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Towards Shipping 4.0. A preliminary gap analysis

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Abstract

The paradigm of Industry 4.0 involves a substantial innovation to the value creation approach thought the supply chain and the application of digital enabling technologies like the Internet of Things (IoT), Big Data Analytics (BDA) and cloud computing. The fourth industrial revolution is thus expected to have a disruptive impact on maritime transport and shipping sectors, where smart ships and autonomous vessels well be part of a new and fully interconnected maritime ecosystem. Specific hardware components, such as sensors, actuators, or processors will be embedded in the ship's key systems in order to provide valuable information to increase the efficiency, sustainability and safety of maritime transport. The big challenge is thus to design more efficient business models where digitized information will be effectively employed to strengthen the value chain. This paper addresses such topic discussing by performing a gap analysis between current (traditional) business models and next generation digitized shipping industry, discussing the maturity level and the technological barriers.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Over the past three decades, the economic landscape of developed economies has experienced a substantial transformation process, which has led to the spread of service economies and corresponding decline of the traditional industrial businesses. Such situation is clearly witnessed by the reduction in the United States' share of global manufacturing activity from 28% in 2002, to 16.5% in 2011 and by the fall of contribution of manufacturing activities to the EU economy from 18.8% to 15.3% of gross value added (GVA) between 2000 and 2014. In recent years, however the consensus among economists about the importance of industrial development for economic growth has re-emerged, and the manufacturing sector has been recognized as a main driver of productivity. Policy makers have thus established new economic objectives, and concentrated their strategies on sustaining the "manufacturing renaissance" of the industrialized economies. The European Commission, for example, has set its sights on increasing the share of manufacturing in total gross value added to 20% by 2020. However, the reindustrialization process designed envisages a drastically renewed approach to the concept of industry involving the creation of value by the exploitation knowledge and technology with the objective to retain a competitive edge in a globalized world (European Commission, 2014). With such features, the term "Industry 4.0" (I4.0) has been introduced to address the expected fourth industrial revolution based on the establishment of cyber-physical production systems, where the interoperability among the systems, the people, and the environment, should allow real-time operation capability and decision making. By implementing such paradigm, smart manufacturing systems will work in a decentralized way to improve production processes accordingly to the demand, within a seamless

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interconnected environment. The achievement of such objective relies on significant technological advances in the areas of information and engineering, and in particular, on the implementation of some key enabling technologies, such as: Internet of Things (IoT), Big Data, Mobile and Augmented Reality, Additive Manufacturing, Cloud based services and Cybersecurity [1,2,3,4,5].

The fourth industrial revolution is also expected to have a substantial impact on the maritime industry ecosystem, which encompasses a wide range of activities, including core maritime activities (e.g. fishing, shipbuilding, shipping, ports, offshore energy), tangent activities (e.g. equipment manufacturing, financial services, tourism) and indirect activities (e.g. miscellaneous manufacturing industries, logistic services). The European maritime cluster is subdivided into seven main categories (Maritime transport; - Food, nutrition, health and ecosystem services; - Energy and raw materials; - Leisure, working and living; - Coastal protection; - Maritime monitoring and surveillance - Shipbuilding and ship repair), and the related economy ("blue economy") generates a gross added value of almost €500 billion a year. Europe plays a major role in today's shipping world, with 41% of the world's total fleet (in dwt) contributing for € 57 billion contribution to EU GDP in 2015 (ECSA). The recent "Ocean Economy in 2030' report edited by the Organization for Economic Co-operation and Development, or OECD estimates that the Ocean Industries can double their contribution to Global Value Creation by 2030 with an increased demand for shipping, shipbuilding, marine equipment, and related services. Such forecasts, however, heavily relay on the substantial technology-based innovation introduced by the I4.0 paradigm, which will be the foundation of a future maritime ecosystem where specific cyber-physical systems ("smart ships"), characterized by new design criteria and operational requirements, will replace traditional vessels in a fully interconnected future maritime ecosystem (Shipping 4.0) with enhanced efficiency, and sustainability. With the increasing technical development and digitalization, the shipping industry is thus undergoing a process of digital transformation that reflects the growing need for better data collection, data processing and data networking. The future of shipping industry is therefore dependent on the process of digital transformation and requires suitable systems for real time acquisition, transmission, storage and analysis of a big amount of relevant data. The digitalized and intelligent networking of data is expected to bring significant advantages to the shipping industry, reducing their operational costs, while increasing the overall revenue and extending the service life of machines.

Additionally, the ships of the future will meet strict requirements related to pollution, and Energy Efficiency. With the aims of promoting, the use of more energy efficient and less polluting equipment and engines the International Maritime Organization (IMO) agenda of the United Nations responsible for maritime affairs issued in 2013 the MARPOL convention to define the fundamental requirements for the maritime shipping sector. