savings which can be made by the effort in the detailed design stage (Muther and Hales 2015). Considering the above, the present study has been focussing on the development of a methodology for designing a concept layout or a preliminary overall layout of SRY. This will form part of the fourth stage, viz., design and engineering, of project cycle of a SRY, as mentioned above. Detailed design of individual facilities in SRY has not been included in the scope of the present study. It is presumed that the stages of SRY project concept prior to design and engineering have already been successfully completed.

Using the preliminary layout design methodology which has been developed in this thesis, it will be possible to generate schematic configuration of a SRY and to estimate areas of the workstations based on the size of obsolete ships and the planned duration of ship recycling. Input information required for the layout design of SRYs include features of the land such as geometry and area of the land; planned annual recycling capacity in terms of LDT; and geometry, number, and size of the primary disassemblies of target obsolete ships. Data about land features will form the boundary conditions for the design. Recycling capacity will be the basis for estimating areas of individual facilities or activity areas whereas the recycling capacity together with the data about the primary disassemblies will form the basis for the area calculations of the locations of structural disassembling.

The scope of work in the development of the proposed methodology includes estimation of size of activity areas and optimisation of their relative locations based on factors such as material flow and the other-than-flow relationships between the activity areas. The optimal location of activity areas have to be determined based on material flow, proximity requirement, and size of the activity area.

The proposed methodology can be summarised into the following steps:

i. Select the type of layout applicable for SRY

ii. Collect information regarding basic input data for layout design of SRY

iii. Identify all activity areas of SRY to be laid out

iv. Estimate intensity of material flow between activity areas in SRY based on the process routes in GSRGP

v. Prepare a From-To Chart and rate the intensities of flow of materials between activity areas based on the SLP procedure

vi. Assign a relative rating for relationships between activity areas based on other-than-flow considerations. Develop a Relationship Chart for other-than-flow factors based on the SLP procedure

vii. Join the flow and other-than-flow ratings onto a Combined Relationship Chart based on the SLP procedure

viii. Develop an Activity Relationship Diagram based on the SLP procedure

ix. Determine space requirements for each of the facilities, balance these areas against the actual space available, and then develop a Space Relationship Diagram

x. Apply modifications and practical limitations to the Space Relationship Diagram in order to generate alternative plans

xi. Carry out evaluation of alternative layouts in terms of costs and intangibles in accordance with the SLP procedure and select a layout plan from the alternatives based on the evaluation

The steps in the methodology have been elaborated in the following subsections:

5.5.1 Selection of Type of Layout for Ship Recycling Yard

It is proposed to go for a general layout for SRY as mentioned under section 5.3 of this thesis.

5.5.2 Collection of Information Regarding Basic Input Data for Layout Design

This step consists of collecting information regarding the basic input data such as P, Q, R, S, and T for layout planning as specified in SLP procedure for the SRY. The corresponding information applicable for layout design problem of SRY is indicated in Table 5.1.

Table 5.1 Basic Input Data for Layout Design Problem of SRY

Layout planner's alphabet (Muther and Hales 2015)	**Type of basic input data for layout planning specified by SLP** (Muther and Hales 2015)	**Corresponding information to be collected for layout design of a SRY**
P	Product	Type of ship
Q	Quantity or volume	Number of ships and their LDT
R	Routing or process sequence	Type of recycling process. Equipment required. Operations and their sequence as per GSRGP.
S	Supporting services	Maintenance, tool repair, medical facilities, sanitary spaces, office spaces, storage, etc.
T	Time or timing	Duration of recycling of a ship

5.5.3 Identification of Activity Areas of Ship Recycling Yard

Identification of the right number and types of departments which are going to be considered for designing layout of facility is the first key step to be performed by the layout designer (Tompkins et al. 2015).

In order to identify the activity areas or facilities in a SRY, a thorough study needs to be carried out for determining the processes and sequences in ship recycling. Depending on the type of ships to be recycled, type of docking method, extent of automation of the processes in the SRY, intensity of labour, etc., there would be some variation in the type of activity areas or facilities to be provided in various SRYs.

It is proposed to SRYs to generate a GSRGP, as described in Chapter 3 of this thesis, for each type of obsolete ship which is planned to be recycled in a SRY. This will help the SRY to identify the processes involved in recycling each ship type and thereby to decide the types of activity areas which are to be included in the layout design of the SRY.

Based on various aspects such as the types of processes indicated in GSRGP proposed in Chapter 3; the prevailing ship recycling practices which were studied through documentation of dismantling of a general cargo ship as mentioned under section 1.3 in Chapter 1 of this thesis, site visits, and published literature (DEFRA 2007; IL&FS Ecosmart 2010; Litehauz 2013; MECON Limited 2013; Sunaryo and Pahalatua 2015; JICA 2017); and the guidelines given by various organisations, this study has identified a comprehensive list of thirty seven activity areas which are to be included in the layout design of SRY. The above list has been presented in Table 5.2 and it is applicable for new SRY which would use a docking arrangement consisting of air bags. The activity areas have been listed in an effective sequential order such that the counter flow, i.e. the flow from one activity area to any activity area above it in the list, is minimum.

For docking arrangements other than air bag method, the activity areas such as Primary Disassembling Area and Winch House shall be replaced by corresponding activity areas of the selected docking method. In this case, initially a GSRGP shall be prepared for identifying the differences in processes due to the variation in both yard facilities and types of obsolete ships. The GSRGP can then be used as a reference document for preparing the list of activity areas in the SRY. Description of activity areas listed in Table 5.2 is given in the following subsections.

Table 5.2 Activity Areas in SRY

Sl. No.	Activity area name
1	Ship
2	Primary Disassembling Area
3	Winch House
4	Secondary Disassembling Area
5	Shot Blasting Area
6	Tertiary Disassembling Area
7	Segregation Area [NonHazardous Material (NHM)]
8	Sorting Area (Steel)
9	Storage (Steel)
10	Storage (Machinery)
11	Storage (Nonferrous Metals)
12	Storage (Miscellaneous)
13	Workshop
14	Storage (Electrical/Electronic)
15	Segregation Area [Hazardous Material (HM)-Asbestos]
16	Segregation Area [Other Hazardous Materials (HMs)]
17	Storage [Hazardous Waste (HW)]
18	Storage (Oil)
19	Storage (Dirty Water)

Table 5.2 Activity Areas in SRY- CONT'D

Sl. No.	Activity area name
20	Waste Disposal Facility
21	Lifting/Handling Installations
22	Ship Recycling (SR) Supporting Services
23	Safety Department
24	Training Centre
25	Medical Unit
26	Amenity for Recycling Workers (Sanitation Facility and Change Room)
27	Subcontractors Office
28	Canteen and Rest Room
29	Office for Recycling Managers
30	Administrative Office
31	Sales
32	Parking Area for Trucks
33	Parking Area for Other Vehicles
34	Entrance/Exit for Material
35	Entrance/Exit for Personnel
36	Security Posts
37	Internal Roads

5.5.3.1 Ship

This refers to the whole ship which is in the docked position and is ready for recycling. Operations during initial stages of recycling, such as removal, segregation, sorting, cleaning, cutting, etc., take place onboard the ship.

5.5.3.2 Primary Disassembling Area

Facilities in this area shall enable docking of ship and ensure that the ship is isolated properly from the marine environment for containment of any spills of hazardous and polluting materials. This area shall facilitate the disassembling of the ship into larger blocks or ring units. Cranes of large capacity shall be provided in this area for transferring the blocks to the Secondary Disassembling Area. This can be an open area. It shall be fully paved and shall be provided with a drainage system for surface water. Pollution traps of sufficient capacity shall be provided in the drainage system in order to control the solid or liquid pollutants that may be spilt.

5.5.3.3 Winch House

This workstation is mainly applicable for SRYs which use slipway method or beaching method for docking the ships for recycling. The Winch House is for accommodating large winches which are used to haul up and drag ships towards dry land using chains or steel wires (OSHA 2010; Hossain 2015; MECON Limited 2013). The winches also do the function of securing ships during and after docking. The required number of winches to be installed in a SRY may vary from one to eight (Litehauz 2013; MECON Limited 2013; JICA 2017; Ministry of Shipping 2017) depending on the size of ship to be handled, available width of slipway, and the selected capacity of winches. The winches are to be properly fenced.

5.5.3.4 Secondary Disassembling Area

Secondary disassembling operations of ship structure, as mentioned in Chapter 3, shall be carried out in this activity area. Material entry to this area shall be mainly the primary disassemblies and the output from this area shall be subdisassemblies of the hull structure. It is proposed to have an impermeable floor of concrete and a drainage system for the Secondary Disassembling Area in order to contain the hazardous substances such as paint, other wastes, and contaminated water.

5.5.3.5 Shot Blasting Area

Shot blasting of hull structural units, as necessary, are to be carried out in this area in order to remove the antifouling paints on the underwater portions of the obsolete ship hull.

5.5.3.6 Tertiary Disassembling Area

Tertiary disassembling operations, as mentioned in Chapter 3, shall be carried out in this area. Mainly, material entry to this area shall be subdisassemblies and output from this area shall be both plates and stiffeners. Similar to the case of Secondary Disassembling Area, it is proposed to have an impermeable floor of concrete and a drainage system for the Tertiary Disassembling Area.

5.5.3.7 Segregation area (Nonhazardous material)

Segregation of NonHazardous Materials (NHMs) into recyclable items and waste shall be carried out in this activity area.

5.5.3.8 Sorting Area (Steel)

Sorting of steel plates and stiffeners according to their sizes and grade shall be performed in this area. Scrap steel shall also be sorted according to their grade and type.

5.5.3.9 Storage (Steel)

Sorted steel, which is intended for rerolling and melting, shall be stored on separate stacks in this open storage area.

5.5.3.10 Storage (Machinery)

This area shall be used for storage of machinery. It includes the machinery which is ready for reuse without any further processing and the machinery which is processed at the workshop. This storage area is to be covered.

5.5.3.11 Storage (Nonferrous Metals)

Stainless steel, cast iron, and nonferrous metals such as copper, aluminium, zinc, lead, and other metals shall be stored separately in this area.

5.5.3.12 Storage (Miscellaneous)

This area shall be utilised for storage of items such as furniture, accommodation fittings, and other miscellaneous items.

5.5.3.13 Workshop

Work shop is intended for overhauling of equipment and fittings, as necessary, in order to just make them into reusable condition.

5.5.3.14 Storage (Electrical/Electronic)

Electrical and electronic items shall be stored separately in this area. There shall be separate storage for reusable items and waste.

5.5.3.15 Segregation area (Hazardous Material-Asbestos)

This area is for segregation of materials containing asbestos. It shall be a covered area and the segregation operations to be carried out shall be in accordance with the regulations and safe practices in ship recycling.

5.5.3.16 Segregation area (Other Hazardous Materials)

This area is intended for segregation of parts containing hazardous materials (HMs) other than asbestos. It shall also be used for segregation of materials containing PCB. It shall be a covered area having proper separate containment for various hazardous materials depending on their hazardous nature. Segregation operations shall be carried out in compliance with the regulations and safe practices in ship recycling.

5.5.3.17 Storage (Hazardous Waste)

This area shall have facility for separate storage for different types of hazardous wastes (HW).

5.5.3.18 Storage (Oil)

Temporary storing of various types of both unused and contaminated oils such as fuel oil, lub oil, hydraulic oil, and other waste oil including sludge shall be made in separate tanks or containers in this area prior to their transport to approved recycling centres.

5.5.3.19 Storage (Dirty Water)

This area shall be provided with facilities for temporary storage of bilge water, ballast water, grey water, and black water, if necessary, prior to their treatment or transportation for their disposal.

5.5.3.20 Waste Disposal Facility

This shall consist of disposal or treatment facilities such as waste water treatment plant, incinerators, and land filling if these are planned to be included in the layout of SRY.

5.5.3.21 Lifting/Handling Installations

The Lifting and Handling Installations refers to forklifts, fixed cranes, mobile cranes (including crawler cranes), other lifting equipment, and dump trucks. This activity area shall also include the marshalling area for the lifting and handling equipment.

5.5.3.22 Ship Recycling Supporting Services

Recycling Supporting Services consists of space for storing equipment for dismantling activities, such as steel cutting equipment, lighting and ventilation equipment, generators, pumps, and welding equipment; materials and consumables required for above equipment; tool rooms; and scaffolding materials

5.5.3.23 Safety Department

Safety Department comprises a firefighting department along with the necessary equipment including fire extinguishers and fire pumps, oil spill prevention equipment, other emergency response facilities, equipment necessary to support the activities in a permit-to-work system, and the space for personnel to support the safety related operations.

5.5.3.24 Training Centre

This department will look after training of workers and other staff of SRY and shall have facilities to support the training activities.

5.5.3.25 Medical Unit

Medical unit consists of the facilities for health and medical services including clinic for rendering aid to casualties and an ambulance.

5.5.3.26 Amenity for Recycling Workers (Sanitation Facility and Change Room)

This facility shall be a building consisting of changing rooms and sanitation facilities for workers in SRY.

5.5.3.27 Subcontractors Office

This office is intended for managers and supervisors of the subcontractors and it comprises the changing rooms and sanitation facilities.

5.5.3.28 Canteen and Rest Room

Building comprising canteen and rest rooms for both officers and workers are included under this category.

5.5.3.29 Office for Recycling Managers

This is intended for the managerial staff of SRY and it shall also include the technical services section.

5.5.3.30 Administrative Office

Offices for SRY management and administration are included under this category. It shall also cover the offices for planning and marketing and the office for external agencies such as Classification Society Surveyors, other Surveyors and Maritime Board officials.

5.5.3.31 Sales

Selling of materials and equipment removed from ship shall be managed by this department.

5.5.3.32 Parking Area for Trucks

This area is intended for parking of the trucks used for transporting materials from SRY to external agencies.

5.5.3.33 Parking Area for Other Vehicles

This area shall be used for parking of vehicles of the customers and employees of the SRY, and the other vehicles of the SRY.

5.5.3.34 Entrance/Exit for Material

This gate is intended for over-the-road vehicles and it shall include a weighbridge.

5.5.3.35 Entrance/Exit for Personnel

This gate is intended for entrance and exit of employees and visitors.

5.5.3.36 Security Posts

Security posts which are required near the entrance and the beach or sea side are included in this category.

5.5.3.37 Internal Roads

The purpose of internal roads is transportation of materials; personnel; and handling equipment, such as cranes, forklifts, and trucks, between the activity areas. These roads shall be suitable for heavy transport. Some of the internal roads may also be utilised by trailers.

5.5.4 Estimation of Intensity of Material Flow between Activity Areas

Analysis of flow of materials is the heart of layout planning where the movement of materials is a major portion of the process (Muther and Hales 2015). In a SRY, the quantity and type of materials and products to be processed will appear randomly. So accurate prediction on recycling content, both in terms of quality and quantity, may be difficult. Ship recycling works are mostly labour intensive and major part of the work during initial stages will take place onboard ship. Therefore, the volume of material transfer and their frequencies cannot be accurately defined. The work requirements associated with the process of recycling various obsolete ships are inconsistent as compared to the process involved in shipbuilding. This will have an adverse effect on the accuracy of estimation of material flow between various activity areas in SRYs (Alkaner et al. 2006a).

In layout design, flow intensity along a process route is defined as the magnitude of movement of materials or products along that path. It can be obtained as the product of number of pieces moved per unit time period and the unit of measure per piece (Muther and Hales 2015). Assessment of the layout from a flow of material perspective can be done with respect to the intensity multiplied by the route distance.

Process routes shown in GSRGO in Figs. 3.4 to 3.9 shall be used as a reference for identifying the activity areas which have material flow between them. Material flow intensities between the activity areas in a SRY are to be estimated after assuming the type and size range of the target obsolete ships. Hess et al. (2001), DNV (2001), IL&FS Ecosmart (2010), Demaria (2010), MECON Limited (2013), Hossain (2015), and Jain et al. (2017) have given detailed information on percentage of onboard materials which are usually found in some of the obsolete ship types. This information may be used unless detailed estimates of target obsolete ships can be made available before the actual dismantling starts.

5.5.4.1 Classes of Materials

For any particular application, SLP permits grouping of various materials into Classes based on similarity in both physical characteristics and nature of transportability.

In the case of ship recycling industry, the output material composition is random. Therefore, it is proposed to consider a division of the hull materials and components of ship into a number of Classes in a layout design context. This will help in estimating the flow intensities of the materials in ship recycling in a better way. Such a division shall be based on the published data available on the quantity of various Classes of materials onboard the obsolete ship in percentage of the ship's LDT.

The Classes of materials shall be selected based on material composition of the type of obsolete ship considered for layout design. For estimating material flow intensity, this study proposes to use the general Classes of materials as presented in Table 5.3. These Classes have been prepared based on the primary waste streams in ship recycling identified by Det Norske Veritas (DNV) (DNV (2001). Such a division of materials into Classes can be applied to any type of ship.

Table 5.3 Classes of Materials Considered for Material Flow Analysis

Class	Material composition
Class ‘a’	Steel including steel scrap
Class ‘b’	Nonferrous scrap
Class ‘c’	Machinery
Class ‘d’	Electrical/electronic equipment
Class ‘e’	Minerals
Class ‘f’	Plastics
Class ‘g’	Liquids, chemicals, and gases
Class ‘h’	Joinery
Class ‘i’	Miscellaneous

5.5.4.2 Equivalent Movement Factor

SLP procedure has introduced an ‘equivalent movement factor’ in the analysis of flow of materials in order to take into account the ease or difficulty associated with different types of materials and different types of handling device. SLP has given values of equivalent movement factors for various types of moves based on factors such as safety, risk, speed, number of people required for making the move, and disruption to production. Multiplication product of intensity and route distance shall be multiplied by equivalent movement factor in order to obtain a basis value to compare the flow of materials along various routes (Muther and Hales 2015).

Equivalent movement factors, which have been given in SLP method, for various types of material movements are shown in Fig. 5.2.

Type of Equipment \ Load Size	Oversized	Long & heavy	Pallet size	Carton/Tote
Over the Road Vehicle	2.5	2.5	2.0	1.5
Yard Crane or Tractor & Cart	5.0	3.5	NA	NA
Bridge Crane	4.0	2.5	NA	NA
Fork Truck - Outdoors / Yard	5.0	4.0	2.0	2.0
Fork Truck - Indoors only	NA	NA	1.0	NA
Man and Cart	NA	NA	NA	0.5

Fig. 5.2 Equivalent Movement Factors for Various Types of Material Moves (Muther and Hales 2015)

As per SLP procedure, for any particular application or industry, the equivalent movement factor is to be taken as 1 for the most common type of movement and it shall be factored relative to 1 for other moves based on their relative effort and cost (Muther and Hales 2015). In this study, for ship recycling operations, the movement of materials which can be carried out using forklifts and which do not project beyond the sides of forklifts has been assumed as the common type of movement and it has been assigned an equivalent movement factor of 1. This also corresponds to the equivalent movement factor value given in Fig. 5.2 for indoor handling of pallet sized items using forklift. Therefore, it is proposed to adopt the equivalent movement factors which are given in SLP and presented in Fig. 5.2 for the layout design of SRY.

5.5.4.3 Flow Intensities

It is proposed to use the value of intensity of flow to rate the material flow along various process routes in ship recycling process.

Therefore,

Flow intensity, $I = N.\ W.\ e_m$ -- **(5.1)**

where

N = number of elements

W = weight/unit of element

e_m = equivalent movement factor given in SLP (Muther and Hales 2015).

5.5.4.4 Flow of Hull Structural Steel between Ship, Primary Disassembling Area, and Secondary Disassembling Area

It has been assumed that the recycling of obsolete ships will be done based on the disassembly concept described in Chapter 3. Primary disassemblies, as defined in Table 3.3, are the main elements to be considered for estimating the material flow intensities between Ship and Primary Disassembling Area, and between Primary and Secondary Disassembling Areas. The maximum possible size of primary disassemblies shall be determined based on the handling capacity of the crane planned for the primary disassembling operations. Therefore, the following parameters shall be substituted in equation 5.1 to estimate the flow intensity values in this case:

W = Weight of each primary disassembly, W_{PD} in t ---------------- **(5.2)**

= Capacity of the crane planned for primary disassembling operation --- **(5.3)**

N = Number of primary disassemblies, N_{PD} -------------------------- **(5.4)**

= Estimated total steel weight of obsolete ship/W_{PD} ------------ **(5.5)**

e_m = 5 from Fig. 5.2 corresponding to oversized item that is handled using crane. In ship recycling, most of the primary disassemblies may be considered as oversized relative to the crane or forklift.

5.5.4.5 Flow of Hull Structural Steel between Secondary Disassembling Area and Shot Blasting Area

For process route between Secondary Disassembling Area and Shot Blasting Area, the main elements of hull structural steel causing material flow are disassemblies which have been defined in Table 3.3 in Chapter 3. The maximum possible size of disassemblies shall be determined based on the handling capacity of the crane planned for the Secondary Disassembling Area. Therefore, to estimate the flow intensity values for the above process route the following parameters shall be substituted in equation 5.1:

W = Weight of each disassembly, W_D --------------------------------- **(5.6)**

= Capacity of crane planned for disassemblies or maximum weight of disassemblies based on the size which trucks can handle --- **(5.7)**

N = Number of disassemblies, N_D ------------------------------------- **(5.8)**

= (Estimated total weight of primary disassemblies with antifouling coating / W_D --- **(5.9)**

e_m = 3.5 from Fig. 5.2 corresponding to long and heavy items handled using yard crane.

5.5.4.6 Flow of Hull Structural Steel between Secondary Disassembling Area and Tertiary Disassembling Area

For process routes between Secondary Disassembling Area and Tertiary Disassembling Area, the main elements of hull structural steel causing material flow are subdisassemblies which have been defined in Chapter 3. The maximum possible size of subdisassemblies shall be determined based on the handling capacity of the crane or forklifts planned for the Secondary Disassembling Area. Therefore, the following parameters shall be substituted in equation 5.1 in order to determine the flow intensity values:

W = Weight of each subdisassembly, W_{SD} -------------------- **(5.10)**

= Capacity of crane planned for subdisassemblies or maximum weight of subdisassemblies based on the size which forklifts can handle----------------------------- **(5.11)**

N = Number of subdisassemblies, N_{SD}------------------------ **(5.12)**

= (Estimated weight of primary disassembly/W_{SD}).N_{PD}-- **(5.13)**

The subdisassemblies or panels may be transported using cranes or forklifts. The equivalent movement factor has been taken as 1 for transportaion of these using forklifts. However, none of the equivalent movement factor values given in Fig. 5.2

correspond exactly to the subdisassemblies which are transported using cranes. Considering that the transportation operations between Secondary Disassembling Area and Tertiary Disassembling Area would take place in a controlled manner and the sizes of structural units are going to be much smaller than the disassemblies, values of equivalent movement factor for subdisassemblies which are handled using crane has been assumed as 2.5 based on the corresponding value of bridge crane for long and heavy items given in Fig. 5.2.

e_m = 2.5 for handling of subdisassemblies using crane

e_m = 1 for handling of subdisassemblies using forklift

5.5.4.7 Flow of Hull Structural Steel between Tertiary Disassembling Area and Storage (Steel) Area

For process routes between Tertiary Disassembling Area and Storage (Steel) area, the main elements of hull structural steel causing material flow are plates and stiffeners. The maximum possible sizes of plates and stiffeners are to be determined based on their standard sizes which are desired by the rolling mills. Therefore, the following parameters shall be substituted in equation 5.1 for the estimation of their flow intensity values:

W = Weight of plate or stiffener, W_{PS} ---------------------------**(5.14)**

= Unit weight corresponding to the standard size of plates or stiffeners desired by mills ------------------------**(5.15)**

N = No of plates or stiffeners, N_{PS} ------------------------------**(5.16)**

= Estimated total steel weight of or stiffeners on the ship/W_{PS} **(5.17)**

e_m = 1 from Fig. 5.2 corresponding to indoor operation of forklift for pallet sized items.

5.5.4.8 Flow of Materials for Other Classes of Materials

For process routes involving various Classes of materials except hull steel, the following formula is proposed:

Total weight of a particular Class of material

= LDT x composition of the class of material in % of LDT of ship---**(5.18)**

where LDT = Light displacement tonnes of largest obsolete ship planned

N = 1

e_m shall be selected from Fig. 5.2 according to the type and size of material under each class.

5.5.5 Preparation of From-To Chart and Rating of Material Flow Intensities between Activity Areas

5.5.5.1 From-To Chart

SLP procedure recommends the use of From-To Chart for analysing flow of materials involving many diversified products (Muther and Hales 2015). Recycling of a ship involves numerous diversified products. From-To Chart is to be prepared by listing the activity areas both down and across the chart. Each intersecting box will represent the flow from one activity area to the other.

In From-To Chart, flow values above the diagonal will indicate the material moves towards completion and below the diagonal will represent the counter flow. Good layout minimises distances between activity areas which have highest flow between them. It also minimises counter flow. Therefore, flow values in both directions are to be estimated and entered between each pair of activity areas in From-To Chart. The total two-way flow value between each pair of activity areas will represent the relationship between these activity areas. Therefore, From-To Chart establishes the closeness relationship based on material flow between activity areas (Muther and Hales 2015).

From-To Chart shall be prepared for each of the Classes of materials specified in Table 5.3.

5.5.5.2 Rating of Flow Intensities

In order to reduce the difficulty and time required for comparing numerical values of flow intensities, SLP proposes to convert flow intensity values into a common rating system based on a Vowel Letter Convention.

Vowel Letter Convention specified in SLP for intensities of flow is as follows (Muther and Hales 2015):

A : Abnormally high intensity of flow

E : Especially high intensity of flow

I : Important intensity of flow

O : Ordinary intensity of flow

U : Unimportant moves of negligible intensity

For this purpose, first a worksheet is to be used to estimate the two way flow intensities between activity areas. Then the flow intensity values shall be plotted on a calibration chart in order to convert the flow intensities into the Vowel Letter Convention by visual identification of breakpoints in the chart. The calibration chart shall be with activity pair on the horizontal axis and intensity values on the vertical axis. Later, this rating shall be used for combining flow and other-than-flow relationships.

In SLP procedure, 'A' rating is to be given for 10% of the highest intensity routes, but having intensity values greater than 40% of the highest intensity value. 'O' rating is to be given for 40% of the lowest intensity routes, but having intensity values upto 10% of the highest intensity value.

5.5.6 Rating of Other-Than-Flow Relationships between Activity Areas and Development of Relationship Chart

Eventhough supporting services are not part of the flow of materials, it is necessary to integrate supporting services with the flow in an organised way (Muther and Hales 2015). In ship recycling, there are a number of incompatible activities. The facilities in which such incompatible activities are carried out shall not be close to each other. SLP proposes Relationship Chart as a systematic way of integrating supporting services with flow of materials and relating each pair of activity areas (Muther and Hales 2015). SLP recommends to carry out rating of the closeness using a Vowel Letter Convention.

5.5.6.1 Ranking of Relationship between Activity Areas

A relative rating, using Vowel Letter Convention, shall be made for the relationships between activity areas in the SRY. This rating shall be based on the other-than-flow considerations. The closeness ratings as per the Vowel Letter Convention and the desired proportions of each of the relationship ratings (or frequencies of rating occurrences) which have been defined in the SLP procedure are presented in Table 5.4.

Table 5.4 Closeness Ratings and Their Recommended Proportions

Vowel rating (Muther and Hales 2015)	**Description of relationship** (Muther and Hales 2015)	**Proportions of relationships in %** (Muther and Hales 2015)
A	Closeness Absolutely necessary	2 to 5
E	Closeness Especially important	3 to 10
I	Closeness Important	5 to 15
O	Ordinary closeness	10 to 25
U	Closeness Unimportant	Nearly 50
X	Closeness not desirable	Depends on nature of the project

Establishing the closeness ratings of the activity areas is a subjective approach which requires experience about the activities to be carried out in the facilities (Chabane 2004).

5.5.6.2 Relationship Chart

Relationship Chart shows rating of relationships between one activity area and the others. This chart shows Vowel Letter rating that indicates the relative importance of closeness between each activity area pair. It also shows supporting reasons, using codes, for the selection of the closeness ratings. Relationship Chart is effective for planning activity areas that are not connected together with a significant material flow pattern (Muther and Hales 2015):

5.5.7 Generation of Combined Relationship Chart

In SLP, a worksheet shall be used to combine the ratings of flow of materials and other-than-flow. In the worksheet, the rating of equivalent flow values between each pair of activity areas is to be converted into a corresponding numerical value according to the SLP procedure. Numerical values for the Vowel ratings used in SLP are shown in Table 5.5.

Table 5.5 Numerical Values for Vowel Ratings

Vowel rating (Muther and Hales 2015)	**Numerical value** (Muther and Hales 2015)
A	4
E	3
I	2
O	1
U	0
X	-1

This shall be followed by conversion of ratings of other-than-flow relations into their numerical values using the information given in Table 5.5. For this purpose, the relative importance or weighing ratio of flow relationships and other-than-flow relationships is to be determined. SLP recommends to take this flow to other-than-flow relation weighing ratio as 1.5 to 2:1 in high volume manufacturing facilities. In this thesis, it is proposed to take the weighing ratio of flow to other-than-flow relationships in the case of SRY as 2:1 considering the large amount of material flow which is going to be critical in deciding the quantity of work, time schedule, and the economic benefits in recycling a ship.

After multiplying the above weighing ratio to the respective numerical values of ratings of flow and other-than-flow, these weighted rating values shall be added. The resulting value shall then be calibrated back into Vowel ratings using a calibration chart. The resulting ratings shall be checked and further adjusted if necessary. This checking is essentially required because the negative values of X ratings may override the flow ratings in some of the cases. The finally assigned ratings of the combined relationships, along with the reasons for the ratings, shall be incorporated into a Relationship Chart to obtain the Combined Relationship Chart.

5.5.8 Development of Activity Relationship Diagram

In SLP, a Relationship Diagram (Activity Relationship Diagram) shall be generated on the basis of the Combined Relationship Chart using a set of symbols, a set of diagramming conventions, and a procedure, which have been specified in SLP. During every step, the diagram needs to be rearranged to get an optimal arrangement.

Relationship Diagram is to be generated graphically by using a number of lines code. The number of lines to be drawn between the activity areas based on the relationship ratings of A, E, I, and O shall be 4, 3, 2, and 1 respectively. The length of lines shall be theoretically in the ratio 1/4: 1/3: 1/2: 1 for A, E, I, O relationships respectively. The diagramming shall commence with A and end with O in the order of vowel letters. Finally X relationships shall be drawn as wiggly lines (Muther and Hales 2015):

A completed Relationship Diagram represents theoretically ideal relationship of the activity areas and it is independent of the area required (Muther and Hales 2015). Considerations may be given regarding the location such as tideline and roads. The actual layout of the SRY shall be mainly based on the Activity Relationship Diagram which will be generated from the Activity Relationship Chart.

5.5.9 Determination of Space Requirements for Facilities and Development of Space Relationship Diagram

5.5.9.1 Space Requirements

Because of the randomness in the volume of material transfer in ship recycling works, it may not be possible to estimate reliable values of manhours and productivity for some of the onboard materials.

For determining space requirements for office buildings and similar features, it is proposed to use standard data from literature (Chabane 2004) on shipbuilding yards and ship repair yards.

Space requirements for the Primary, Secondary, Tertiary Disassembly Areas and Storage (Steel) area shall be determined based on the approximate area which would be required by each structural unit in the space and the number of such structural units that are going to occupy, at a time, the space under consideration. Size of the structural units may be estimated using approximate weights and number of units which can be calculated using the procedure given in section 5.5.4.

Space requirements for storage areas of other items shall be estimated based on the number of obsolete ships which are planned for recycling at a time and the material composition of each of these obsolete ships in percentage of LDT. Published data on the storage areas of various SRYs across the world may be used as a reference to arrive at the area values.

The estimated area requirements are to be balanced against the space possibly available by reconsidering the area requirements and configuration of the activity area.

5.5.9.2 Space Relationship Diagram

Space Relationship Diagram can be formed by incorporating the space allocations of various facilities into the Activity Relationship Diagram. The geographical arrangement of activity areas in the Activity Relationship Diagram are to be retained. The activity areas are to be drawn initially as rectangular blocks unless there is a requirement on the shape of the activity area. The activity areas are to be spread out to draw the relationship lines. The Space Relationship Diagram would represent a rough layout which needs to be adjusted and rearranged to form the final layout.

5.5.10 Modifications on the Space Relationship Diagram and Generation of Alternative Layouts

This step consists of making adjustments on the Space Relationship Diagram in order to incorporate modifications and practical limitations. The modifying considerations may be with respect to handling methods, type of storing, site conditions, utilities, type of aisles, etc. (Muther and Hales 2015). A number of layout alternatives shall be generated based on the modifying considerations, practical limitations, and the space requirements.

5.5.11 Evaluation of Alternative Layouts and Selection of Optimal Layout

Evaluation of layout alternatives is the last step in the SLP method. For layout design problems with multiple objectives, finding an optimal design from the layout alternatives may be difficult. It is proposed to adopt two of the evaluations methods specified in SLP procedure for evaluation of the alternatives in order to select a layout for SRY. The selected methods are weighted factor analysis and transport work comparison.

5.5.11.1 Weighted Factor Analysis

Weighted factor analysis method is used to evaluate intangible costs. It involves listing all the factors which are significant in deciding on the layout selection, weighing the relative importance of the factors with respect to each other, and rating the alternative layouts against one factor at a time. Weighted values are to be found and then summed up. The total values are to be used for comparing the layouts.

The relevant factors adopted in this study, from the factors which are specified in the SLP procedure for evaluation of alternatives, and the proposed weight values for these factors in the case of SRY are listed in Table 5.6.

Table 5.6 Factors for Weighted Factor Analysis

Sl. No	Factor	Weight or relative rating
1	Flow or movement effectiveness	10
2	Adaptability and versatility	10
3	Safety and housekeeping	10
4	Materials handling effectiveness	9
5	Space utilisation	9
6	Storage effectiveness	8
7	Effectiveness of supporting service integration	7
8	Ease of supervision and control	7
9	Equipment utilisation	7
10	Ease of future expansion	5
11	Maintenance problems	3
12	Utilisation of natural conditions, building or surroundings	2
13	Working conditions and employee satisfaction	1

5.5.11.2 Transport Work Comparison

Transport work for a flow route between two activity areas is the multiplication product of flow intensity and distance between the two activity areas. Transport work gives an indication about the relative material handling cost. Value of transport work for a flow route between two activity areas in a layout alternative can be obtained by finding the multiplication product of two way flow intensity between the two activity areas, which is taken from the From-To Chart, and the distance between them, which is taken from the alternative layout plan (Muther and Hales 2015). The total transport work for a layout alternative can be obtained by summing up the transport work values of all activity area pairs. Similarly, the total transport work values for other layout alternatives can be found.

These values can be compared and the layout alternative having the lowest value of the total transport work can be selected as the optimal layout.

5.6 CASE STUDY OF A NEW SHIP RECYCLING YARD

Based on the proposed methodology that has been presented under section 5.5, a case study has been conducted for the concept layout design of a new SRY. The case study is presented in the following sections. Firstly, few assumptions have been made regarding the type of ship and the throughput. A list of activity areas has been prepared for the case study based on the comprehensive list of activity areas given in Table 5.2. Space requirements for the activity areas have been determined based on standard data for shipyards, which have been available from the literature and the published statistics on existing SRYs.

5.6.1 Input Data and Assumptions

Input data which are required for the concept layout design of SRYs have been defined in this section. In addition, the assumptions which have been made regarding the location, geometry, and features of the land; size of primary disassemblies of ships to be recycled; and planned recycling capacity of the SRY have been specified. Construction of a fresh SRY has been considered for development of the layout. Generally, extensive size range of obsolete ships may be recycled in a SRY after it becomes operational. However, during the layout design stage, the SRY has to be designed to suit certain size range of ships. Method to be selected for docking the ships is dependent on the size of the ship (DNV 2001).

The SRY shall be capable of handling all ships which are smaller than the maximum size of ship specified in the input data. Annual recycling capacity of a SRY refers to the total LDT of all ships which are recycled in the SRY in a year. Input data with respect to the features of SRY and particulars of obsolete ships for attempting the case study have been listed in Table 5.7.

Types of technologies opted for various recycling processes such as docking, cutting, and material handling in a new SRY will have an influence on the concept layout design of the SRY. The opted technologies determine the size and shape requirements of various activity areas and the orientation of the docking mechanism. The technologies adopted for the SRY in the case study have been described in subsections from 5.6.1.1 to 5.6.1.4.

Table 5.7 Main Input Data for Concept Layout Design of SRY

Sl. No	Description	Particulars
1	Docking method	Air bag
2	Type of obsolete ships	Bulk carrier
3	Maximum size of ships that can be recycled	10000 LDT
4	Maximum number of ships of 10000LDT size that can be recycled at a time	2 (at different stages of progress of recycling)
5	Annual recycling capacity	40000 LDT

5.6.1.1 Docking Method

This case study has been done for developing of SRY concept layout. Air bag method has been considered as the docking method. Air bag method has been used for shipbuilding and ship repair in the shipyards worldwide. One of the SRYs in India is attempting to use the air bag method for recycling of ships (MECON Limited 2013) because of the reduced chances of chaffing action of ship’s bottom with beach sand using this method. For the case study, three winches have been assumed for assisting the docking operation. This assumption has been made based on the docking requirement of a similar sized ship using air bags (MECON Limited 2013). The winches are to be properly fenced.

5.6.1.2 Cutting Technology for Steel

It is proposed to use oxy-acetyline cutting technology for cutting of ship’s steel in the case study. Oxy-acetyene cutting technology has been widely used in all the major ship recycling countries for cutting of steel plates and sections.

5.6.1.3 Decoating Technology

In the case study of concept layout design, shot blasting method is proposed for removal of antifouling paints from the shell plating in way of underwater areas of the obsolete ship. Shot blasting method is a common process that has been practised for surface preparation of steel plates in shipbuilding yards and ship repair yards.

5.6.1.4 Material Handling Technology

It has been assumed that the handling and transportation of materials and equipment will be done using forklifts, mobile cranes including crawler cranes, and dump trucks; similar to the case of any shipbuilding or ship repair yard.

5.6.1.5 Geometry and Features of Land

This data is important since it has considerable influence on the size and shape of the activity areas as well as on the orientation of the docking arrangement. For the case study, it has been assumed that the land is rectangular in shape and there is sea on one side of the land. The SRY is to be located in a major ship recycling nation such as India. It is considered that there are no constraints at the site for construction of the SRY. The SRY is to be newly developed. There is no existing facility that is to be integrated with the new SRY.

5.6.1.6 Size of the Largest Obsolete Ship

For the case study, the SRY has been assumed to be equipped for recycling Handymax bulk carriers with a maximum LDT of 10000. The recycling work to be carried out by the SRY has been is assumed to be labour intensive. The above type and size of an obsolete ship has been chosen for the case study since reliable information on material composition of a similar ship has been available from the literature (Jain et al. 2017). Approximate dimensions which have been selected for the Handymax bulk carrier of 10000 LDT are Length OverAll (LOA) = 190 m, Breadth = 30 m, Depth = 16 m, and Draught = 12 m.

5.6.1.7 Ship Recycling Schedule

Average period for recycling a Handymax bulk carrier of 10000 LDT in an existing ship recycling facility in India has been around four months (Hiremath et al. 2015; Demaria 2010). The same period has been considered for the case study. For the case study, the SRY has been considered to be equipped for recycling upto a maximum of four ships of 10000 LDT each in a year. Out of these four, two ships which would be at different stages of disassembling progress can be recycled simultaneously. Annual ship recycling schedule which has been assumed for the SRY in the case study is shown in Fig. 5.3.

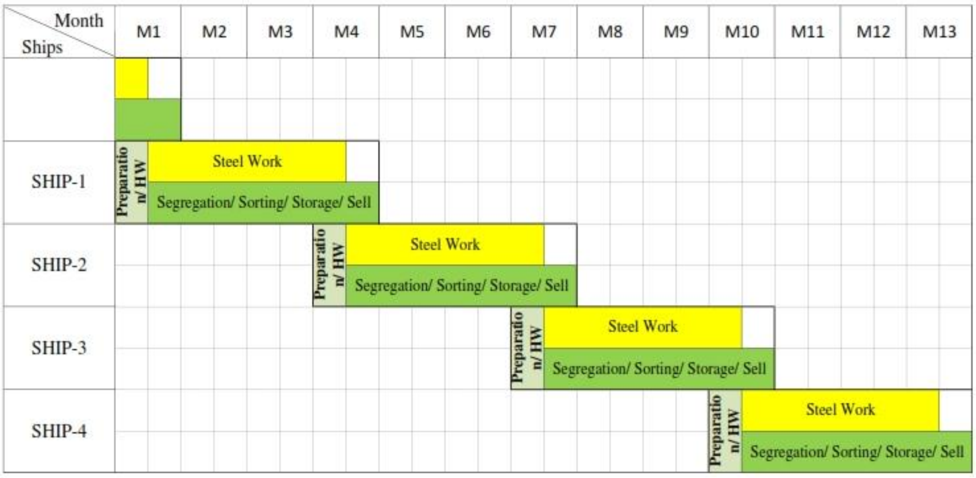


Fig. 5.3 Ship Recycling Schedule
(M1, M2 etc. refers to Month1, Month 2 etc. respectively)

In order to increase annual recycling capacity of the SRY, the aim shall be to quickly transfer maximum amount of recycling work from the Primary Disassembling Area to other activity areas and thereby minimise the time and the extent of recycling work which are carried out in the Primary Disassembling Area for each obsolete ship. This will facilitate an early availability of Primary Disassembling Area to the next obsolete ship for its docking and commencement of its recycling operations.

5.6.1.8 Annual Recycling Capacity of SRY

Based on the maximum size of 10000 LDT of an obsolete ship specified in section 5.6.1.6 and the recycling schedule with four ships per year as given in Fig. 5.3, the annual recycling capacity of the SRY has been calculated as 40000 LDT.

