Circular Economy in Shipbuilding and Marine Networks – A Focus on Remanufacturing in Ship Repair

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Abstract. There are about 85,000 ships in the world, with 82 % being at least 5 years old, and over half at least 15 years old [4]. All of these ships require, or will require, regular repair and maintenance. The European shipbuilding and marine industry is highly networked. The EU-28 marine supplies industry's 1st and 2nd tier enterprises employed about 390,000 people in up to about 30,000 companies [10].

In short remanufacturing is an industrial process of restoring used products to an 'as new' condition. Remanufacturing is a key strategy within the circular economy and an important technology for reducing CO_2 emission, saving material, labour, energy and prolonging the "end-of life" of products, components and systems.

The paper describes different types of ship repair activities, their frequency and the collaborative networks involved. Furthermore, for each type of repair activity the paper reports the potential of applying remanufacturing approaches, involved companies and their role in a remanufacturing process.

Keywords: Circular economy · Remanufacturing · Marine industry · Shipyards · Ship repair · Collaborative networked in remanufacturing

1 Introduction

In December 2015, the European Commission published *Closing the loop — An EU action plan for the circular economy*, a new strategy that aims to support the transition to a circular economy in the EU [1]. According to the action plan, the transition to a more circular economy is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource-efficient and competitive economy. The action plan sets out a large number of initiatives that address all stages of the product life cycle.

Also, the maritime industries need products with reduced environmental impact and less emissions, involving components suitable for a prolonged lifetime. IMO (the International Maritime Organization), the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships, has introduced regulations that shipowners need to adhere to. One example of these initiatives is the establishment of the Emission Control Areas (ECA) to limit the

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emission of SOx by limiting the maximum sulphur content of the fuel oils used on-board. Other actions are the proper control and management of ships' ballast water that has become a major challenge for the global shipping industry. These imposed regulations will have a positive environmental impact, but in addition voluntary measure are also needed. This requires understanding how the circular economy can be implemented and promoted in the maritime industry, and how companies can assess their potential for circular economy forms. In recent decades, European maritime industry has been dealing with increased competition from shipyards in Asia, forcing Europeans to specialize in the construction and production of cruise ships, ferries, special purpose ships and luxury yachts.

2 Circular Economy and Remanufacturing

The circular economy is a generic term for an industrial economy that produces neither waste nor pollution. More precisely, according to the Ellen MacArthur Foundation [2] "*A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, and aims for the elimination of waste through the superior design of materials, products and production systems.*"

Remanufacturing is a key strategy within the circular economy. There are many definition of remanufacturing. According to the Automotive Parts Remanufacturers Association [5], remanufacturing is the process of returning a used product to at least its original performance with a warranty that is equivalent to or better than that of the newly manufactured product. From a customer viewpoint, the remanufactured product can be considered the same as a new product. Figure 1 positions remanufacturing in the waste hierarchy and in Fig. 2 remanufacturing is shown within the circular economy.

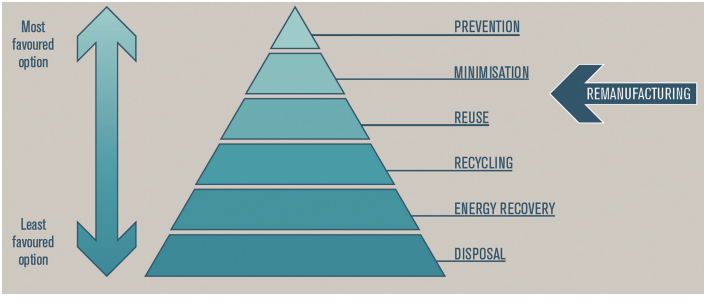

Fig. 1. Remanufacturing in the waste hierarchy [3]

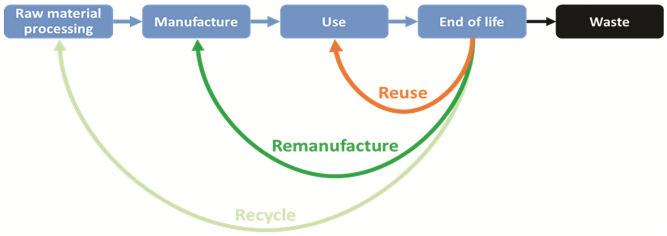

Fig. 2. Remanufacturing in the context of the circular economy [4]

2.1 Remanufacturing Processes

Remanufacturing systems can be seen as consisting of two interrelated processes, the *external* and *internal* processes. The external processes can be referred to as the process of coordinating the input of cores (used products) and the output of remanufactured products to customers. The internal processes coordinate the operations within the "factory walls". The processes are shown below in Fig. 3.

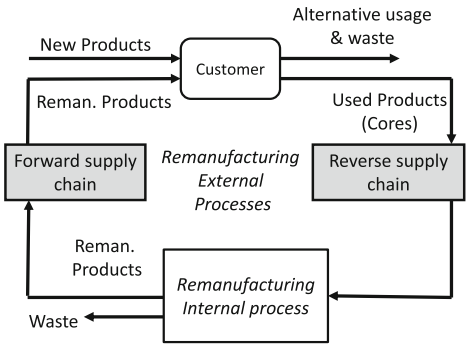

Fig. 3. External and internal processes of remanufacturing systems (adapted from [6])

The external processes in a remanufacturing system are limited to the input and output from the actual remanufacturing (internal) processes, which transform cores into remanufactured products through different manufacturing operations and the replacement of components, Fig. 3.

From a logistics perspective, the logistical system spanning product recovery operations can be referred to as a restorative closed-loop supply chain. The forward chain covers the flow of physical products from producer to customer, while the reverse chain consists of the flow of physical products from customer to producer. Thus a remanufacturing system is a typical representation of the Circular Economy.

The forward supply chain process of remanufactured products has in many cases the same features as normal supply chains of new manufactured products to customers. The same types of distribution systems and partners can be involved. A challenge for remanufacturing is to efficiently arrange the reverse chain, involving the difficulty of predicting the number of cores coming back from customer.

The remanufacturing internal processes contain the necessary physical manufacturing steps to recondition the incoming cores to the required quality level. The generic (internal) remanufacturing process is described in Fig. 4 [7]. When a core undergoes a remanufacturing process, it may pass through a number of specific operations. In no specific order, these are: inspection, cleaning, disassembly, reprocessing, reassembly, testing and storage.

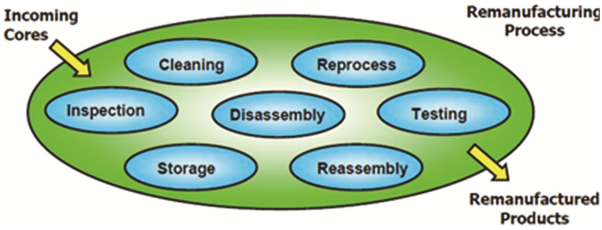

Fig. 4. Generic remanufacturing internal process [7]

There are different types of companies that perform remanufacturing (internal process). These companies can be classified according to their relationship to the product manufacturer, i.e. the Original Equipment Manufacturer (OEM); (1) the OEM itself, (2) contracted "official" contractors, and (3) independent remanufacturers.

In the first two cases, OEMs retain at least some control over both the numbers and the quality of the remanufactured products. Relationships between contractors and OEMs can involve mutually beneficial information flows regarding both original design specifications and product failure modes and frequencies [11].

The external processes can be difficult for the remanufacturing company to organise and manage. Logistics operators, core collection, storage and warehousing are often included in the networks. A more detailed analysis of potential networking forms can be found in [12] including *Industry-specific remanufacturing networks, Location-based remanufacturing networks*, *Remanufacturing parks* and *Remanufacturing ecosystems*.

2.2 Benefits from Remanufacturing

The Remanufacturing benefits are manifold. Remanufacturing it is good for:

Customers. Remanufactured parts and components provide same as original performance and reliability at costs typically only 50–80 % of a new. Instant availability gives customers more options at repair and overhaul time. The results are maximum productivity and lower costs.

Business. Remanufacturing is based on an exchange system where customers return cores in exchange for our remanufactured products. Remanufacturing is an additional option to support customers and help lower owning and operating costs. Profit margins are often bigger for remanufactured products than for new products.
Environment. The business of returning end of life components to same as original condition, reduce waste and minimize the need for raw material to produce new parts, keeping non-renewable resources in circulation for multiple lifetimes, and reduces energy consumption and greenhouse gas emissions. Material and energy savings are up to 90 %.
Society. Remanufacturing creates a large number of job positions, requiring skilled personnel.

Remanufacturing thus support circular economy in it's all three dimensions, economic, environmental and social.

3 Remanufacturing in the Shipbuilding and Marine Industry

3.1 The European Shipbuilding Industry

The European shipbuilding industry is the global leader in the construction of complex vessels such as cruise ships, ferries, mega-yachts and dredgers. It also has a strong position in building submarines and other naval vessels. The European marine equipment industry is a world leader for a wide range of equipment needed on-board ships and in harbours, ranging from propulsion systems, through large diesel engines and environmental and safety systems, to cargo handling and electronics systems.

Ship repair is an important part of the marine industry. Ship repair does not necessarily require dry docking, as work can be undertaken alongside the vessels at berths or at sea, Table 1 gives an overview of different types of ship repair activities. Normally ships are dry docked for maintenance and overhaul at regular time intervals e.g. every 2–3 years. Larger ship conversion services alter the structure or configuration of vessels so as to enable them to carry out a different purpose than was originally intended when the vessel was built. Some special characteristics of the ship repair business include:

- Significant planning and scheduling activity well in advance rather than *ad hoc* or unplanned activities.
- Short delivery times – an intensive short period to mitigate the earning opportunities lost while the ship is unable to generate sales.
- Use of a variety of skilled labour in collaborative networks
- Labour-intensive i.e. low level of automation.
- Involving a wide variety of products.
- One-off large ships, but many small components and work objects.

Table 1. Different types of ship repair activities, their frequency, typical location and duration.

	Milestones of ships Lifecycle	Frequency	Location	Duration
1	Maintenance	Continuous	Any	n/a
2	Small-scale voyage repairs	Occasionally	At sea	hours
3	On-Board repair	Occasionally	Harbour	hours, days
4	Planed dry-docking, ship overhaul	2 times in 5 years	Repair Yard	~ 2 weeks
5	Large-scale Retrofit & Refurbishment.	After 10 – 15 years of operation	Repair Yard	~ 3-4 weeks
6	Modernisation extends the commercial life by an other 20 years.	First lifetime is usually 20 – 30 years	Repair Yard	~ 3-4 weeks
7	Conversion, Lengthening, Transformation to other usage	n/a	Repair Yard	~ 1-3 months
8	Emergency repair & damage repair	No scheduled	Any	variable

3.2 Circular Economy in the Marine Industry

Ships have always been recycled. The material used for building ships, in the old days wood, or nowadays steel has always been valuable. In recycling, the shipping industry is a forerunner of other industries, such as the automotive and aviation sectors. Some 95–98 % of ship materials by weight are recycled [9]. However, the majority of ship demolitions take place in what can only be called horrific circumstances in Asia, where ships are pulled up on muddy beaches (beaching) [8]. The demolition is dangerous, costs many lives and is very polluting.

Referring to Fig. 1, recycling is not the most favourable form of circular economy. Reuse, repair, retrofit, refurbish and remanufacturing are forms of circular economy where not only the material is used, but also other value in form a labour and energy. Using the above-mentioned forms of circular economy, are ways to prolong the lifetime of a marine structure.

Ship repair is an industrial branch that is not very often addressed in the "Remanufacturing community". Table 2 below gives an overview of European Remanufacturing intensity in different industrial sectors according to a recent study in the ERN project [4].

From the table, we can see that the remanufacturing intensity (share of business domain) in the marine sector is very low. Although complete ships are not remanufactured in the sense that they are not restored to an 'as new' condition, the principles of remanufacturing can be applied to small sections, components and other marine equipment. As the marine remanufacturing typically occurs at the component level, there is potential for 'leakage' in the numbers to other sectors. For example, remanufacturers of diesel engines may identify themselves as being in the machinery of the HDOR sector.

Table 2. Summary of European remanufacturing activities across industry sectors [4]

Sectors	Turnover (€bn)	Firms	Employment ('000)	Cores ('000)	Intensity
Aerospace	12.4	1,000	71	5,160	11.5%
Automotive	7.4	2,363	43	27,286	1.1%
EEE	3.1	2,502	28	87,925	1.1%
Furniture	0.3	147	4	2,173	0.4%
DOR	4.1	581	31	7,390	2.9%
Machinery	1.0	513	6	1,010	0.7%
Marine	0.1	7	1	83	0.3%
Medical equipment	1.0	60	7	1,005	2.8%
Rail	0.3	30	3	374	1.1%

4 Opportunities for Remanufacturing in Ship Repair

Below we review the different types of ship repair activities according to Table 1. We also use the generic remanufacturing process, with its external and internal processes (Fig. 3), to analyse the roles played by the shipyard and the ship (shipowner) in the remanufacturing processes.

Remanufacturing in Small Scale Ship Repair. The first three types of ship repair activities (maintenance, small scale voyage repairs and on-board repair) according to Table 1 are typically small and do not require dry docking. Figure 5 illustrates the potential roles of the remanufacturing product customer, core supplier and process owner. The cores are collected from the ship and sent to a remanufacturing company for reconditioning. The remanufactured product is then used in other ships (or in other business domains).

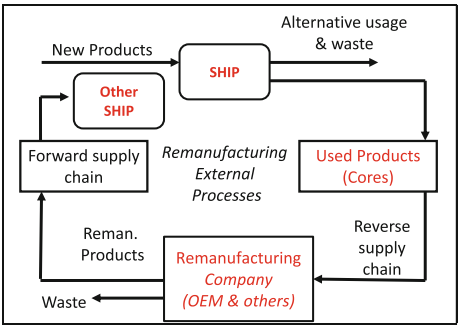

Fig. 5. Remanufacturing in small scale ship repair activities.

Examples of this type of repair activity are corrective maintenance, e.g. breakdown maintenance, spare parts and component replacement and HVAC system maintenance, but also planned maintenance, predictive maintenance and preventive maintenance.

Remanufacturing in Planned Dry-Dockings and Ship Overhauls. These types of ship repair require the involvement of a ship repair yard and typically also dry docking of the ship. The frequency of planned dry-docking is approximately 2 times in 5 years. Figure 6 illustrates the corresponding roles in the potential remanufacturing process. In this case, the cores are collected at the repair yard and sent to a remanufacturing company for reconditioning. The remanufactured product is then used at other yards (or in other business domains). In some cases the product used can be used for other purposes after processing (second life). An example of an external remanufacturing company (OEM) could be a diesel engine manufacturer using remanufactured components such as cylinder covers, pistons, piston crowns, piston rods, exhaust valves, cylinder covers or connecting rods.

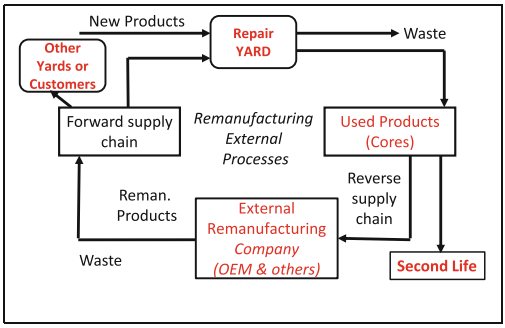

Fig. 6. Remanufacturing in planned dry-docking.

Remanufacturing in Large Scale Ship Repair and Refurbishments. This type of passenger ship repair is typically performed after 10–15 years of operation. It involves a ship repair yard and often also a specialised turnkey provider for refurbishment

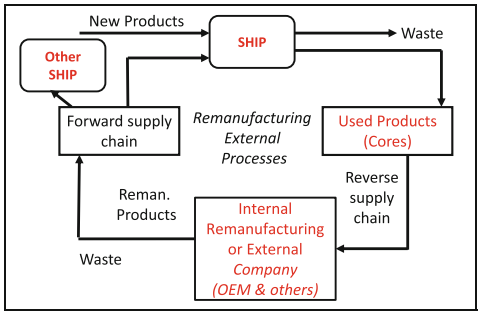

Fig. 7. Remanufacturing in large scale ship retrofit and refurbishment.

services. Figure 7 illustrates the corresponding roles in the potential remanufacturing process. The cores are collected from the ship and internally reconditioned at the yard or sent to a turnkey provider for reconditioning. The remanufactured product is then used in other ships (or in other business domains).

An example of this is remanufacturing of a complete cabin (*restoring it to "as new" condition) or remanufacturing of cabin components,* including re-upholstery of soft goods, textiles (draperies, head boards, refinishing of fixed furniture, new wall, floor and ceiling surfaces, bathroom floors and walls, bathroom furniture and fittings, technical electrical, HVAC and piping, etc.

Remanufacturing in Ship Conversions. These types of major ship repair and modification activities (modernisation, extending the ship's commercial life by approx. 20 years and conversion, lengthening, transformation to other usage) can be performed, although not for all ships, after the first ship lifetime e.g. usually after 20–30 years. Figure 8 illustrates the corresponding roles in the potential remanufacturing process.

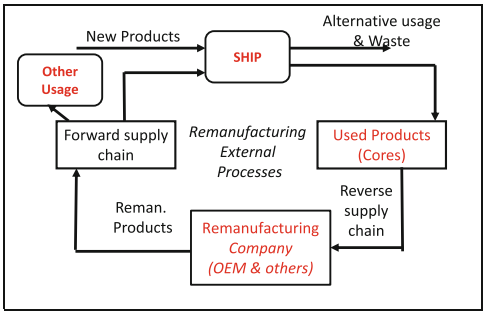

Fig. 8. Remanufacturing in major ship transformation and modification activities.

Table 3 lists the different ship repair activities together with their potential for remanufacturing.

Table 3. Remanufacturing opportunities in ship repair.

	Milestones of ships Lifecycle	Reman. Opportunity	Role of Ship (Ship Owner)	Role of Repair Yard
1	Maintenance	Yes	Core supplier	n/a
2	Small-scale voyage repairs	Yes	Core supplier	n/a
3	On-board repair	Yes	Core supplier	n/a
4	Planed dry-docking, ship overhaul	Yes	Customers of reman parts	Core collection, Prepare 2nd life
5	Large-scale Retrofit & Refurbishment	Yes	Customer of reman parts	Remanufacturer
6	Modernisation extend the commercial life by another 20 years.	Minor	Core supplier	Core collector
7	Conversion, Lengthening, Transformation to other usage	Minor	Core supplier	Core collector
8	Emergency & damage repair	n/a	n/a	n/a

4.1 Challenges and Opportunities of Applying Remanufacturing in Ship Repair

From Figs. 5, 6, 7, 8 and Tables 1 and 3 we can conclude that remanufacturing opportunities are more evident in ship repair activities focused on component level and smaller operations. There are many challenges involved, for example:

- There are few standard products
- The uncertain timing and quantity of returned cores
- Reverse logistics: from different locations. Small quantity of products collected from each source.
- Difficulty in achieving an economy of scale.
- Employees' knowledge and skills in remanufacturing
- Finding a suitable customer (ship) for the refurbished parts.

On the other hand there are also potential opportunities for profitable remanufacturing, e.g.

- Ship series, sister ships
- Big ships, more similar components
- Partnership with OEMs for components and systems
- Upgrade of technology to the latest standard
- Response to environmental legislation
- Better reputation, attract workforce

4.2 Growing Markets

The number of seagoing vessels is continuously increasing. Especially the number of passenger ships in the cruise industry has grown considerably. Ship repair is a permanent element of the maritime industry. It will always be needed. Periodic and emergency maintenance and repair work are essential so as to keep vessels operable and attractive for cruise passengers. All vessels must undergo special surveys every five years, in addition to regular repairs, in order to remain seaworthy and fulfil regulatory requirements. Economically, many ship owners have found it more profitable to increase the life of their existing fleet due to the high building costs of a new vessel. Furthermore ship-owners are reluctant to sell their older tonnage on the second hand market. The owners would rather keep their high quality cruise vessels than sell them to future competitors. Environmental issues caused by accidents and oil spills put pressure on ship owners to improve their maintenance standards. The results are increased maintenance and repair work for the yards. All in all, there is a positive outlook for remanufacturing as a part of circular economy in the ship repair industry.

5 Conclusions

Remanufacturing represents a "win-win-win" situation: customers need to pay less for the remanufactured products or components; remanufacturing companies earn more and there are environmental benefits. As a whole, remanufacturing is expected to contribute

to all three dimensions of sustainability (environment, economy, society). Remanufacturing saves material and energy resources, prevents waste, creates skilled jobs and produces substantial savings compared to new goods with new components. It makes products available at lower prices; it makes a contribution to conservation of materials and energy, and it provides employment opportunities. Thus through becoming more common, remanufacturing can contribute to the circular economy in Europe.

The paper discusses how remanufacturing could be applied in the different types of ship repair activities. The yard could take different roles in the remanufacturing value chain and reverse logistics operations. The paper reviews challenges and opportunities of applying the remanufacturing concepts in the marine domain. There is evidence of a potential for growth in applying remanufacturing in ship repair activities.

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