5.6.1.9 Disassembly Concept

The proposed SRY has been assumed to follow the disassembly concept proposed in section 3.3.1. Sizes of primary disassemblies, disassemblies, and subdisassemblies have been determined based on the methodology given under sections from 5.5.4.4 to 5.5.4.6.

5.6.2 Activity Areas in the SRY

Bringing down the number of activity areas will help to reduce the computational efforts required for SLP assisted layout design. 37 activity areas presented in Table 5.2 have been brought down to 23 activity areas for the case study by combining the activity areas that may always stay adjacent to each other. For example, the Sorting Area (Steel) in Table 5.2 has been considered as part of Tertiary Disassembling Area in Table 5.8 for the case study.

For the case study, it has been assumed that the disposal of wastes shall be carried out outside the SRY premises. In addition, it has been considered that the Internal Road is to be incorporated as part of the modifying considerations which will be applied on the Space Relationship Diagram. Therefore, Waste Disposal Facility and Internal Road have not been included in Table 5.8. The above assumptions have been made to bring down the number of activity areas only for the case study. The final list of activity areas selected for the case study is presented in Table 5.8.

Code numbers of some of the activities indicated in the GSRGP, which has been shown in Figs. 3.4 to 3.9, have been incorporated in Table 5.8 against the corresponding activity areas in which these activities are to be carried out. It is proposed to extend this concept to the entire recycling activities as per the GSRGP.

Types of activity areas have been indicated using the sign convention specified by SLP procedure and these are presented in Fig. 5.4.

5.6.3 Intensities of Material Flow

Material flow intensities for various Classes of materials have been estimated, as per the methodology given in section 5.5.4, and these have been described in this section.

Table 5.8 Selected List of Activity Areas for the SRY

Activity area number	Activity area name for the case study	Activity areas included from Table 5.2.	Sample of code numbers of activities from GSRGP
1	Ship	Ship	S1P010
2	Primary Disassembling Area	Primary Disassembling Area	S2P029
3	Winch House	Winch House	S2P001
4	Secondary Disassembling Area	Secondary Disassembling Area	S3P004
5	Shot Blasting Area	Shot Blasting Area	S3P001
6	Tertiary Disassembling Area	Tertiary Disassembling Area Sorting Area (Steel)	S4P008
7	Segregation Area (NHM)	Segregation Area (NHM)	S2P068
8	Storage (Steel)	Storage (Steel)	S4P011
9	Storage (Machinery)	Storage (Machinery)	S4P001
10	Storage (Miscellaneous)	Storage (Nonferrous Metals) Storage (Miscellaneous)	S4P009
11	Workshop	Workshop	S4P002
12	Storage (Electrical/Electronic)	Storage (Electrical/Electronic)	S4P006
13	Segregation Area (HM)	Segregation Area (HM-Asbestos). Segregation Area (Other HMs)	S2P069
14	Storage (HW)	Storage (HW)	S4P014

Table 5.8 Selected List of Activity Areas for the SRY- CONT'D

Activity area number	**Activity area name for the case study**	**Activity areas included from Table 5.2.**	**Sample of code numbers of activities from GSRGP**
15	Storage (Liquids)	Storage (Oil) Storage (Dirty Water)	S4P007
16	Lifting/Handling Installations	Lifting/Handling Installations	
17	SR Supporting Services	SR Supporting Services Safety Department Training Centre Medical Unit	
18	Amenity for Workers	Amenity for Recycling Workers (Sanitation Facility and Change Room)	
19	Canteen	Canteen and Rest Room	
20	Administrative Office	Office for Recycling Managers Administrative Office Sales	
21	Parking area (Trucks/Vehicles)	Parking area for Trucks. Parking area for Other Vehicles	
22	Entrance/Exit	Entrance/Exit for material Entrance/Exit for personnel	
23	Security Post	Security Posts	

ACTIVITY AREAS		Type of Space								U	Y
No.	Name/Description	Operation	Handling	Transport	Inspection	Delay/Staging	Storage	Service/Support	Office or Bldg. Feature	U - Underroof	Y-Yard
1	Ship	1									Y
2	Primary Disassembling Area	2									Y
3	Winch House		3							U	
4	Secondary Disassembling Area	4									Y
5	Shot Blasting Area	5									Y
6	Tertiary Disassembling Area	6									Y
7	Segregation Area (NHM)	7									Y
8	Storage (Steel)						8				Y
9	Storage (Machinery)						9			U	
10	Storage (Miscellaneous)						10			U	
11	Workshop	11								U	
12	Storage (Electrical/Electronic)						12			U	
13	Segregation Area (HM)	13								U	
14	Storage (HW)						14			U	
15	Storage (Liquids)						15			U	
16	Lifting/Handling Installations		16								Y
17	SR Supporting Services							17		U	
18	Amenity for Workers								18	U	
19	Canteen								19	U	
20	Administrative Office								20	U	
21	Parking area (Trucks/Vehicles)								21		Y
22	Entrance/Exit			22							Y
23	Security Post								23	U	

Fig. 5.4 Activity Areas in SRY Indicated Using SLP Recommended Symbols (Form No -150 from Muther and Hales 2015)

5.6.3.1 Composition of Onboard Materials

Based on the published data on material composition of an 11044 LDT bulk carrier (Jain et al. 2017), the material composition of each Class of onboard materials for the case study has been estimated and it is presented in Table 5.9.

Based on the material composition given in Table 5.9, the intensities of material flow between various activity areas have been estimated and these are explained in the sections from 5.6.3.2 to 5.6.3.10. It has been assumed that the Ship will be positioned in the Primary Disassembling Area. Therefore, no specific value has been assigned for the material flow from Ship to the Primary Disassembling Area., since every component from Ship will have to be transported through the Primary Disassembling Area. Ship is considered as a separate activity area since the orientation of ship has an influence on the layout design of the SRY.

Table 5.9 Quantity of Material Classes for 10000 LDT Bulk Carrier

Class	**Material composition**	**Quantity in % of LDT of ship** (Jain et al. 2017)	**Quantity in tonnes for the ship used in the case study**
Class ‘a’	Steel including steel scrap	84.60	8460
Class ‘b’	Nonferrous scrap	1.04	104
Class ‘c’	Machinery	6.18	618
Class ‘d’	Electrical/electronic equipment	1.24	124
Class ‘e’	Minerals	2.52	252
Class ‘f’	Plastics	1.19	119
Class ‘g’	Liquids, chemicals and gases	1.03	103
Class ‘h’	Joinery	1.28	128
Class ‘i’	Miscellaneous	0.92	92

5.6.3.2 Flow Intensities of Class ‘a’ Materials

Intensities of flow of Class ‘a’ materials, which consists of steel including steel scrap, from each activity area to other activity areas have been estimated and these are presented in this subsection.

Material flow of Class ‘a’ materials from Primary Disassembling Area to Secondary Disassembling Area

Out of the 8460 t of steel as mentioned in Table 5.9, it has been assumed that the steel weights of hull and superstructure, together with the steel components of outfit items, are 7460 t and 1000 t respectively.

Crane capacity that has been fixed for the Primary Disassembling Area is 100 t. Therefore, using equations 5.2 and 5.3 for the hull structure,

$$W = W_{PD}$$

$$= 100 \text{ t}$$

Using equations 5.4 and 5.5,

$$N = N_{PD}$$

$$= \text{Estimated total steel weight of obsolete ship/ } W_{PD}$$

$$= 7460 \text{ t} / 100 \text{ t}$$

$$= 74.6 \text{ numbers}$$

$$\approx 75 \text{ numbers.}$$

e_m = 5 (from section 5.5.4.4.)

Therefore, using equation 5.1,

Flow intensity of Class ‘a’ materials on the hull, from Primary Disassembling Area to Secondary Disassembling Area, I

$$= N. W. e_m$$

$$= 75 \text{ x } 100 \text{ t x } 5$$

$$= 37500 \text{ t}$$

Similarly for superstructure, using equations 5.2 and 5.3,

$$W = W_{PD}$$

$$= 100 \text{ t}$$

Using equations 5.4 and 5.5,

$$N = N_{PD}$$

$$= \text{Estimated total steel weight of obsolete ship/} W_{PD}$$

$$= 1000 \text{ t} / 100 \text{ t}$$

$= \quad 10$ numbers.

$e_m \quad = \quad 5 \qquad$ (from section 5.5.4.4)

Therefore, using equation 5.1,

Flow intensity Class ‘a’ materials on the superstructure, from Primary Disassembling Area to Secondary Disassembling Area, I

$= \quad N. W. e_m$

$= \quad 10 \text{ x } 100 \text{ t x } 5$

$= \quad 5000$ t

Material flow of Class ‘a’ materials from Secondary Disassembling Area to Shot Blasting Area

It has been assumed that 20 numbers of disassemblies of weight 25 t each will be transported to the Shot Blasting Area for carrying out blasting to remove the antifouling paint. Depending on the hazardous content and underwater area of various ships, requirement on the number and weight of disassemblies to be transported for blasting can vary. The above requirement for this transportation can be made more accurate if exact information about the extent of antifouling coating on the underwater area of each obsolete ship can be made available.

For hull structure, using equation 5.6,

$W \quad = \quad W_D$

$= \quad 25$ t (fixed)

Using equation 5.8,

$N \quad = \quad N_D$

$= \quad 20$ numbers (fixed)

$e_m \quad = \quad 3.5 \qquad$ (from section 5.5.4.5)

Therefore, using eqn. 5.1,

Flow intensity of Class ‘a’ materials from Secondary Disassembling Area to Shot Blasting Area, I

$$= N.\ W.\ e_m$$

$$= 20 \text{ x } 25 \text{ t x } 3.5$$

$$= 1750 \text{ t}$$

Material flow of Class ‘a’ materials from Secondary Disassembling Area to Tertiary Disassembling Area

It has been assumed that smaller cranes of capacity less than 25 t will be used for transporting the subdisassemblies or panels to the Tertiary Disassembling Area. Since all steel materials from Secondary Disassembling Area are to be transported to Tertiary Disassembling Area, the multiplication product of W and N in equation 5.1 has been taken as equal to the total weight of Class ‘a’ materials.

Therefore,

W = 8460 t (from Table 5.9)

N = 1

e_m = 2.5 (from section 5.5.4.6)

Therefore, using equation 5.1,

Flow intensity of Class ‘a’ materials from Secondary Disassembling Area to Tertiary Disassembling Area, I

$$= N.\ W.\ e_m$$

$$= 1 \text{ x } 8460 \text{ t x } 2.5$$

$$= 21150 \text{ t}$$

Material flow of Class ‘a’ materials from Tertiary Disassembling Area to Storage (Steel) area

It is assumed that forklifts will be used for transporting the plates and stiffeners from the Tertiary Disassembling Area to the Storage (Steel) area. Since all steel materials from Tertiary Disassembling Area are to be transported to Storage (Steel), the multiplication product of W and N in equation 5.1 has been taken as equal to total weight of Class ‘a’ materials.

Therefore,

W = 8460 t (from Table 5.9)

N = 1

e_m = 1 (from section 5.5.4.7)

Therefore, using equation 5.1,

Flow intensity Class ‘a’ materials from Tertiary Disassembling Area to Storage (Steel), I

= N. W. e_m

= 1 x 8460 t x 1

= 8460 t

5.6.3.3 Flow Intensities of Class ‘b’ Materials

Class ‘b’ materials are nonferrous materials including copper, zinc, aluminium, and bronze (DNV 2001). The nonferrous metals shall be transferred from Primary Disassembling Area to Storage (Miscellaneous).

Using equations from section 5.5.4.8,

Total weight of Class ‘b’ materials, W

= 104 t (from Table 5.9)

N = 1

e_m = 1 (from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity Class ‘b’ materials, I

= N. W. e_m

= 1 x 104 t x 1

= 104 t

5.6.3.4 Flow Intensities of Class ‘c’ Materials

Class ‘c’ materials consist of machinery which is to be transferred from Primary Disassembling Area to Storage (Machinery) and Workshop.

Using equations from section 5.5.4.8,

Total weight of Class ‘c’ materials, W

= 618 t (from Table 5.9)

N = 1

e_m = 2 (from Fig. 5.2 for forklifts used outdoors/ yard)

The transportation of Class ‘c’ materials using forklift has been considered to be a more difficult movement than the corresponding transportation of Class ‘b’ materials. So a larger value of e_m has been assumed for Class ‘c’ materials (e_m = 2) than the Class ‘b’ materials (e_m = 1).

Therefore, using equation 5.1,

Flow intensity Class ‘c’ materials, I

= N. W. e_m

= 1 x 618 t x 2

= 1236 t

It has been assumed that, out of the above flow intensity value of 1236 t, 50% of the flow intensity will be from Primary Disassembling Area to Storage (Machinery) and the remaining 50% will be from Primary Disassembling Area to Workshop.

5.6.3.5 Flow Intensities of Class 'd' Materials

Class 'd' materials consist of electrical and electronic equipment such as switchboards, consoles, control panels, sensors, navigational aids, instruments, and domestic electrical items (DNV 2001).

Using equations from section 5.5.4.8,

Total weight of Class 'd' materials

= 124 t (from Table 5.9)

Exact information on composition of hazardous materials in electrical and electronic equipment has not been published yet. Therefore, it has been assumed that the hazardous content of Class 'd' materials will be 1 t. The above 1 t of Class 'd' materials is to be transported to Segregation Area (HM) in order to segregate the hazardous materials. Remaining 123 t of Class 'd' materials are to be transported to Storage (Electrical/Electronic).

W	=	123 t	for material flow from Primary Disassembling Area to Storage (Electrical/Electronic)
W	=	1 t	for material flow from Primary Disassembling Area to Segregation Area (HM)
N	=	1 each	
e_m	=	1	(from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of Class 'd' materials from Primary Disassembling Area to Storage (Electrical/Electronic), I

= N. W. e_m

= 1 x 123 t x 1

= 123 t and

Flow intensity of Class ‘d’ materials from Primary Disassembling Area to Segregation Area (HM), I

= N. W. e_m

= 1 x 1 t x 1

= 1 t

5.6.3.6 Flow Intensities of Class ‘e’ Materials

Class ‘e’ materials comprise asbestos and mineral wool used for insulation, ceramics, tiles, glass, windows, etc. (DNV 2001)

Using equations from section 5.5.4.8,

Total weight of Class ‘e’ materials

= 252 t (from Table 5.9)

It has been noticed that there is wide variation in asbestos content onboard of obsolete ships and that the content of asbestos in a ship is independent of the ship size (DNV 2001). Therefore, it has been assumed that the weight of Asbestos Containing Materials (ACM) of Class ‘e’ type will be 20 t and its asbestos content will be 10 t. ACMs shall be initially transported to Segregation Area (HM) in order to segregate the asbestos. The segregated asbestos shall be transferred to Storage (HW) and the remaining 10 t of the segregated nonhazardous materials shall be transported to Storage (Miscellaneous). Class ‘e’ materials, excluding the ACMs, having a weight of 232 t shall be transported from Primary Disassembling Area directly to Storage (Miscellaneous).

W = 20 t for material flow from Primary Disassembling Area to Segregation Area (HM)

W = 10 t for material flow from Segregation Area (HM) to Storage (HW)

W	=	10 t	for material flow from Segregation Area (HM) to Storage (Miscellaneous)
W	=	232 t	for material flow from Primary Disassembling Area to Storage (Miscellaneous)
N	=	1 each	
e_m	=	1	(from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of ACMs belonging to Class ‘e’ from Primary Disassembling Area to Segregation Area (HM), I

= N. W. e_m

= 1 x 20 t x 1

= 20 t

Flow intensity of asbestos from Segregation Area (HM) to Storage (HW), I

= N. W. e_m

= 1 x 10 t x 1

= 10 t

Flow intensity of segregated nonhazardous materials from Segregation Area (HM) to Storage (Miscellaneous), I

= N. W. e_m

= 1 x 10 t x 1

= 10 t

Flow intensity of Class ‘e’ materials, excluding the ACMs, from Primary Disassembling Area to Storage (Miscellaneous)

= N. W. e_m

= 1 x 232 t x 1

= 232 t

5.6.3.7 Flow Intensities of Class ‘f’ Materials

Class ‘f’ materials include plastic pipe work, fittings, furniture, light fittings, etc. (DNV 2001).

Using equations from section 5.5.4.8,

Total weight of Class ‘f’ materials, W

= 119 t (from Table 5.9)

The Class ‘f’ materials shall be initially transported from the Primary Disassembling Area to Segregation Area (NHM). After segregating the reusable items and nonhazardous wastes from the Class ‘f’ materials in the Segregation Area (NHM), both the reusable items and the wastes are to be transported to Storage (Miscellaneous) and stored separately.

$N = 1$

$e_m = 1$ (from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of Class ‘f’ materials from Primary Disassembling Area to Segregation Area (NHM), I

$= N.\ W.\ e_m$
$= 1 \times 119\ t \times 1$
$= 119\ t$

Flow intensity of Class ‘f’ materials from Segregation Area (NHM) to Storage (Miscellaneous), I

$= N.\ W.\ e_m$
$= 1 \times 119\ t \times 1$
$= 119\ t$

5.6.3.8 Flow Intensities of Class 'g' Materials

Class 'g' materials include fuel oil, lub oil, hydraulic fluids, refrigerants, cargo residues, sludge, chemicals, polluted waters, etc. (DNV 2001).

Using equations from section 5.5.4.8,

Total weight of Class 'g' materials, W

= 103 t (from Table 5.9)

The Class 'g' materials shall be transported from Primary Disassembling Area to Storage (Liquids). The liquids may be pumped out or may be transferred in drums depending on the quantity and type of liquid.

N = 1

e_m = 1 (from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of Class 'g' materials, I

= N. W. e_m

= 1 x 103 t x 1

= 103 t

5.6.3.9 Flow Intensities of Class 'h' Materials

Class 'h' materials include partitions, panelling, ceiling, accommodation doors and frames, furniture, composite timber products, etc. (DNV 2001).

Using equations from section 5.5.4.8,

Total weight of Class 'h' materials, W

= 128 t (from Table 5.9)

The Class 'h' materials shall be transported from the Primary Disassembling Area to Storage (Miscellaneous).

N = 1

e_m = 1 (from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of Class 'h' materials, I

= N. W. e_m

= 1 x 128 t x 1

= 128 t

5.6.3.10 Flow Intensities of Class 'i' Materials

Class 'i' materials include domestic wastes, radiation sources, mercury, batteries, etc. (DNV 2001).

Using equations from section 5.5.4.8,

Total weight of Class 'i' materials, W

= 92 t (from Table 5. 9)

It is practically impossible to predict accurate quantity of each type of hazardous materials under Class 'i' since it varies for various types of ships. Therefore, it has been assumed that 50% of the weight of Class 'i' materials will be hazardous in nature. The hazardous materials under Class 'i' are to be transported to Storage (HW). Remaining materials of Class 'i' are to be transported to Segregation Area (NHM) for segregating the reusable items and nonhazardous wastes. These segregated materials are to be transported to Storage (Miscellaneous) and stored separately.

N = 1 each

e_m = 1 (from Fig. 5.2 for forklifts used indoor)

Therefore, using equation 5.1,

Flow intensity of hazardous materials belonging to Class ‘i’ from Primary Disassembling Area to Storage (HW), I

= N. W. e_m

= 1 x (50% of 92 t) x 1

= 46 t

Flow intensity of Class ‘i’ materials from Primary Disassembling Area to Segregation Area (NHM), I

= N. W. e_m

= 1 x (50% of 92 t) x 1

= 46 t

Flow intensity of nonhazardous materials from Segregation area (NHM) to Storage (Miscellaneous), I

= N. W. e_m

= 1 x (50% of 92 t) x 1

= 46 t

5.6.3.11 From-To Chart

Based on the procedure given in section 5.5.5.1, From-To Charts for the nine Classes of materials from Class ‘a’ to ‘i’ have been generated and these are shown in Figs. 5.5 to 5.13. Fig 5.14 shows the summarised From-To Chart which has been obtained by combining From-To Charts of all the nine Classes.

Class a

FROM-TO-CHART

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *1* of *9*

Item(s) Charted:
a *Steel including steel scrap*

Basis of Values:
(Quantity x weight(t)/ item x e_m)

No.	Activity or Operation FROM / Name/Description / Activity or Operation TO — FROM: Activity Name	Ship 1	Primary Disassembling Area 2	Winch House 3	Secondary Disassembling Area 4	Shot Blasting Area 5	Tertiary Disassembling Area 6	Segregation Area (NHM) 7	Storage (Steel) 8	Storage (Machinery) 9	Storage (Miscellaneous) 10	Workshop 11	Storage (Electrical/Electronic) 12	Segregation Area (HM) 13	Storage (HW) 14	Storage (Liquids) 15	Lifting/Handling Installations 16	SR Supporting Services 17	Amenity for Workers 18	Canteen 19	Administrative Office 20	Parking area (Trucks/Vehicles) 21	Entrance/Exit 22	Security Post 23	TOTAL
1	Ship																								0
2	Primary Disassembling Area				42500																				42500
3	Winch House																								0
4	Secondary Disassembling Area					1750	21150																		22900
5	Shot Blasting Area				1750																				1750
6	Tertiary Disassembling Area								8460																8460
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	44250	1750	21150	0	8460	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 5.5 From-To Chart for Class ‘a’ Materials (Form No -136a from Muther and Hales 2015)

Class b

FROM-TO-CHART

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *2* of *9*

Item(s) Charted:
b Nonferrous scrap

Basis of Values:
(Quantity x weight(t)/ item x em)

No. | Name/Description | Activity or Operation TO | Activity or Operation FROM | FROM:

No.	Activity Name	1 Ship	2 Primary Disassembling Area	3 Winch House	4 Secondary Disassembling Area	5 Shot Blasting Area	6 Tertiary Disassembling Area	7 Segregation Area (NHM)	8 Storage (Steel)	9 Storage (Machinery)	10 Storage (Miscellaneous)	11 Workshop	12 Storage (Electrical/Electronic)	13 Segregation Area (HM)	14 Storage (HW)	15 Storage (Liquids)	16 Lifting/Handling Installations	17 SR Supporting Services	18 Amenity for Workers	19 Canteen	20 Administrative Office	21 Parking area (Trucks/Vehicles)	22 Entrance/Exit	23 Security Post	TOTAL
1	Ship																								0
2	Primary Disassembling Area										104														104
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	0	104	0	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 5.6 From-To Chart for Class ‘b’ Materials (Form No -136a from Muther and Hales 2015)

Class c

FROM-TO-CHART

Item(s) Charted: c Machinery

Basis of Values: (Quantity x weight(t)/ item x em)

Plant: *SR Yard (Air bag method)*
By: *Jayaram S*
Date: *11.12.2017*

Project: *PhD- Research*
With:
Page: 3 of 9

No.	Name/Description (Activity or Operation FROM / Activity or Operation TO)	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	TOTAL
No.	FROM: Activity Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area									618		618													1236
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	618	0	618	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 5.7 From-To Chart for Class ‘c’ Materials (Form No -136a from Muther and Hales 2015)

Class d

FROM-TO-CHART

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *4* of *9*

Item(s) Charted:
d Electrical/ electronic equipment

Basis of Values:
(Quantity x weight(t)/ item x em)

No.	Name/Description (Activity or Operation FROM: / Activity or Operation TO)	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	TOTAL
No.	**Activity Name**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area												123	1											124
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	0	0	0	123	1	0	0	0	0	0	0	0	0	0	0	

Fig. 5.8 From-To Chart for Class ‘d’ Materials (Form No -136a from Muther and Hales 2015)

Class e

FROM-TO-CHART

Item(s) Charted: *e Minerals*

Basis of Values: (Quantity x weight(t)/ item x em)

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *5* of *9*

No.	Name/Description (Activity or Operation FROM → Activity or Operation TO)	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	TOTAL
No.	**FROM: Activity Name**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area										232			20											252
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)										10				10										20
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	0	242	0	0	20	10	0	0	0	0	0	0	0	0	0	

Fig. 5.9 From-To Chart for Class ‘e’ Materials (Form No -136a from Muther and Hales 2015)

Class f

FROM-TO-CHART

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *6* of *9*

Item(s) Charted:
f Plastics

Basis of Values:
(Quantity x weight(t)/ item x em)

No.	Activity Name (FROM) / Activity or Operation (TO)	1 Ship	2 Primary Disassembling Area	3 Winch House	4 Secondary Disassembling Area	5 Shot Blasting Area	6 Tertiary Disassembling Area	7 Segregation Area (NHM)	8 Storage (Steel)	9 Storage (Machinery)	10 Storage (Miscellaneous)	11 Workshop	12 Storage (Electrical/Electronic)	13 Segregation Area (HM)	14 Storage (HW)	15 Storage (Liquids)	16 Lifting/Handling Installations	17 SR Supporting Services	18 Amenity for Workers	19 Canteen	20 Administrative Office	21 Parking area (Trucks/Vehicles)	22 Entrance/Exit	23 Security Post	TOTAL
1	Ship																								0
2	Primary Disassembling Area							119																	119
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)										119														119
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	119	0	0	119	0	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 5.10 From-To Chart for Class ‘f’ Materials (Form No -136a from Muther and Hales 2015)

Class g

FROM-TO-CHART

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *7* of *9*

Item(s) Charted:
g Liquids, chemicals, and gases

Basis of Values:
(Quantity x weight(t)/ item x em)

No.	Activity or Operation FROM / Name/Description / Activity or Operation TO	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	**TOTAL**
No.	**FROM: Activity Name**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area															103									103
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103	0	0	0	0	0	0	0	0	

Fig. 5.11 From-To Chart for Class ‘g’ Materials (Form No -136a from Muther and Hales 2015)

Class h

FROM-TO-CHART

Item(s) Charted: *h Joinery*

Basis of Values: (Quantity x weight(t)/ item x em)

Plant *SR Yard (Air bag method)* Project *PhD- Research*
By *Jayaram S* With
Date *11.12.2017* Page *8* of *9*

No.	Name/Description (Activity or Operation FROM: / Activity or Operation TO)	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	TOTAL
No.	Activity Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area										128														128
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)																								0
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0	0	0	0	

Fig. 5.12 From-To Chart for Class ‘h’ Materials (Form No -136a from Muther and Hales 2015)

Class i

FROM-TO-CHART

Item(s) Charted: *i Miscellaneous*

Basis of Values: (Quantity x weight(t)/ item x em)

Plant *SR Yard (Air bag method)*
By *Jayaram S*
Date *11.12.2017*

Project *PhD- Research*
With
Page *9* of *9*

No.	Name/Description — Activity or Operation FROM / Activity or Operation TO	Ship	Primary Disassembling Area	Winch House	Secondary Disassembling Area	Shot Blasting Area	Tertiary Disassembling Area	Segregation Area (NHM)	Storage (Steel)	Storage (Machinery)	Storage (Miscellaneous)	Workshop	Storage (Electrical/Electronic)	Segregation Area (HM)	Storage (HW)	Storage (Liquids)	Lifting/Handling Installations	SR Supporting Services	Amenity for Workers	Canteen	Administrative Office	Parking area (Trucks/Vehicles)	Entrance/Exit	Security Post	**TOTAL**
No.	**Activity Name**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	Ship																								0
2	Primary Disassembling Area							46							46										92
3	Winch House																								0
4	Secondary Disassembling Area																								0
5	Shot Blasting Area																								0
6	Tertiary Disassembling Area																								0
7	Segregation Area (NHM)										46														46
8	Storage (Steel)																								0
9	Storage (Machinery)																								0
10	Storage (Miscellaneous)																								0
11	Workshop																								0
12	Storage (Electrical/Electronic)																								0
13	Segregation Area (HM)																								0
14	Storage (HW)																								0
15	Storage (Liquids)																								0
16	Lifting/Handling Installations																								0
17	SR Supporting Services																								0
18	Amenity for Workers																								0
19	Canteen																								0
20	Administrative Office																								0
21	Parking area (Trucks/Vehicles)																								0
22	Entrance/Exit																								0
23	Security Post																								0
	TOTAL	0	0	0	0	0	0	46	0	0	46	0	0	0	46	0	0	0	0	0	0	0	0	0	

Fig. 5.13 From-To Chart for Class ‘i’ Materials (Form No -136a from Muther and Hales 2015)

From To Summary

FROM-TO-CHART

Item(s) Charted: *COMBINED*

Basis of Values: *(Quantity x weight(t)/ item x em)*

Plant: *SR Yard (Air bag method)*
By: *Jayaram S*
Date: *11.12.2017*

Project: *PhD- Research*
With:
Page: ___ of ___

No.	Activity Name (FROM) / TO →	1 Ship	2 Primary Disassembling Area	3 Winch House	4 Secondary Disassembling Area	5 Shot Blasting Area	6 Tertiary Disassembling Area	7 Segregation Area (NHM)	8 Storage (Steel)	9 Storage (Machinery)	10 Storage (Miscellaneous)	11 Workshop	12 Storage (Electrical/Electronic)	13 Segregation Area (HM)	14 Storage (HW)	15 Storage (Liquids)	16 Lifting/Handling Installations	17 SR Supporting Services	18 Amenity for Workers	19 Canteen	20 Administrative Office	21 Parking area (Trucks/Vehicles)	22 Entrance/Exit	23 Security Post	TOTAL
1	Ship	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Primary Disassembling Area	-	-	-	42,500	-	-	165	-	618	464	618	123	21	46	103	-	-	-	-	-	-	-	-	44,658
3	Winch House	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Secondary Disassembling Area	-	-	-	-	1,750	21,150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22,900
5	Shot Blasting Area	-	-	-	1,750	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,750
6	Tertiary Disassembling Area	-	-	-	-	-	-	-	8,460	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8,460
7	Segregation Area (NHM)	-	-	-	-	-	-	-	-	-	165	-	-	-	-	-	-	-	-	-	-	-	-	-	165
8	Storage (Steel)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Storage (Machinery)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Storage (Miscellaneous)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Workshop	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Storage (Electrical/Electronic)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	Segregation Area (HM)	-	-	-	-	-	-	-	-	-	10	-	-	-	10	-	-	-	-	-	-	-	-	-	20
14	Storage (HW)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Storage (Liquids)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Lifting/Handling Installations	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	SR Supporting Services	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Amenity for Workers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	Canteen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	Administrative Office	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	Parking area (Trucks/Vehicles)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	Entrance/Exit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	Security Post	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TOTAL	-	-	-	44,250	1,750	21,150	165	8,460	618	639	618	123	21	56	103	-	-	-	-	-	-	-	-	

Fig. 5.14 Summarised From-To Chart for All Classes Ttogether (Form No -136a from Muther and Hales 2015)

Based on the procedure given in section 5.5.5.2, the calibration chart which has been prepared using the format given in SLP procedure for carrying out ranking of the two way flow intensities is presented in Fig. 5.15. Pairs of activity areas in terms of the activity area numbers given in Table 5.8 have been plotted on the horizontal axis and intensity values in tonnes have been plotted on the vertical axis. Based on SLP procedure, the recommended ranges for each of the ratings A, E, I, O, and U have been given in section 5.5.5.2. Accordingly, flow intensity values corresponding to ‘A’ rating has been chosen as greater than 17000 t and the flow intensity values of ‘O’ rating as less than 3000 t. Values of intensity range corresponding to ‘E’ and ‘I’ ratings have been equally divided between 3000 t and 17000 t.

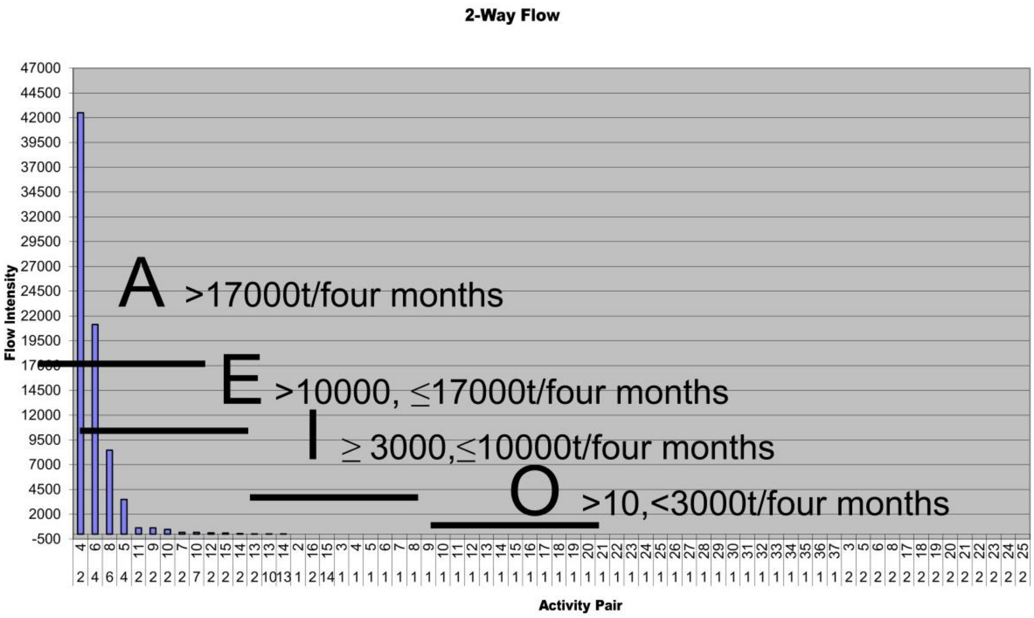


Fig. 5.15 Calibration Chart for Two-Way Flow Intensities (Format from Muther and Hales 2015)

5.6.4 Relationships based on Other-Than-Flow Considerations

Procedure given in section 5.5.6 for rating the other-than-flow relationships between activity areas has been followed to generate the Activity Relationship Chart for the case study.

5.6.4.1 Activity Relationship Chart

Ratings of closeness relationships between various activity area of a SRY based on the other-than-flow considerations are proposed in this study. The proposed closeness ratings have been arrived at based on the sequence of activities listed in GSRGP, published data on existing SRYs, and relative locations of major activity areas, such as Primary Disassembling Area, Secondary Disassembling Area, and Ship, in the model facility layouts proposed by various agencies (SBC 2003; ILO2004; IMO 2012a). The author's experience in ship repair, the visual documentation of recycling of a ship at Azheekkal, Kannur, Kerala, and the author's interactions with the working personnel in the ship breaking yard at Azheekkal also have helped to arrive at the above ratings.

As per the SLP procedure, reasons for assigning the closeness ratings between various activity area pairs are to be incorporated in the Relationship Chart. In this study, the reasons which have been considered for allocating the proposed ratings of closeness relationships of activity areas in the SRY are given in Table 5.10.

Table 5.10 Reasons for Closeness Relationships of Activity Areas in SRY

Number	Reason
1	Flow of material
2	Common space and environment
3	Safety
4	Cleanliness, Appearance
5	Accessibility
6	Shared equipment & personnel
7	Supervision
8	Utilities/Convenience
9	Contamination, Dirt, Hazard
10	Interference with operations
11	Noise, Disturbance

Activity Relationship Chart, which has been generated based on SLP, showing the proposed closeness relationships between the activity areas of the SRY in the case study is shown in Fig. 5.16.

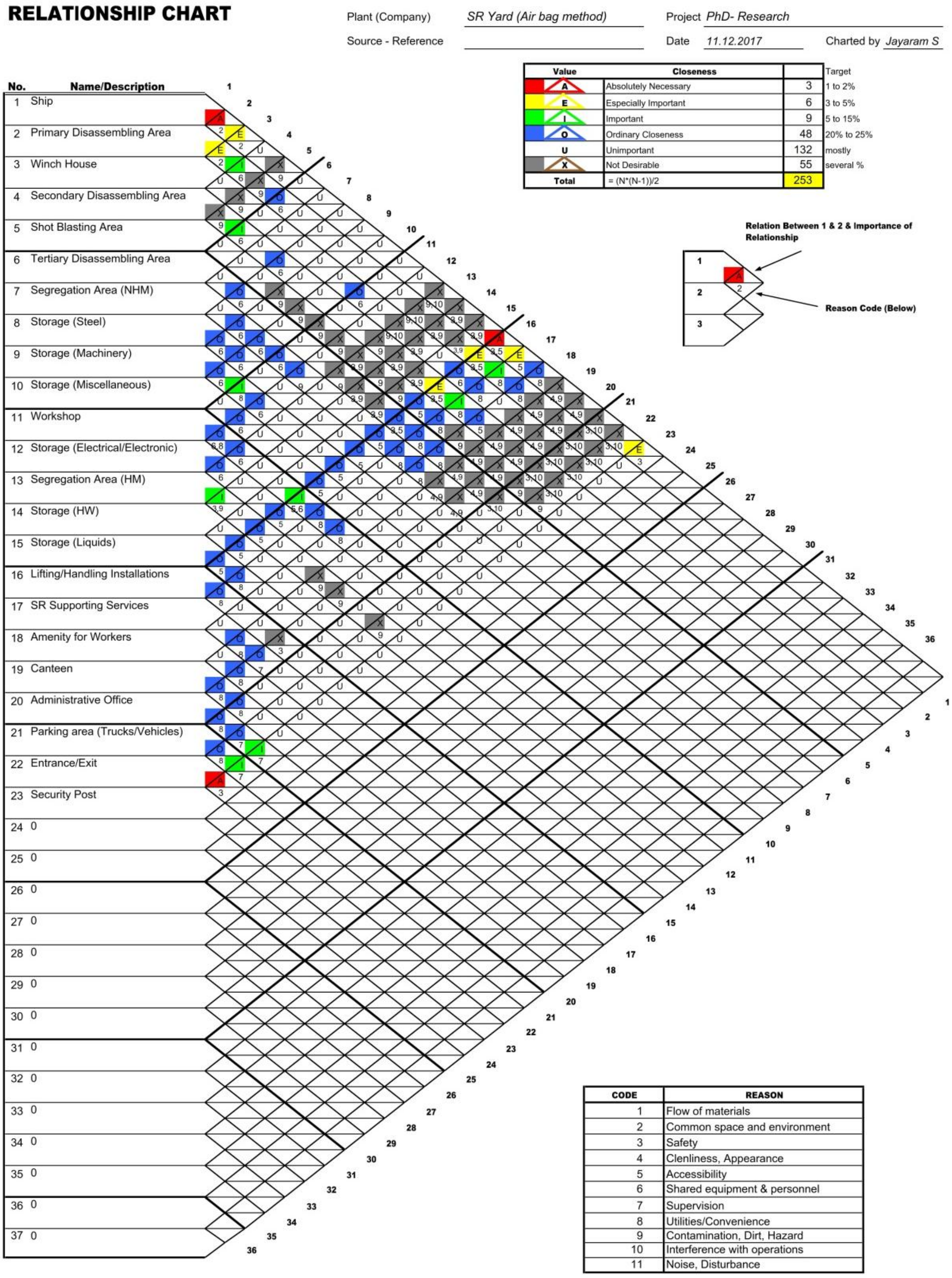


Fig. 5.16 Relationship Chart for Other-Than-Flow Relations for the SRY (Form No - 131 from Muther and Hales 2015)

5.6.5 Combined Relationship Chart

The flow and other-than-flow relations have been expressed using Vowel Letter Convention of SLP based on the procedure described in section 5.5.7. A worksheet in the format given in SLP procedure has been used to convert the flow and other-than-flow relations into corresponding numerical values and then to combine these values to obtain the combined relationship ratings. Part of the above worksheet which has been prepared for the case study is presented in Fig. 5.17.

COMBINING FLOW & SERVICE RELATIONSHIPS

Ratio of Flow to Other-Than-Flow:		
2	to	1

Plant (Company) *SR Yard (Air bag method)* Project *PhD- Research*
Flow Source / Reference
Other-Than-Flow Source
Date *11.12.2017*
By *Jayaram S*
Sheet   of

	Line #	Activity-Pair		FLOW-OF-MATERIAL INTENSITY From-To	To-From	2-Way	Vowel Rating	Value	Wt.	OTHER-THAN-FLOW RELATIONSHIPS Vowel Rating	Reasons	Value	Wt.	RESULTANT COMBINED RELATIONSHIPS Combined Value	Combined Rating	Final Assigned Rating	Comments
1-2		1	2	0.0	0.0	0.0	U	0	2	A	2	4	1	4	A	A	
1-16		1	16	0.0	0.0	0.0	U	0	2	A	3,5	4	1	4	A	A	
2-4		2	4	42500.0	0.0	42500.0	A	4	2	I	6	2	1	10	A	A	
4-6		4	6	21150.0	0.0	21150.0	A	4	2	I	6	2	1	10	A	A	
6-8		6	8	8460.0	0.0	8460.0	I	2	2	O	6	1	1	5	A	A	
13-14		13	14	10.0	0.0	10.0	O	1	2	I	3,9	2	1	4	A	A	
22-23		22	23	0.0	0.0	0.0	U	0	2	A	3	4	1	4	A	A	
1-3		1	3	0.0	0.0	0.0	U	0	2	E	2	3	1	3	E	E	
1-17		1	17	0.0	0.0	0.0	U	0	2	E	5	3	1	3	E	E	
1-23		1	23	0.0	0.0	0.0	U	0	2	E	3	3	1	3	E	E	
2-3		2	3	0.0	0.0	0.0	U	0	2	E	2	3	1	3	E	E	
2-16		2	16	0.0	0.0	0.0	U	0	2	E	3,5	3	1	3	E	E	
4-16		4	16	0.0	0.0	0.0	U	0	2	E	3,5	3	1	3	E	E	
7-10		7	10	165.0	0.0	165.0	O	1	2	O	6	1	1	3	E	E	
2-7		2	7	165.0	0.0	165.0	O	1	2	U		0	1	2	I	I	
2-9		2	9	618.0	0.0	618.0	O	1	2	U		0	1	2	I	I	
2-10		2	10	464.0	0.0	464.0	O	1	2	U		0	1	2	I	I	
2-11		2	11	618.0	0.0	618.0	O	1	2	U		0	1	2	I	I	
2-12		2	12	123.0	0.0	123.0	O	1	2	U		0	1	2	I	I	
2-17		2	17	0.0	0.0	0.0	U	0	2	I	8	2	1	2	I	I	
4-17		4	17	0.0	0.0	0.0	U	0	2	I	8	2	1	2	I	I	
9-11		9	11	0.0	0.0	0.0	U	0	2	I	8	2	1	2	I	I	
10-13		10	13	0.0	10.0	10.0	O	1	2	U		0	1	2	I	I	
11-16		11	16	0.0	0.0	0.0	U	0	2	I	5,6	2	1	2	I	I	
20-23		20	23	0.0	0.0	0.0	U	0	2	I	7	2	1	2	I	I	
21-23		21	23	0.0	0.0	0.0	U	0	2	I	7	2	1	2	I	I	
1-18		1	18	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
2-6		2	6	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
2-18		2	18	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
3-11		3	11	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
3-16		3	16	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
3-17		3	17	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
4-8		4	8	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
4-18		4	18	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
5-16		5	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
5-17		5	17	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
6-16		6	16	0.0	0.0	0.0	U	0	2	O	3,5	1	1	1	O	O	
6-17		6	17	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
6-18		6	18	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
7-9		7	9	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
7-11		7	11	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
7-12		7	12	0.0	0.0	0.0	U	0	2	O	9	1	1	1	O	O	
7-16		7	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
7-17		7	17	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
7-18		7	18	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
8-9		8	9	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
8-10		8	10	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
8-16		8	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
9-10		9	10	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
9-12		9	12	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
9-16		9	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
10-12		10	12	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
10-16		10	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	
11-12		11	12	0.0	0.0	0.0	U	0	2	O	6,8	1	1	1	O	O	
11-13		11	13	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
11-17		11	17	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
11-18		11	18	0.0	0.0	0.0	U	0	2	O	8	1	1	1	O	O	
12-13		12	13	0.0	0.0	0.0	U	0	2	O	6	1	1	1	O	O	
12-16		12	16	0.0	0.0	0.0	U	0	2	O	5	1	1	1	O	O	

Fig. 5.17 Worksheet for Combining Flow and Other-Than-Flow Relationships for the SRY (Form No -142 from Muther and Hales 2015)

The calibration chart which has been prepared using the format given in SLP procedure for carrying out ranking of the combined relationships is presented in Fig. 5.18.

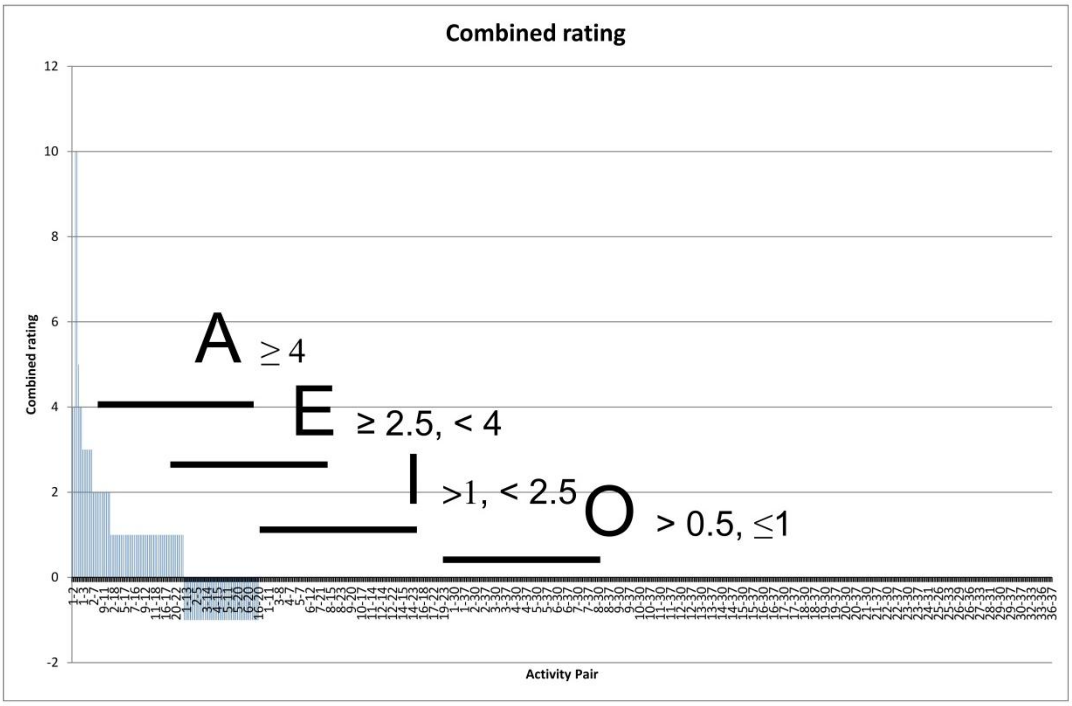


Fig. 5.18 Calibration Chart for Combined Relationships (Format from Muther and Hales 2015)

Combined Relationship Chart, which has been obtained by incorporating the combined relationship ratings from the above worksheet in Fig. 5.17, is presented in Fig. 5.19.

5.6.6 Activity Relationship Diagram

Activity Relationship Diagram has been arrived at following the procedure described in section 5.5.8. Fig. 5.20 shows the Activity Relationship Diagram which has been developed in the case study for the proposed SRY. Lines corresponding to O and X relationships have been eliminated from the Fig. 5.20 for clarity.

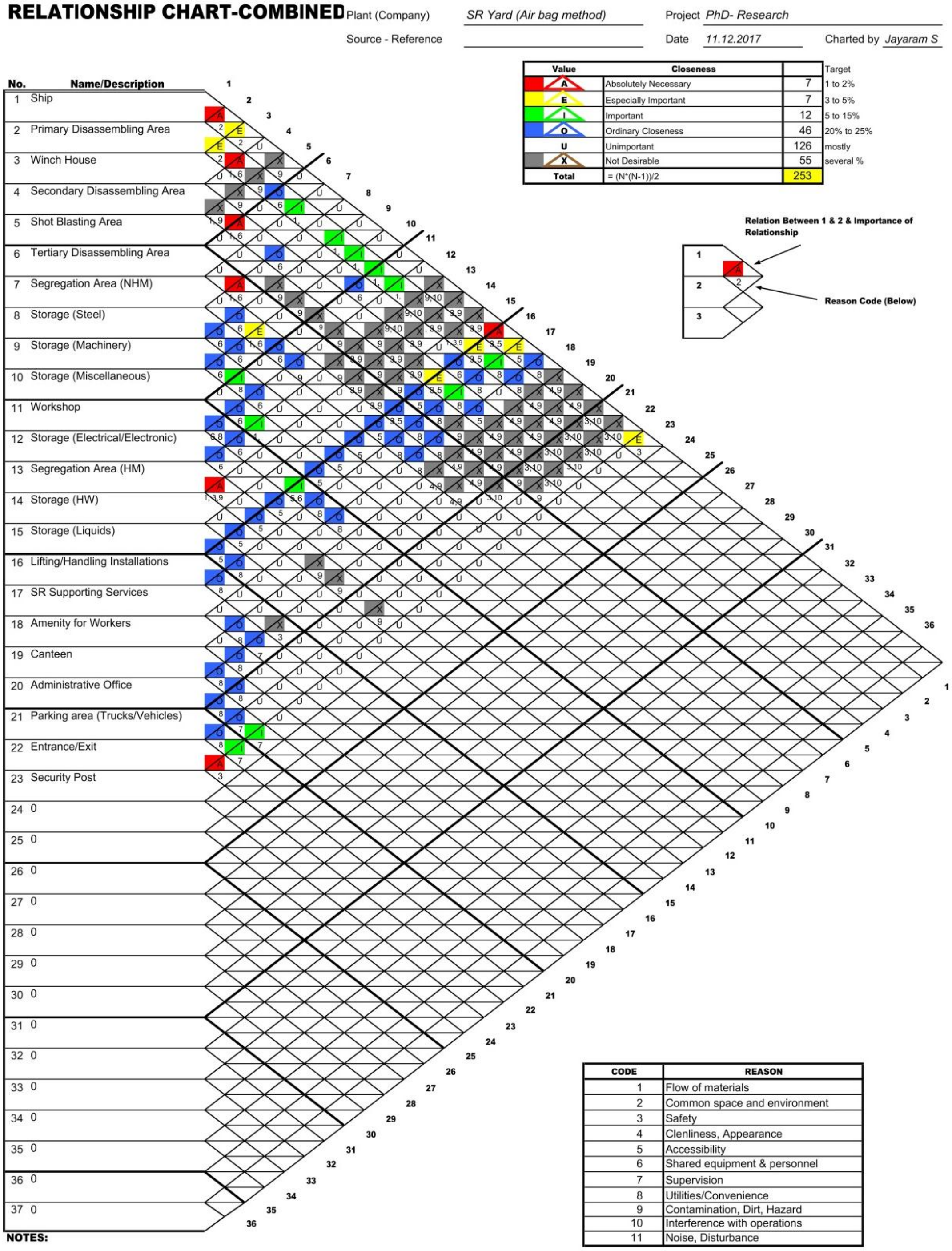


Fig. 5.19 Combined Relatonship Chart for the SRY (Form No -131 from Muther and Hales 2015)

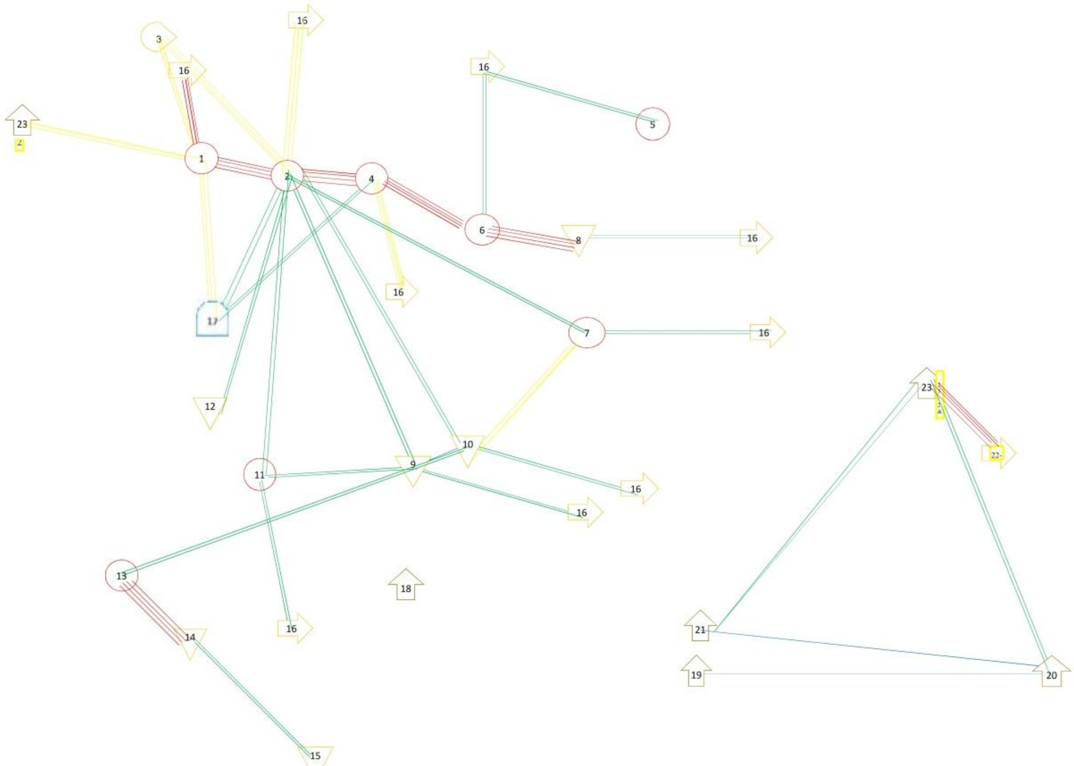


Fig. 5.20 Activity Relationship Diagram for the SRY

5.6.7 Space Determination

Estimation of the space requirements for various activity areas has been carried out in this thesis and it has been described in the sections 5.6.7.1 to 5.6.7.22

5.6.7.1 Primary Disassembling Area

Area of Primary Disassembling Area shall be sufficient to accommodate the largest obsolete ship planned by the SRY. There shall be sufficient space around the Ship both for lowering of the primary disassemblies and for the movement of man and machine.

From section 5.6.1.6, the largest obsolete ship that has been planned for the SRY in the case study has LOA of 190 m and breadth of 30 m. Space of width of 5 m each has been allocated on port and starboard sides of the ship for clearance between the Ship and the onboard components which would be kept beside the ship after their removal from the ship. Space of 15 m width has been allocated on both sides of the ship, further outside the above 5 m wide area, for keeping primary disassemblies which are similar to block assemblies in shipbuilding. 10 m wide passage has been allocated outside the above 15 m wide space for access by forklifts, cranes, and working personnel. 10 m wide clearance has been proposed at the forward and aft ends as access route for material handling systems. The proposed arrangement of Primary Disassembling Area with the above clearances has been presented in Fig. 5.21. Boundary of Primary Disassembling Area has been shown in blue lines in the Fig. 5.21.

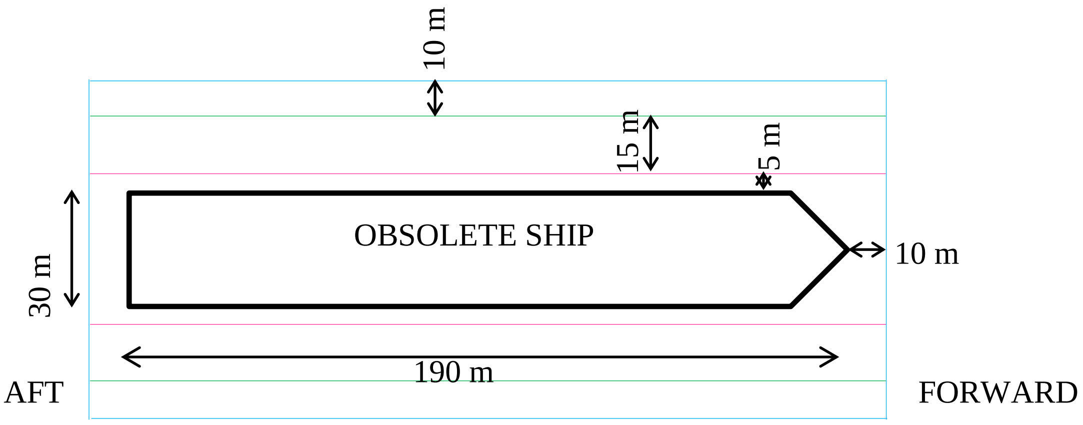


Fig. 5.21 Dimensions and Access of Primary Disassembling Area

From Fig. 5.21, length and width of Primary Disassembling Area have been calculated as 210 m and 90 m respectively.

5.6.7.2 Winch House

It has been assumed that the ship will be docked in the direction perpendicular to the coastline. Assuming that three winches will be utilised to assist docking of ships as mentioned in section 5.6.1.1, a space having size 60 m x 40 m has been allocated for the area to be covered by all the three winches together with the space between them. Out of this size, 40 m shall be along the landward direction (i.e. fore-aft direction of the ship) and 60 m shall be in the athwartship direction of the ship. Handling equipment like forklifts and cranes shall also be held in this area when these are not in use, similar to the arrangement in a SRY that is attempting air bag method of docking for ship recycling purpose (MECON Limited 2013).

5.6.7.3 Secondary Disassembling Area

Size of each of the primary disassemblies which will be dismantled in the Secondary Disassembling Area has been considered to be 10 m length x 15 m width (= half breadth of ship) x 16 m depth. Therefore, the maximum size of area that is going to be occupied by each disassembly will be 15 m x 16 m. Proposed arrangement of positioning the primary disassemblies in the Secondary Disassembling Area has been indicated in Fig. 5.22. Considering 4 primary disassemblies being handled at a time, size of the area required for Secondary Disassembling Area has been calculated from the Fig. 5.22 as 43 m x 45 m. Requirement on accessibility to the Secondary Disassembling Area from its sides shall be considered as part of the modifying considerations while generating the layout alternatives and it is presented in section 5.6.9. Boundary of Secondary Disassembling Area has been shown in blue lines in the Fig. 5.22.

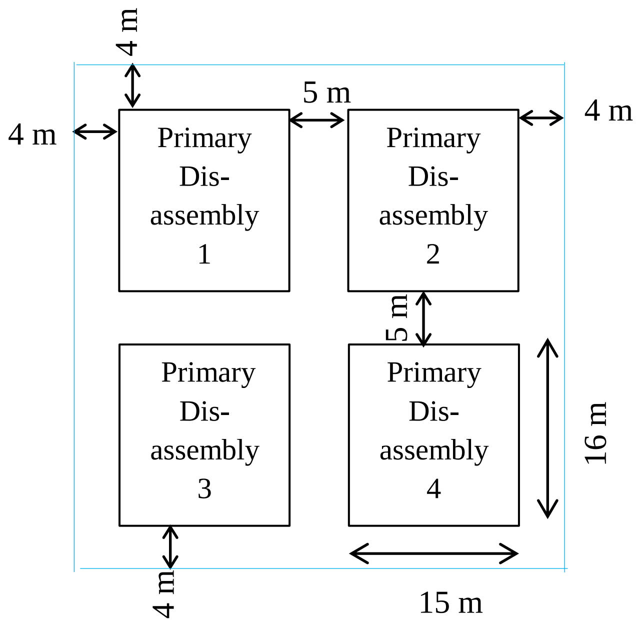


Fig. 5.22 Dimensions and Access of Secondary Disassembling Area

5.6.7.4 Shot Blasting Area

A cell of size 20 m x 20 m has been assumed for the blasting of disassemblies. Size of each disassembly has been assumed to be about half of that of a primary disassembly. From section 5.6.7.3, size of a primary disassembly is 10 m x 15 m x 16 m. Therefore, with half of the size of a primary disassembly, it would be possible to accommodate one disassembly in a 20 m x 20 m area for carrying out its shot blasting. This area value has been assumed based on the area of blasting space followed in a shipbuilding yard which undertakes building of 100 m ships. This type of shipbuilding yards use 2 numbers of 20 m x 20 m cells for shot blasting (Chabane 2004).

5.6.7.5 Tertiary Disassembling Area

It has been assumed that subdisassemblies of size 4 m x 3.5 m will be transported from Secondary Disassembling Area to Tertiary Disassembling Area. The above size has been selected based on the assumption that the size of subdisassemblies would be about one-fourth of that of a primary disassembly. Proposed arrangement of positioning the subdisassemblies in the Tertiary Disassembling Area has been indicated in Fig. 5.23.

Considering 10 subdisassemblies being handled at a time, size of the area required for Tertiary Disassembling Area has been calculated from the Fig. 5.23 as 29.5 m x 16 m. Requirement on accessibility to the Tertiary Disassembling Area from its sides shall be considered as part of the modifying considerations while generating the layout alternatives, as mentioned in section 5.6.9.

5.6.7.6 Segregation Area (NHM)

Area which will be used for the segregation of nonhazardous materials has been assumed as 10 m x 10 m.

5.6.7.7 Storage (Steel)

Size of area for storage of steel materials has been taken as 50 m x 30 m. This area value has been determined by scaling the corresponding area of storage of steel in SRYs which were planned for handling similar size of ships (MECON Limited 2013; Sunaryo and Pahalatua 2015). The above scaling has been done with respect to LDT of the largest ship that can be recycled in the SRYs. 20% area has been included in the above area as buffer storage to cater for additional storage of steel during situations like strikes by material handling operators.

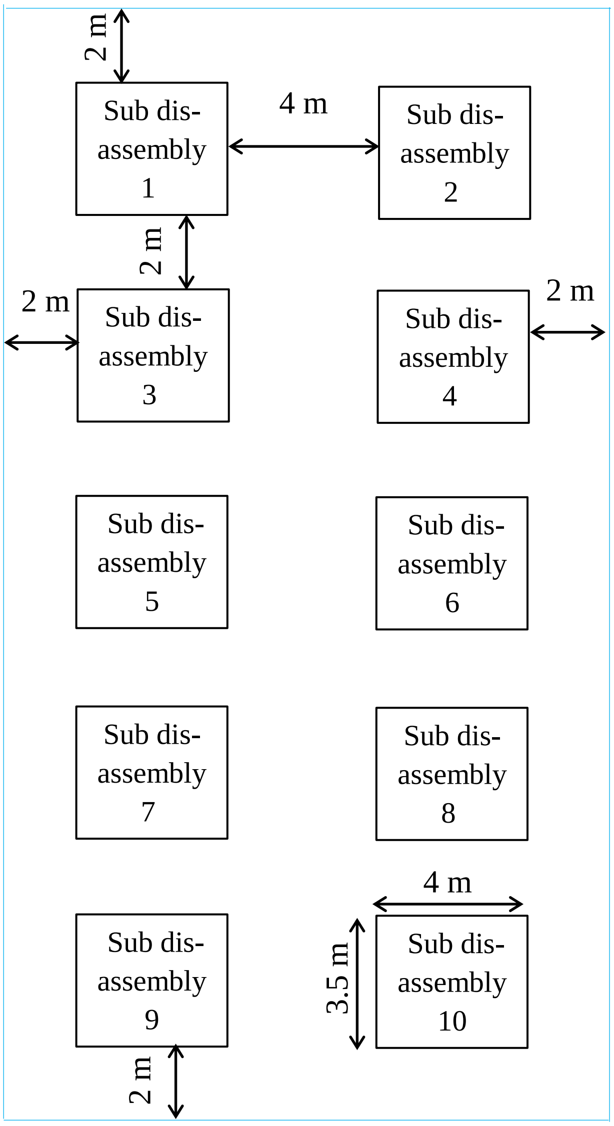


Fig. 5.23 Dimensions and Access of Tertiary Disassembling Area

5.6.7.8 Storage (Machinery)

Area of Storage (Machinery) has been estimated as 1600 sq. m. This area value has been determined with reference to the machinery storage area values of other SRYs, which have been available from the published literature (Litehauz 2013;

MECON Limited 2013; Sunaryo and Pahalatua 2015). The above mentioned area values of the SRYs from the published literature have been scaled with respect to the LDT of ships recycled in their SRYs in order to obtain the corresponding values for the case study.

5.6.7.9 Storage (Miscellaneous)

Area for miscellaneous storage shall include storage areas for nonferrous metals, outfit scrap items, nonhazardous items belonging to Class 'i' materials, and other miscellaneous items such as furniture and accommodation fittings.

Approximate area for miscellaneous storage has been estimated as 1000 sq. m. This area value has been obtained by scaling the corresponding storage area values of a SRY, which has been planned to handle similar size of ships (MECON Limited 2013), with respect to the LDT of obsolete ships. This area of 1000 sq. m also includes 20% buffer area.

5.6.7.10 Workshop

Area of workshop has been assumed as 400 sq. m.

5.6.7.11 Storage (Electrical/Electronic)

Area of Storage (Electrical/Electronic) has been estimated as 450 sq. m. This area has been determined by scaling the electrical items storage area of other SRYs, from the published literature, with respect to the LDT of largest ship that can be recycled in these SRYs (MECON Limited 2013; Sunaryo and Pahalatua 2015).

5.6.7.12 Segregation Area (HM)

Considering the fact that the hazardous content of obsolete ships cannot be accurately predicted in the present scenario, area of Segregation Area (HM) has been assumed to be same as that of a SRY which has planned to handle similar kind of ships (MECON Limited 2013). Accordingly, the area for hazardous material segregation has been taken as 225 sq. m.

5.6.7.13 Storage (HW)

The area of hazardous waste storage has been selected as 400 sq. m. by comparing with the corresponding areas of other SRYs from the published literature (Litehauz 2013). The area from the published literature has been scaled with respect to LDT of ships recycled in these SRYs.

5.6.7.14 Storage (Liquids)

The area of space for liquid storage has been selected as 500 sq. m. based on the comparison with the information available from the published literature (Litehauz 2013) on SRYs having similar capacity.

5.6.7.15 Lifting/ Handling Installations

Area required for marshalling of lifting and handling installations has been included under area of Winch House in section 5.6.7.2. Additional area for this purpose has been allocated in the parking area and it has been specified under section 5.6.7.20.

5.6.7.16 SR Supporting Services

This activity area comprises Safety Department, Training Centre, Medical Unit, and other SR Supporting Services such as storage space for cutting gases and cutting equipment. Areas of Safety Department, Training Centre, and Medical Unit have been estimated using the standards available from literature on shipbuilding yards (Chabane 2004). Requirement of area for other items listed above have been assumed based on published data on SRYs which handle ships of similar size (Litehauz 2013; MECON Limited 2013). Total area requirement that has been estimated for SR Supporting Services is 2500 sq. m.

5.6.7.17 Amenity for Workers

The space for sanitation and change rooms has been assumed as 200 sq. m. It has been selected based on the area of sanitation and change rooms in SRYs of similar recycling capacity (Litehauz 2013; MECON Limited 2013).

5.6.7.18 Canteen

Area for Canteen has been selected as 400 sq. m. (Chabane 2004).

5.6.7.19 Administrative Office

The area for Administrative Office has been selected based on the standard, for administrative office area in shipbuilding yard, of 15 sq. m per person (Chabane 2004). Number of personnel who will be using the Administrative Office has been taken as 20 which include Sales department staff and recycling managers in addition to the other administrative staff (Litehauz 2013). Therefore, the required area of Administrative Office has been calculated as 300 sq. m.

5.6.7.20 Parking Area

The parking area has been taken as 1600 sq. m. The area has been estimated based on the space requirement of 50 cars, 2 dumper trucks, 1 forklift, and 3 mobile cranes.

5.6.7.21 Entrance/ Exit

Area for entrance and exit has been assumed as 25 sq. m.

5.6.7.22 Security Post

Two security posts have been considered for the layout design of the SRY. The security post near entrance gate has been allocated an area of 10 sq. m. A weighbridge having an area of 50 sq. m. shall be attached to this security post. The other security post shall be located near the ship on the seaside and it has been allocated an area of 10 sq. m.

5.6.8 Space Relationship Diagram

Fig. 5.24 shows the Space Relationship Diagram, which has been developed in this study for the proposed SRY, based on the procedure described in section 5.5.9.

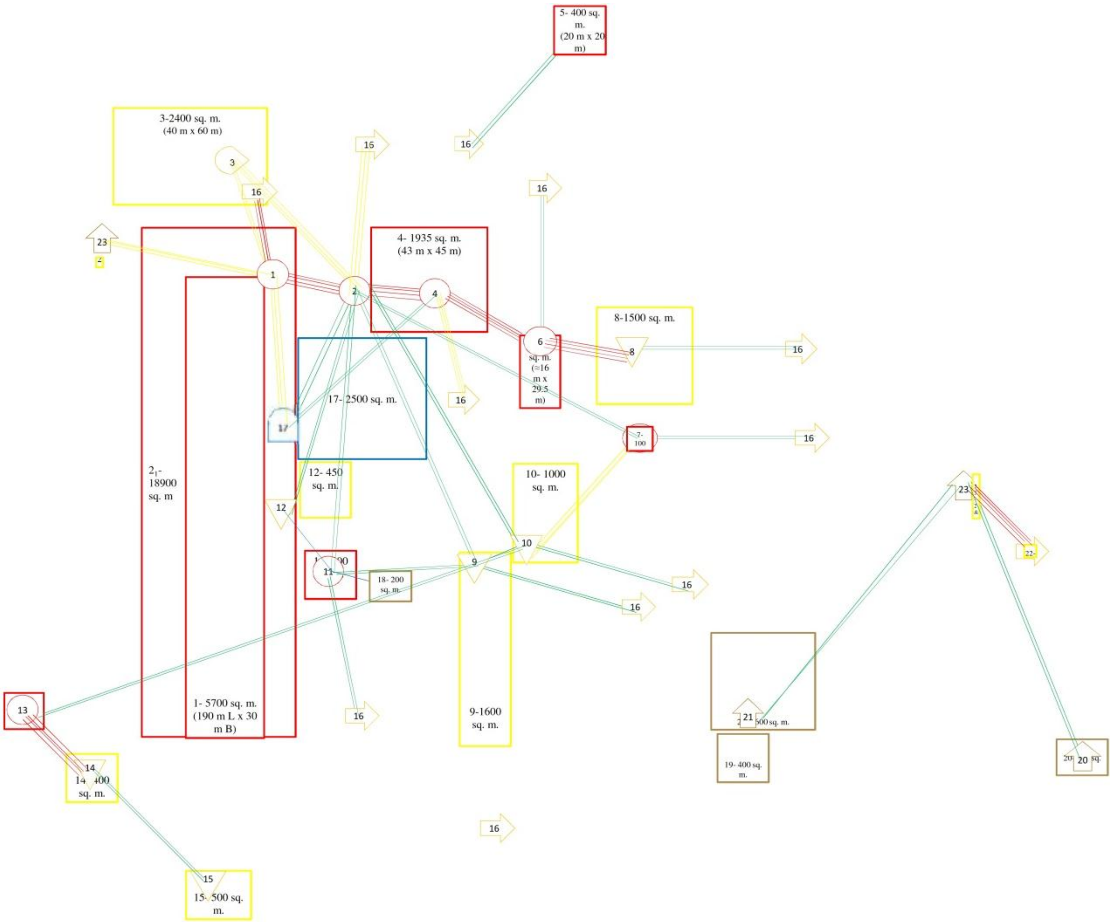


Fig. 5.24 Space Relationship Diagram

5.6.9 Modifications and Limitations

As per the SLP procedure, a number of modifying considerations and limitations are to be applied on the Space Relationship Diagram for generating layout alternatives. In this study, development of only two alternatives viz., Layout-A and Layout-B has been done. The alternatives have been limited to two since the case study has been carried out only for the purpose of demonstrating the proposed methodology of concept layout design of SRYs. The proposed methodology shall be extended to generate maximum number of practical layout alternatives by applying relevant modifying considerations.

The following modifying considerations have been applied for developing the first layout alternative, viz., Layout-A from the Space Relationship Diagram:

i. The plot of SRY is of rectangular shape and there is sea interface only on one side, as mentioned in section 5.6.1.5.

ii. External road and coastline are parallel and these are located on the opposite sides of the plot of SRY.

iii. Fore-aft direction of the Ship is perpendicular to the coastline, as mentioned in section 5.6.7.2.

iv. Activity areas related to steel material are to be placed on one side of the Ship. Storage Areas, Segregation Areas, and Workshop are to be located on the other side of the Ship.

v. Ship is to be positioned in such a way that it is fully within the Primary Disassembling Area.

vi. Winch House is to be positioned on the forward side of the Ship. Primary Disassembling Area and Winch House are to be placed together like a combined space with no passage in between. Internal Roads are to be provided around the above combined space.

vii. Minimum width of internal roads is to be 10 m.

viii. Entrance to the SRY is to be aligned with one of the internal roads which is beside the Primary Disassembling Area.

ix. Internal Roads are to be provided all around each of the activity areas, viz., SR Supporting Services, Secondary Disassembling Area, and Tertiary Disassembling Area, for facilitating access by material handling systems through all four sides.

x. All activity areas are to be of rectangular shape.

5.6.10 Layout Alternatives

Layout-A has been developed from the Space Relationship Diagram after applying the modifications specified in section 5.6.9 and it has been presented in Fig. 5.25. The activity areas have been indicated in the Fig. 5.25 using the activity area numbers given in Table 5.8 and using their symbols given in Fig. 5.4.

The second layout alternative, viz., Layout-B, has been presented Fig. 5.26. It has been generated by interchanging the locations of Storage (Machinery) and Storage (Electrical/Electronic) shown in Layout-A.

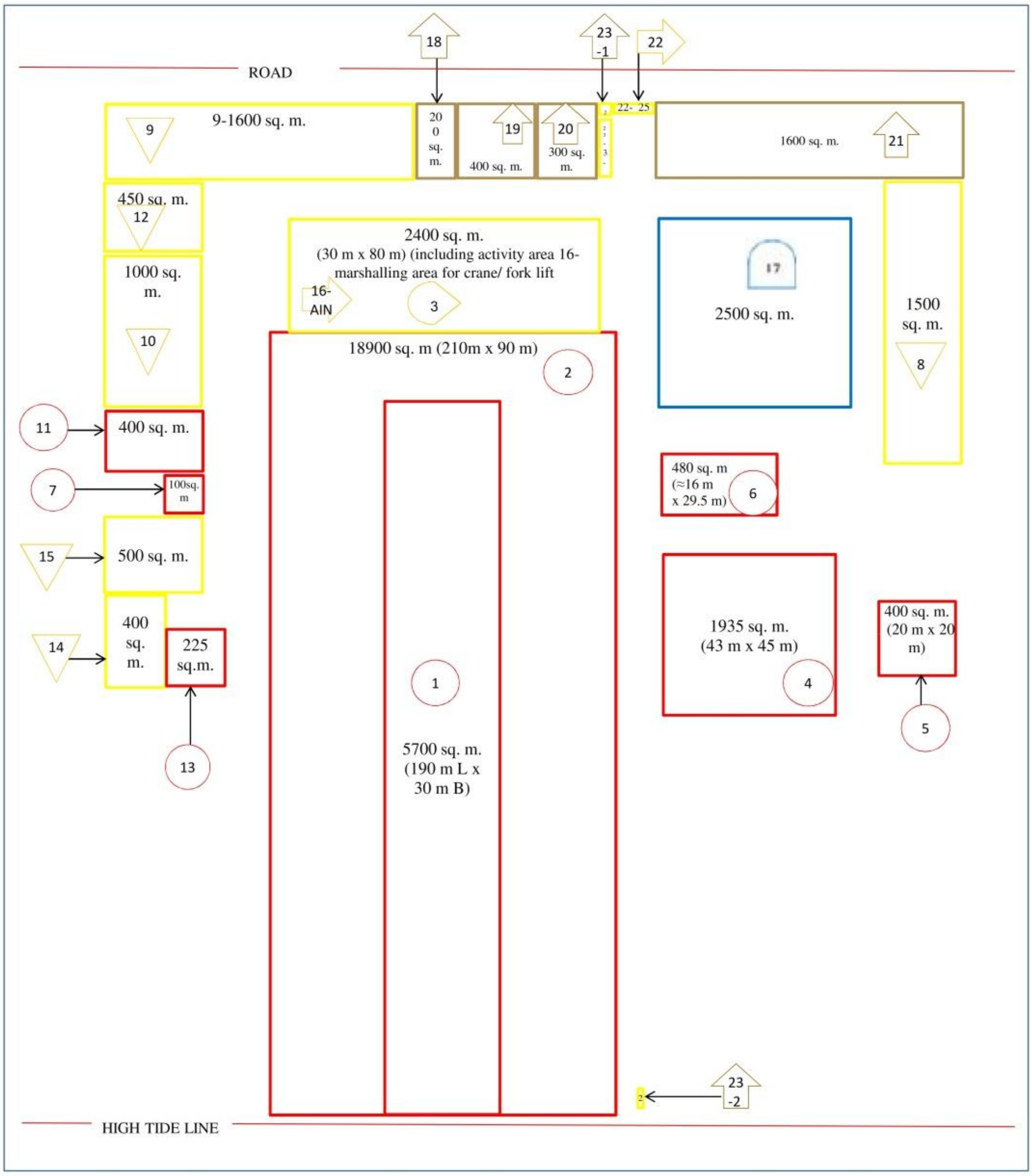


Fig. 5.25 Layout-A

5.6.11 Evaluation of Layouts and Selection of Optimal Layout

The two layout alternatives, viz. Layout-A and Layout-B, have been evaluated using two methods viz., weighted factor analysis and transport work comparison.

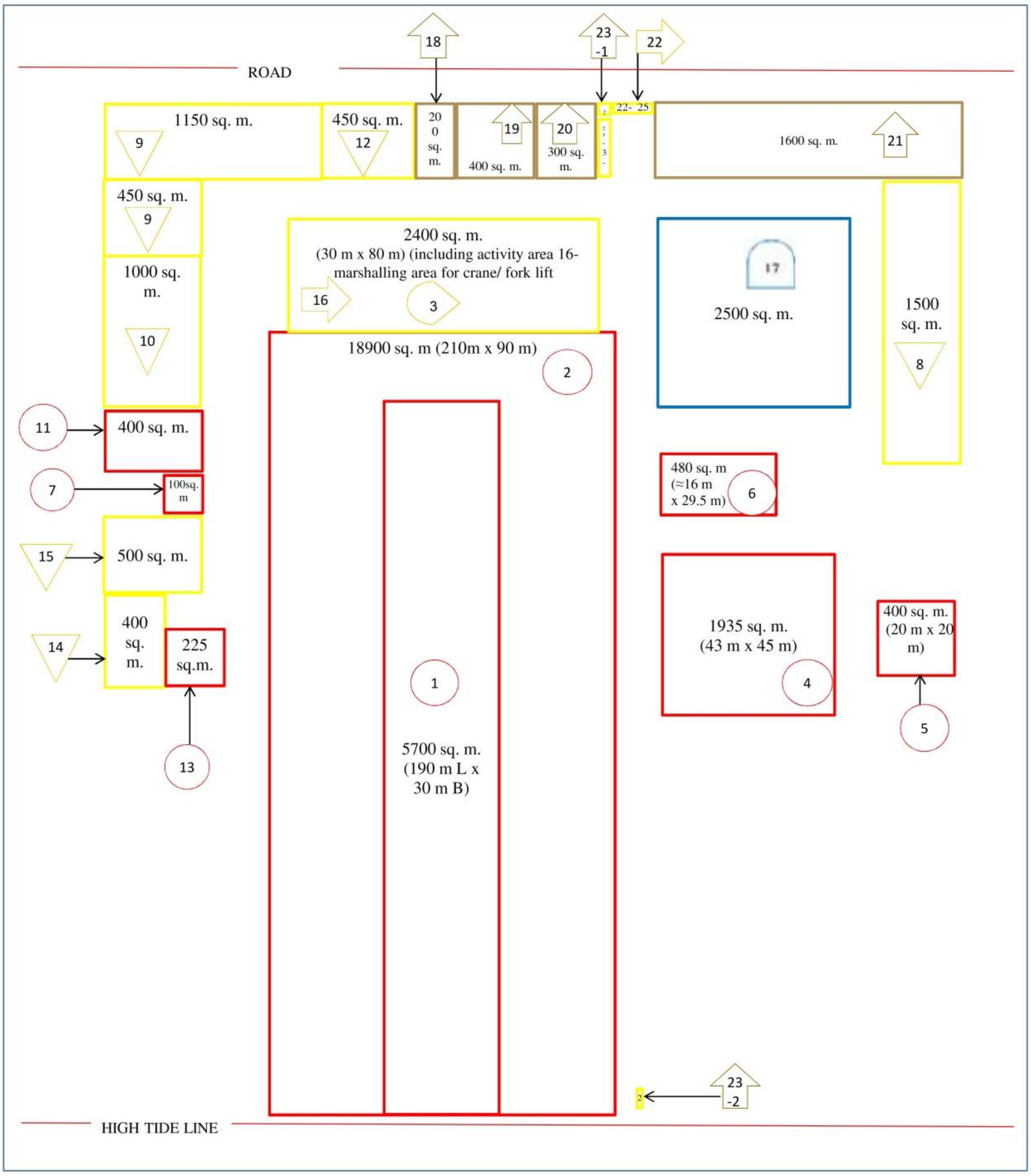


Fig. 5.26 Layout-B

5.6.11.1 Weighted Factor Analysis

Weighted factor analysis has been carried out, based on the procedure described in 5.5.11.1, for the two layout alternatives. The factors and their weights have been taken from Table 5.6 for carrying out this analysis. Based on the SLP method, Vowel Letter Convention has been used for rating the layout alternatives with respect to the above factors. Description of the Vowel Letters has been given in Fig. 5.27. Numerical values for the Vowel ratings have been taken from Table 5.5. Difference between the arrangements of Layout-A and Layout-B is on the relative locations of two activity areas, viz., Storage (Machinery) and Storage (Electrical/Electronic). Accordingly different ratings have been given for the two layout alternatives with respect to the ‘storage effectiveness’ factor.

Results from the evaluation of alternatives using weighted factor analysis are given in Fig. 5.27.

EVALUATING ALTERNATIVES

Plant *SR Yard (Air bag method)*
Project *PhD- Research* Date *11.12.2017*

Weights set by ________ Tally by ________
Ratings by ________ Approved by ________

EVALUATING DESCRIPTION			
A	Almost Perfect	O	Ordinary Results
E	Especially Good	U	Unimportant Results
I	Important Results	X	Not Acceptable

Description of Alternatives:
Enter a brief phrase identifying each alternative.
A. *Layout-A*
B. *Layout-B*
C.
D.
E.

FACTOR / CONSIDERATION	WT.	RATINGS AND WEIGHTED RATINGS A	B			
1 *Flow or movement effectiveness*	10	E 30	E 30			
2 *Adaptability and versatility*	10	I 20	I 20			
3 *Safety and housekeeping*	10	I 20	I 20			
4 *Materials handling effectiveness*	9	I 18	I 18			
5 *Space utilisation*	9	I 18	I 18			
6 *Storage effectiveness*	8	I 16	O 8			
7 *Effectiveness of supporting service integration*	7	I 14	I 14			
8 *Ease of supervision and control*	7	I 14	I 14			
9 *Equipment utilisation*	7	I 14	I 14			
10 *Ease of future expansion*	5	I 10	I 10			
11 *Maintenance problems*	3	I 6	I 6			
12 *Utilisation of natural conditions, building or surroundings*	2	I 4	I 4			
13 *Working conditions and employee satisfaction*	1	I 2	I 2			
Totals		186	178			

Reference Notes:
a. ________ d. ________
b. ________ e. ________
c. ________ f. ________

Fig. 5.27 Evaluation of Layout Alternatives Using Weighted Factor Analysis (Form No -173 from Muther and Hales 2015)

It can be seen from the weighted factor analysis that the Layout-A is better than the Layout-B, in terms of intangible costs.

5.6.11.2 Transport Work Comparison

Transport work calculations for Layout-A and Layout-B have been carried out based on the procedure described in section 5.5.11.2. Results of the transport work calculations for Layout-A and Layout-B are presented in Fig. 5.28 and Fig. 5.29 respectively.

TRANSPORT WORK CALCULATION									*Layout-A*
Line #	Activity-Pair		FLOW-OF-MATERIAL INTENSITY (t)			Distance in meters. Centre to centre straightline	Transport work: Two way flow intensity x distance (t.m)	Remarks
			From-To	To-From	2-Way			
2-4	2	4	42500	0	42500	83	3527500	
4-6	4	6	21150	0	21150	42	888300	
6-8	6	8	8460	0	8460	69	583740	
4-5	4	5	1750	1750	3500	45	157500	
2-11	2	11	618	0	618	109	67362	
2-9	2	9	618	0	618	162	100116	
2-10	2	10	464	0	464	132	61248	
2-7	2	7	165	0	165	95	15675	
7-10	7	10	165	0	165	43	7095	
2-12	2	12	123	0	123	156	19188	
2-15	2	15	103	0	103	92	9476	
2-14	2	14	46	0	46	86	3956	
2-13	2	13	21	0	21	69	1449	
10-13	10	13	0	10	10	85	850	
13-14	13	14	10	0	10	17	170	
						Total Transport Work	5443625.00	

Fig. 5.28 Transport Work Calculation for Layout-A (Format from Muther and Hales 2015)

TRANSPORT WORK CALCULATION								*Layout-B*
Line #	Activity-Pair		FLOW-OF-MATERIAL INTENSITY (t)			Distance in meters. Centre to centre straightline	Transport work: Two way flow intensity x distance (t.m)	Remarks
			From-To	To-From	2-Way			
2-4	2	4	42500	0	42500	83	3527500	
4-6	4	6	21150	0	21150	42	888300	
6-8	6	8	8460	0	8460	69	583740	
4-5	4	5	1750	1750	3500	45	157500	
2-11	2	11	618	0	618	109	67362	
2-9	2	9	618	0	618	166	102588	
2-10	2	10	464	0	464	132	61248	
2-7	2	7	165	0	165	95	15675	
7-10	7	10	165	0	165	43	7095	
2-12	2	12	123	0	123	156	19188	
2-15	2	15	103	0	103	92	9476	
2-14	2	14	46	0	46	86	3956	
2-13	2	13	21	0	21	69	1449	
10-13	10	13	0	10	10	85	850	
13-14	13	14	10	0	10	17	170	
						Total Transport Work	5446097.00	

Fig. 5.29 Transport Work Calculation for Layout-B (Format from Muther and Hales 2015)

It can be seen from the transport work comparison that the transport work, and thereby the operational costs corresponding to Layout-A is less than that of Layout-B.

Based on the evaluation of the two layout alternatives for the case study, which has been presented in sections 5.6.11.1 and 5.6.11.2, it can be concluded that the Layout-A is a better alternative than the Layout-B.

From the above analysis it is clear that the weighted factor analysis and the transport work comparison, which have been described in sections 5.6.11.1 and 5.6.11.2 respectively, can be used to compare any two layout alternatives of SRYs. Therefore, it can be concluded that these methods of evaluation can also be used to compare the prevailing layout of an existing SRY with its alternative layout proposals based on feasible modifying considerations, provided reliable values of intensities of material flow between various activity areas are available. This will enable identification of the possible areas of improvement in the prevailing layout of the existing SRY.

5.7 LIMITATIONS OF THE PROPOSED METHODOLOGY

The main limitations of this methodology lie in the assumptions made regarding the recycling capacity, material flow intensities of various classes of materials, and the space area requirements. These limitations are caused partly due to the inaccessibility of some of the data regarding the SRYs in the South Asian countries. However, in this study the emphasis has been on the development of a methodology for the layout design of SRYs based on the SLP procedure. The SLP procedure has revealed to be an efficient and suitable method of concept layout planning for the initial design stage of new projects in which only a broad definition of quantitative data is possible. The reliability of the reference data used in the methodology can be further improved as a future work when more data on the efficient SRYs become available. By establishing a World Fleet Database, as proposed in section 3.2.2.1, accurate information on material content of ships can be obtained through feedback from the ship recycling industry. This information will enable a better estimation of layout design parameters such as material flow intensity.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

This thesis addresses various issues related to ship recycling such as the need to identify roles and responsibilities of stakeholders in various phases of ship recycling, the need for systematic plans showing detailed subdivision of recycling processes for carrying out recycling of ships efficiently, the lack of utilisation of product models of ships for the recycling stage, and the absence of well planned layouts of ship recycling yards. The essential inputs for this research studies have been the indepth literature survey and documentation in the form of videos and photos of physical dismantling of a general cargo ship at the ship recycling yard (SRY) of Steel Industrials Kerala Limited (SILK), located in Azheekal, Kannur of Kerala.

Captured documentation has suggested that there has been lack of utilisation of systematic plans indicating various ship recycling processes in a detailed manner. System sequence of the processes in carrying out recycling of ships are found missing. The absence of utilisation of product models of ships for the recycling stage has been noticed. Layouts of most of the existing ship recycling facilities in the major ship recycling countries are found to be developed without a well planned layout design. A definite need was felt in three major areas in ship recycling, to **generate systematic guidance plans for carrying out recycling of ships**, to propose **guidelines for extending utilisation of product models of ship to recycling stage of ships**, and to develop a **methodology for concept layout design of SRYs**.

Three strategies have been developed on ship recycling in this study in order to address the above issues. The **first strategy** is **development of a concept plan** named **Ship Recycling Guidance Plan** (SRGP) for facilitating recycling of ships in an efficient and sustainable manner, which offer a general framework consisting of two parts viz., **Strategic Ship Recycling Guidance Plan** (SSRGP) and **General Ship Recycling Guidance Plan** (GSRGP). SSRGP indicates roles and responsibilities of global stakeholders in ship recycling and the interaction between the stakeholders in the global ship recycling industrial sector. GSRGP has been developed to address the operational level in ship recycling. Detailed steps to be followed in the recycling of an obsolete ship have been developed and presented in the thesis. GSRGP is represented in the form of flow charts. In GSRGP, a disassembly concept has been proposed for progressive dismantling of ship structure at three levels of disassembly of obsolete ships. Beaching method, which is the most common in a global perspective, has been adopted for the development of both SSRGP and GSRGP. SRGP has been developed and presented as a reference document for generating a recycling guidance plan for every ship to be recycled in a SRY.

The **second strategy** involves **development of guidelines** called '**Product Modelling for Ship Recycling**' (PMSR) guidelines for extending '*modelling for*' concept in ship recycling engineering. PMSR guidelines are proposed to **enrich product models of ships from a recycling perspective during various other life cycle stages of ships**. Adoption of PMSR would make a ship close to a real **transparent ship.** Desired features of a product model for recycling application have been presented using a few 2D images. A 3D walk-through model of a typical engine room of a bulk carrier has been presented as a case study for demonstration purpose.

The **third strategy** involves **development of concept layouts of SRYs**. This strategy is to be realised through **implementation of layout design methodology** proposed in this thesis. The proposed methodology is based on Systematic Layout Planning (SLP) procedure that has been in practice for an effective layout design of industrial facilities. A **list of activity areas to be included in layout design of SRYs** has been generated in this study. A **procedure for estimation of material flow intensity for various classes of materials** has been presented. **Relative closeness ratings have been identified** for each pair of activity areas in SRY.

6.2 CONCLUSIONS

i. A concept plan called ship recycling guidance plan (SRGP) has been developed for recycling of obsolete ships. The guidance plan developed in this thesis consists of two parts which are applicable for the strategic level and the operational level in recycling of ships. It has been concluded that the ship recycling guidance plan developed in this thesis can act as a reference document which will enable SRYs for generating and implementing a recycling guidance plan in compliance with IMO regulations for each ship to be recycled.

ii. Guidelines for enrichment of product models of ships from a ship recycling perspective have been developed. The product models which are generated as per the guidelines will enable the ship owners and SRYs to utilise them for improving safety, productivity, and environmental friendliness in the recycling stage of ships. It has been concluded that by implementation of the guidelines for enrichment of the product model, it would be possible to make a ship very close to a real transparent ship.

iii. A methodology for generation of efficient layouts applicable for SRYs has been developed based on the SLP procedure. Layout alternatives generated using the developed methodology can be compared using the methods specified in SLP procedure in order to select an optimal layout. The proposed methodology can also be used to identify areas of improvement in layouts of existing SRYs. It has been concluded that the proposed methodology of layout design will enable the prospective SRYs to design an efficient layout during the initial stages of development of the yards.

6.3 RECOMMENDATIONS

The following recommendations are made based on the present study:

1. a. International Agency for Ship Recycling (IASR) is to be constituted to look after matters exclusively related to ship recycling.

. b. It is recommended that a World Fleet Database be generated to facilitate an information bank in ship recycling. Updating of the World Fleet Database is to be through feedbacks obtained from various stakeholders in the global ship recycling industrial sector.

c. Product model of ships, which is enhanced with recycling related aspects proposed in this study, is to be considered as a SCF-specific document that contains the recycling related information specified by IMO as part of the Goal Based Ship Construction Standards.

2. a. To facilitate efficient recycling of ships it is recommended that SSRGP must be prepared by SRYs for all obsolete ships recycled there. Apart from the listed stakeholders in this thesis, additional stakeholders for specialised ships shall be identified and their roles and responsibilities are to be incorporated in the SSRGP.

. b. SRYs shall use SSRGP as a reference document for planning and coordinating stake holders in recycling of ships.

   c. Progressive disassembling of ship structure shall be carried out in accordance with the disassembly concept proposed in this thesis.

   d. A detailed disassembling plan is to be prepared for all obsolete ships based on the 'disassembly concept' proposed in this study.

   e. An extensive GSRGP shall be developed by the SRY based on the framework of GSRGP proposed in this thesis. GSRGP shall be ship-specific since each type of ship would have a number of special items onboard. Preparation of GSRGP shall be led by a competent person who has thorough knowledge of safe practices and procedures applicable for dismantling specific types of ships.

   f. SRY shall make their own standards for safe practices to be followed for each of the processes mentioned in the GSRGP.

   g. Enrichment of product models of ships shall be carried out by SRY or a consultant authorised by the SRY. The enrichment process shall include important information as per the Ship Recycling Guidance Plans (SRGP) as supporting text to the ship's components.

   h. To facilitate the SRY personnel to carry out ship recycling activities efficiently, it is recommended that the SRY must generate a 3D walk-through model.

i. Ship recycling yards shall arrange, either directly or through a consultant, for incorporating their standards, guidelines, and videos and images demonstrating the best practices related to ship recycling in the product model of obsolete ships in order to utilise the product model during recycling of the ship.

j. Features of the walk-through models of ships for utilisation during recycling stage shall be made as per the guidelines proposed in this study. The proposed conceptual idea of the walk-through model shall be extended to entire onboard systems and equipment in order to make it a practical walk-through model for ship recycling.

k. Concepts layouts of new SRYs shall be designed according to the methodology proposed in this thesis. Activity areas to be included in the layout design are to be selected from the proposed list of activity areas in this study. Design parameters to be used for the layout design shall be based on the type of obsolete ships which are targeted by the SRY as their activity category.

l. Energy consumption in ship recycling shall be reduced by adoption of systematic procedures for structural disassembling of obsolete ships. Disassembling concept proposed in this thesis can be considered as one of such systematic procedures. During structural disassembling, amount of irregular shaped steel scrap shall be minimised and plates shall be cut to the desired sizes of rolling mills so that the energy consumption of cutting will be minimised and utilisation of steel plates by rolling mills will be maximised. Energy consumption for material handling and transportation in ship recycling operations shall be minimised by laying out the activity areas in a SRY effectively.

3. a. Three additional stakeholders are identified in this study viz., Ship Recycling State Maritime Administration (Regional), Pre-owned Item seller (Ship Recycling Product Market), and Pre-owned Item Customer (Ship Recycling Product Market). It is recommended that the regulatory

authorities in the ship recycling industry shall take initiatives to make the three stakeholders who have been identified in this research work as part of sustainable recycling programmes of the State.

b. Stakeholders shall take additional responsibilities in maintaining and updating the status of 3D product model at each stage of the life cycle of a ship.

6.4 SIGNIFICANT CONTRIBUTIONS

i. A strategic level ship recycling guidance plan has been developed in this study and the plan indicates roles and responsibilities of stakeholders and the required interactions between the stakeholders in global ship recycling industrial sector.

ii. It is proposed to constitute a new body called IASR to regulate the ship recycling activity. In this study, the roles and responsibilities of IASR and its required interactions with other stakeholders are specified.

iii. It is proposed to generate a World Fleet Database to support sustainable recycling of ships. Responsibilities of various stakeholders in generating and updating the data in the World Fleet Database are proposed.

iv. The stakeholders viz., Ship Recycling State Maritime Administration (Regional), Pre-owned Item seller (Ship Recycling Product Market), and Pre-owned Item Customer (Ship Recycling Product Market), who have not been considered as part of the ship recycling system based on the published literature, are identified. Roles and responsibilities of the additionally identified stakeholders and their required interactions with other stakeholders for sustainable recycling in the ship recycling industrial sector are proposed.

v. Development of an operational level ship recycling guidance plan has been carried out in this study. The plan indicates various processes and subprocesses which are to be followed in ship recycling activity. The operational level ship recycling guidance plan can assist a SRY in preparation of extensive ship recycling plans in compliance with IMO guidelines.

vi. A disassembly concept consisting of progressive structural dismantling of ships at three levels, i.e. primary, secondary, and tertiary disassembling has been developed for ship recycling.

vii. A set of guidelines containing 'Product Modelling for Ship Recycling' (PMSR) has been developed for applying '*modelling for*' concept in ship recycling engineering. The guidelines are intended for carrying out enrichment of 3D models of ships at various life cycle stages of ships and for making a ship closer to real transparent ship. Typical features desired for a walk-through model of a ship for application in ship recycling stage, are proposed using 2D images. A walk-through model is generated for part of the engine room and accommodation areas of a bulk carrier in order to demonstrate some of the proposed features of a walk-through model.

viii. A methodology has been developed in the form of steps for generation of concept layouts of SRYs based on the SLP procedure. In the methodology, a comprehensive list of activity areas required to be considered in the layout design of SRYs has been identified. A method for estimation of quantitative values of flow intensities for various classes of materials in ship recycling operation has been proposed. A procedure for estimating space requirements of various ship recycling activity areas in a SRY has been recommended. Relative closeness ratings between various activity areas in a SRY and reasons for assigning these ratings are identified and listed. A case study of concept layout out design of a SRY is presented for demonstrating the utilisation of the proposed methodology of layout design and a schematic drawing indicating the selected layout is presented.

6.5 SCOPE OF FUTURE WORK

i. Development of ship recycling guidance plan for specialised types of vessels such as nuclear propelled ships.

ii. Implementation of advanced digital information technology application to capture changes on structure and material components of existing ships for incorporation into the product models of ships.

iii. Studies for extending the application of SLP based layout design to generate layout models in the activity areas identified by this thesis.

iv. Generation of database of design parameters which are to be used for layout design of SRYs practising various types of docking methods.

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APPENDIX – A

SCREENSHOTS OF WALK-THROUGH MODEL OF THE BULK CARRIER

A walk-through model has been generated for the bulk carrier described in Chapter 4. Development of 3D model of the ship has been done using the Ship Constructor software. The model has been exported to Autodesk Navisworks software for creating the walk-through model.

The walk-though model has been generated only for a few components and systems in engine room and for a 2-men cabin in the accommodation. Images and videos related to the disassembly and recycling aspects have been added as links. Such images and videos can be opened by clicking the corresponding links. It is proposed to extend the above concept to the entire ship covering all the compartments and systems. Screenshots of the walk-through model are presented below from Fig. A.1 to Fig. A.7.

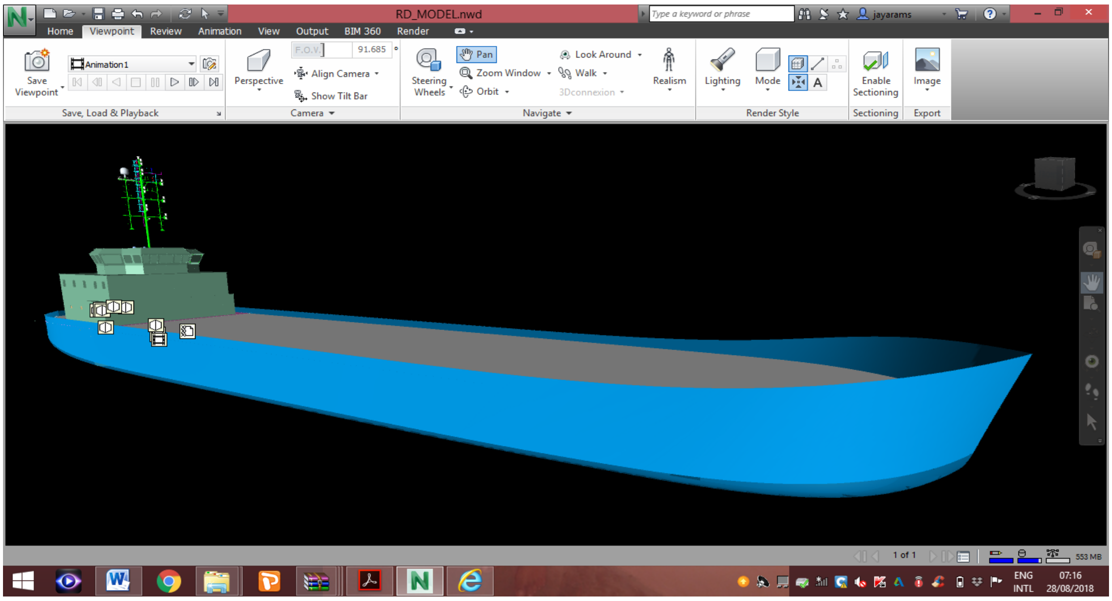

Fig. A.1 Screenshot of walk-through model: Exterior view of bulk carrier

Fig. A.1 shows screenshot of the exterior perspective view of a bulk carrier.

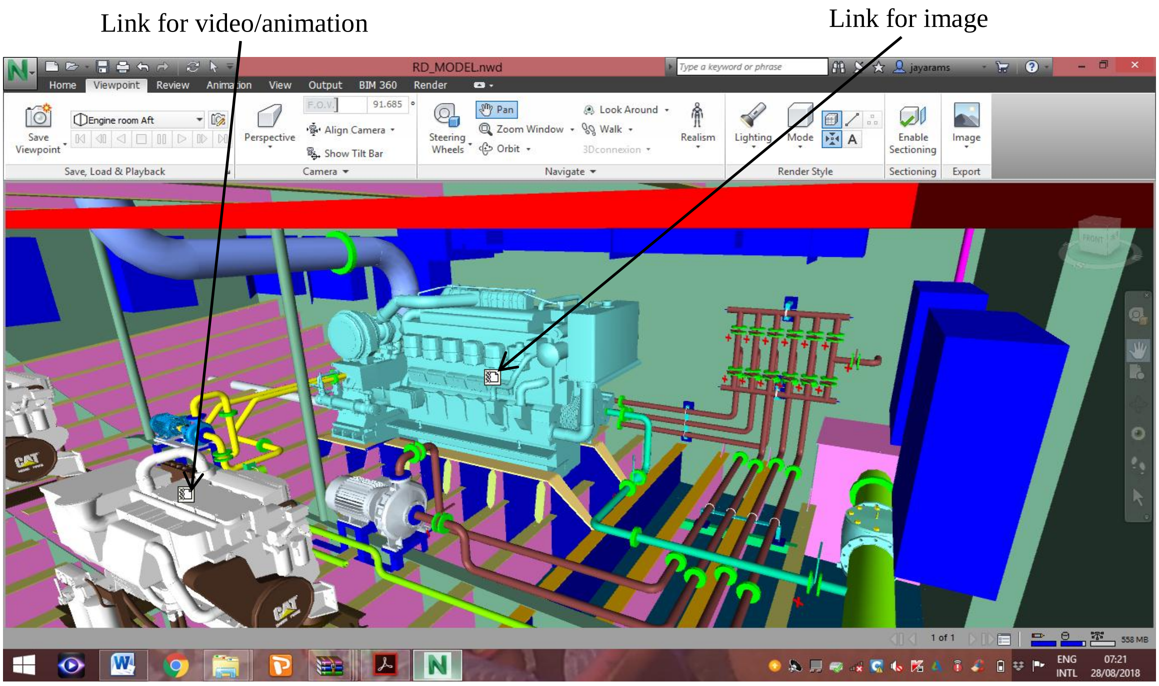

Fig. A.2 Screenshot of walk-through model: View in way of engine room aft

Fig. A.2 shows screenshot of the walk-through model showing the machinery on aft-port side in the engine room. The links for the videos for the auxiliary generator and images for the main engine are shown in the above figure.

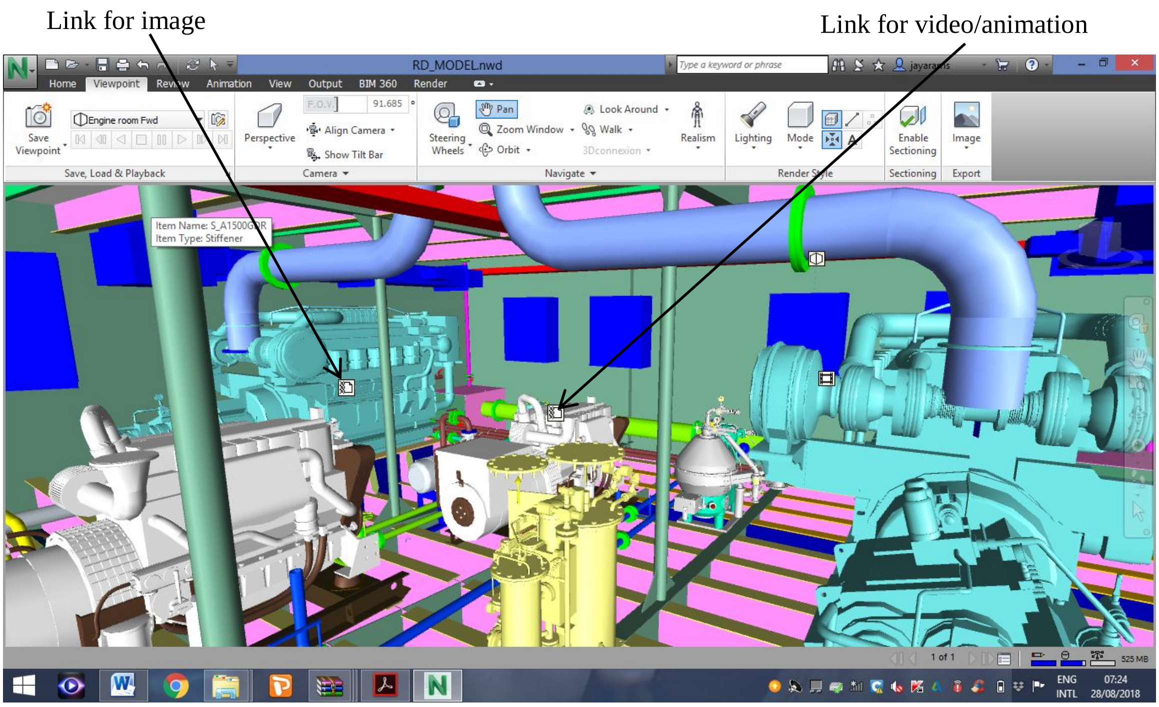

Fig. A.3 Screenshot of walk-through model: View in way of engine room forward

Fig. A.3 shows screenshot of the walk-through model showing the view from aft of the engine room machinery. The links for the videos for the auxiliary generator and images for the main engine are shown in the above figure.

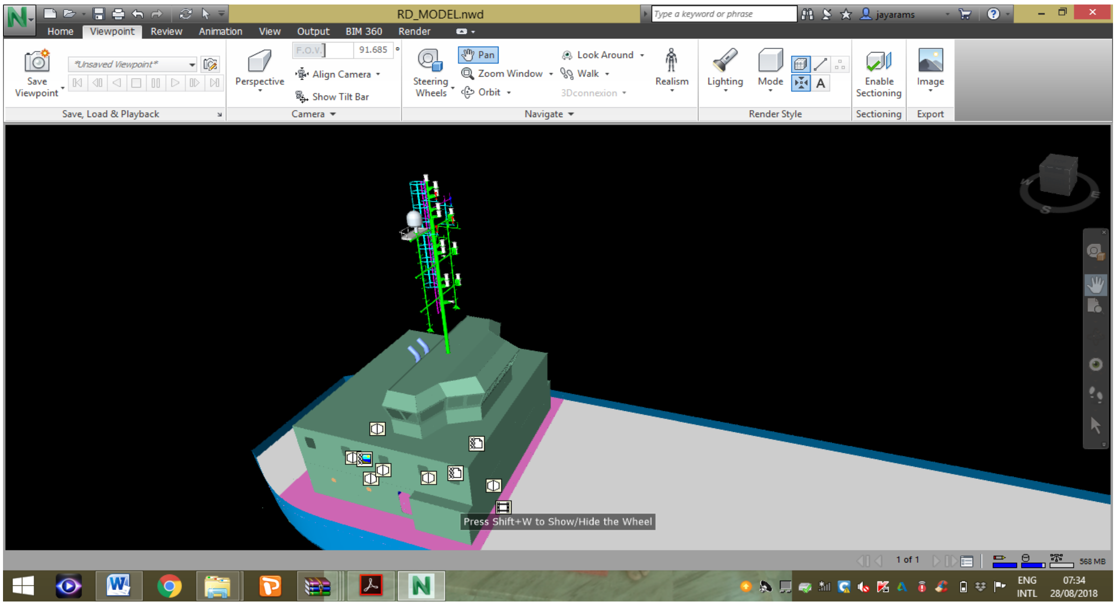

Fig. A.4 Screenshot of walk-through model: View in way of deckhouse

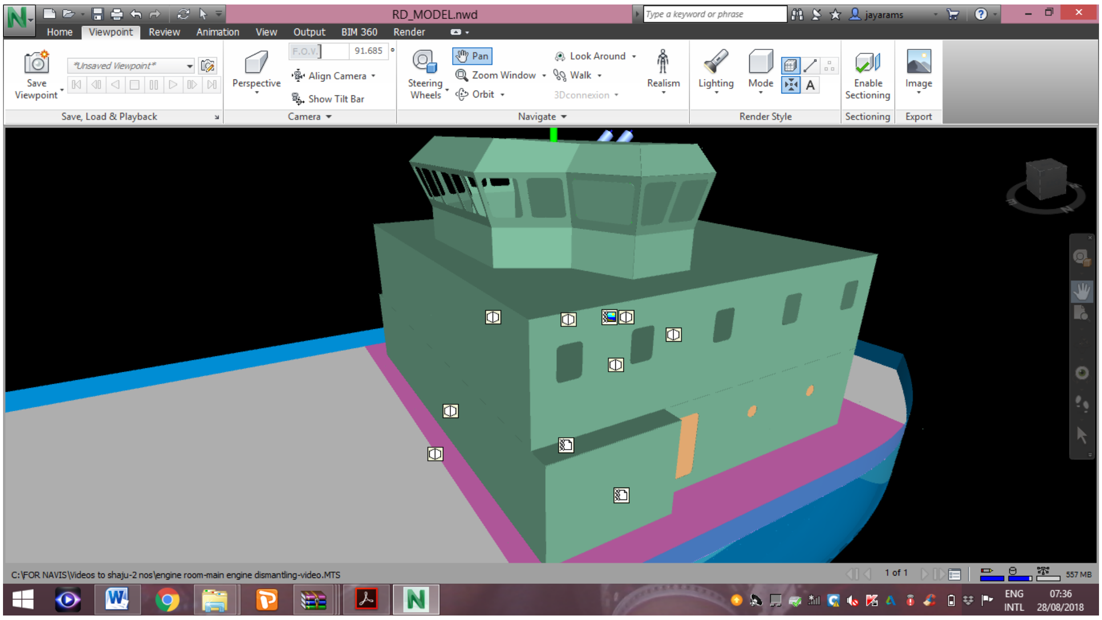

Fig. A.5 Screenshot of walk-through model: View in way of deckhouse

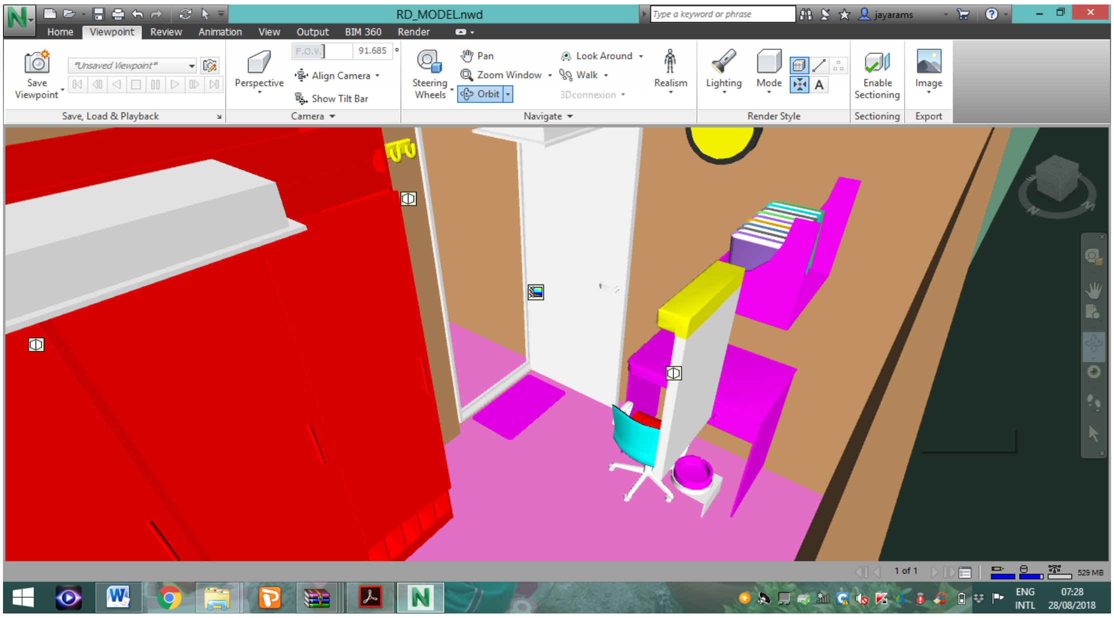

Fig. A.6 Screenshot of walk-through model: View in way of 2 men cabin in the accommodation area

Fig. A.6 shows screenshot of the walk-through model showing the view of a 2-men cabin in the accommodation area along with the internal fittings

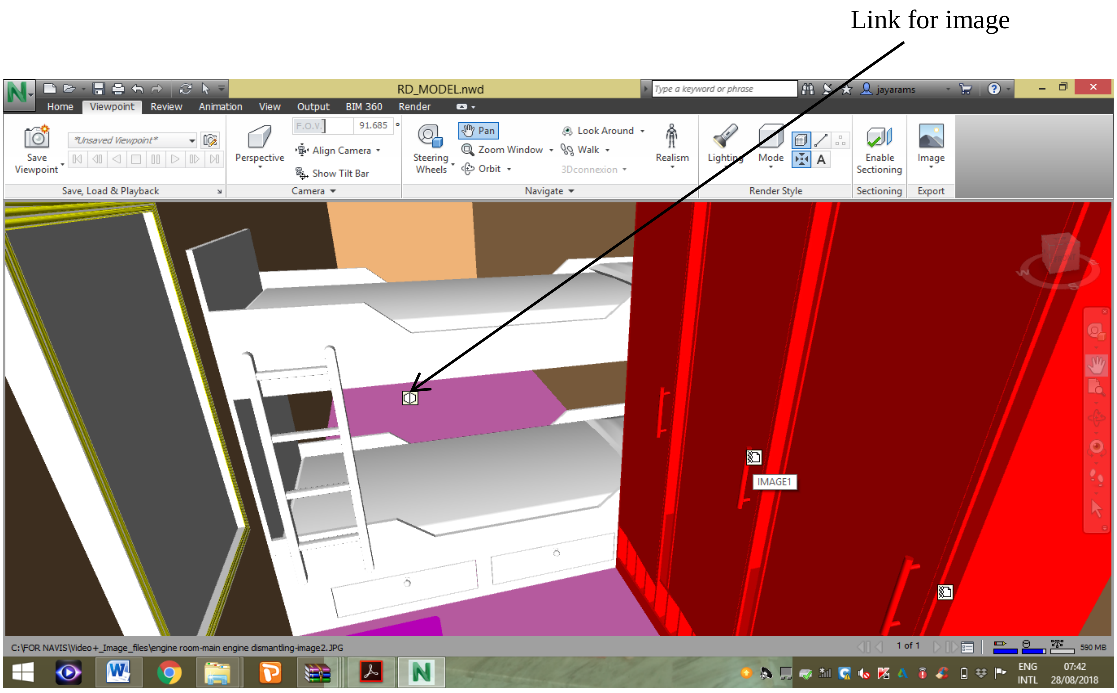

Fig. A.7 Screenshot of walk-through model: View in way of bunk in 2 men cabin

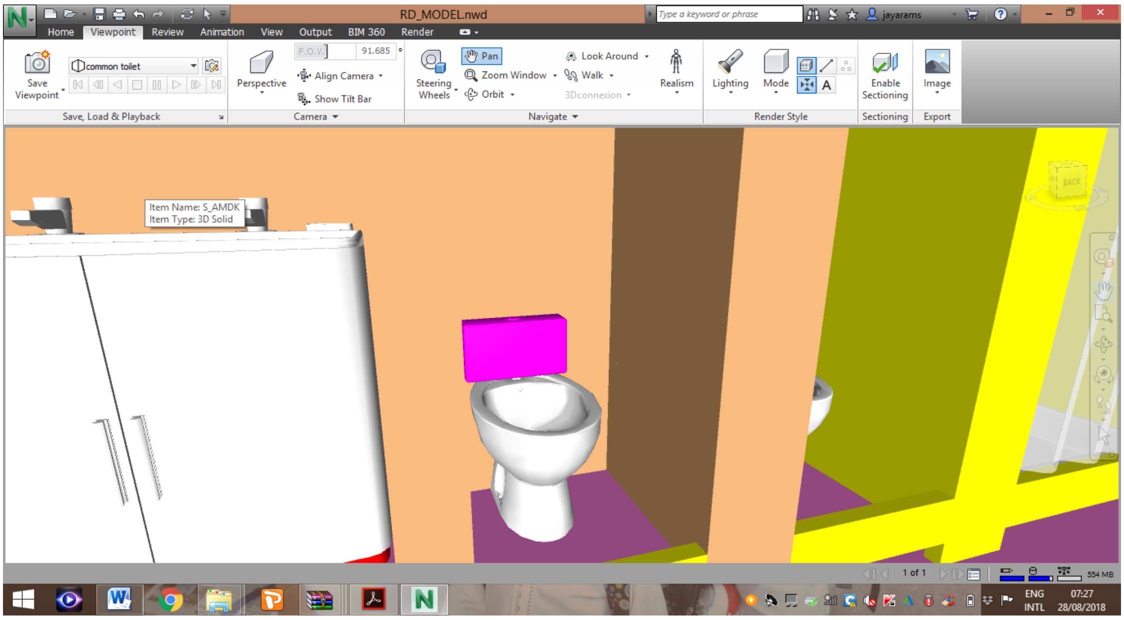

Fig. A.8 Screenshot of walk-through model: View in way of toilet in the accommodation area

Fig. A.8 shows screenshot of the walk-through model showing the sanitary space in way of accommodation.

APPENDIX – B

RECOMMENDATIONS FOR RESOLUTION OF LACUNAS IN SHIP RECYCLING

A tabulated summary of various lacuna areas in the current ship recycling is indicated in Table B.1. A brief description of how these lacunas have been recommended for resolution in the thesis has been given against each of the lacunas in the Table B.1.

Table B.1 Lacunas in the Existing Ship Recycling System and the Recommendations in the Thesis for Resolution of the Lacunas

Sl. No.	Lacunas in existing ship recycling system	Recommendations in the thesis for resolution of the lacunas
1	There has been deficiency of systematic plans which identify roles and responsibilities of stakeholders in ship recycling. There has been lack of systematic plans for monitoring of interactions which are required between stakeholders in ship recycling.	A systematic plan for the strategic level in recycling of ships, which is named Strategic Ship Recycling Guidance Plan (SSRGP), has been developed in the form of line diagrams. This plan indicates roles and responsibilities of stakeholders and the required interactions between the stakeholders in the global ship recycling industrial sector. Ship Recycling Yards (SRYs) shall use SSRGP as a reference document for planning and coordinating stake holders in recycling of ships.
2	There has been deficiency of a regulatory body at the international level to exclusively look after ship recycling issues worldwide.	It is proposed to constitute an international body called International Agency for Ship Recycling (IASR) to regulate ship recycling activities and to look after matters exclusively related to recycling of ships. Roles and responsibilities of IASR and its required interactions with other stakeholders have been specified in the thesis.

Table B.1 Lacunas in the Existing Ship Recycling System and the Recommendations in the Thesis for Resolution of the Lacunas - CONT'D

Sl. No.	Lacunas in existing ship recycling system	Recommendations in the thesis for resolution of the lacunas
3	There is absence of information bank on particulars of obsolete ships and ship recycling related information on these ships.	It is recommended to generate an information bank named World Fleet Database which is to be maintained by IASR. The World Fleet Database shall consist of the information related to ship recycling such as, particulars of ships which have been withdrawn from service, particulars of ships which are recycled at various SRYs, and particulars of SRYs in which ship recycling is carried out and the type of recycling method followed for each ship. Information for the World Fleet Database can be collected through feedback from statutory bodies such as Flag State Maritime Administration (FSMA), Ship Recycling State Maritime Administration (SRSMA), Competent Authorities, Shipowners, Ship Classification Societies and Ship Recycling Promotional Bodies.
4	Some of the stakeholders, who have been involved in the global ship recycling scenario, have not yet been included as part of the existing ship recycling system, as per the published literature.	Three stakeholders, viz. SRSMA (Regional), Pre-owned Item Seller, and Pre-owned Item Customer, which are to be included as part of the documentation on ship recycling system, have been identified. These three stakeholders have been added to the ship recycling system that is proposed in this thesis. Roles and responsibilities of the above three stakeholders and their required interactions with other stakeholders for sustainable recycling in the ship recycling industrial sector have been proposed.

Table B.1 Lacunas in the Existing Ship Recycling System and the Recommendations in the Thesis for Resolution of the Lacunas - CONT'D

Sl. No.	Lacunas in existing ship recycling system	Recommendations in the thesis for resolution of the lacunas
5	There has been deficiency of detailed ship recycling plan which shows systematic arrangement of various ship recycling processes and subprocesses in a sequential order. There is also absence of a clear methodology to prepare a Ship Recycling Plan which is required by IMO.	An operational level ship recycling guidance plan called General Ship Recycling Guidance Plan (GSRGP) has been proposed in the form of flow charts. GSRGP indicates systematic arrangement of various processes and subprocesses which are to be followed in the recycling of ships. GSRGP can act as a reference technical document that enables a SRY to generate a Ship Recycling Plan, which is in compliance with IMO guidelines, for each ship destined to be recycled in their yard
6	There has been lack of a concept or methodology for progressive structural disassembling of hull	A concept called Disassembly Concept has been proposed for structural disassembling of ship into smaller units. It consists of three progressive levels of disassembling such as primary, secondary, and tertiary. The Disassembly Concept is analogous to the assembly concept in shipbuilding
7	There has been lack of utilisation of product models of ships for ships' recycling stage. Sufficient consideration has not been given on recycling aspects at the time of generation of ship's product models in the design stage of ships.	A set of guidelines containing 'Product Modelling for Ship Recycling' (PMSR) concept has been developed for applying '*modelling for*' concept in ship recycling engineering. PMSR guidelines indicate both the characteristics to be enriched on a ship's product model during each life cycle stage of a ship and the stakeholders to whom the responsibility of enrichment shall be assigned. PMSR guidelines are intended to facilitate the utilisation of ship's product models in the recycling stage of ships. Typical features desired for a walkthrough model of a ship for application in ship recycling stage have been proposed using a few 2D images.

Table B.1 Lacunas in the Existing Ship Recycling System and the Recommendations in the Thesis for Resolution of the Lacunas - CONT'D

Sl. No.	Lacunas in existing ship recycling system	Recommendations in the thesis for resolution of the lacunas
8	There has been absence of well planned design in the layouts of existing Ship Recycling Yards in major ship recycling countries in South Asia. There has been lack of a methodology to generate optimal concept layouts of new SRYs. There has been unavailability of published data on design parameters for layout design of Ship Recycling Yards.	A methodology for generation of concept layouts of SRYs has been developed based on the Systematic Layout Planning (SLP) procedure. The methodology has been developed in the form of steps and it is applicable for the initial stages of development of SRYs. In the methodology, a comprehensive list of activity areas required to be considered in the layout design of SRYs has been identified. A procedure for estimation of material flow intensity for various classes of materials has been presented. Relative closeness ratings have been identified for each pair of activity areas in SRY. A procedure for estimating space requirements of various workstations or activity areas in a SRY has been recommended.

LIST OF PUBLICATIONS ON THE BASIS OF THIS THESIS

I REFEREED JOURNALS

[1] Jayaram, S., K. Sivaprasad, and C. G. Nandakumar. 2018. “Recycling of FRP Boats.” *International Journal of Advanced Research in Engineering and Technology* 9(3): 244-252. http://www.iaeme.com/IJARET/issues.asp?JType=IJARET &VType=9&IType=3

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II PEER-REVIEWED JOURNAL

[1] Sivaprasad, K., S. Jayaram, and C. G. Nandakumar. 2012. “Recycling of Decommissioned Naval Fleet.” *International Journal of Innovative Research and Development* 1(10): 318-329. http://www.ijird.com/ index.php/ijird/article/view/34959/28156

III PRESENTATION IN CONFERENCES

[1] Jayaram, S., K. Sivaprasad, and C. G. Nandakumar. 2012. “Recycling of Composite Marine Structures.” In *Proceedings of the XXVIII National Convention of Mechanical Engineers and National Seminar on Emerging Technologies in Product Development for Safe and Sustainable Mobility*, B-65-68. Coimbatore, India.

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DECLARATION

I declare that the entries made in this document are correct and true to the best of my knowledge. .

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Date: 14.09.2018

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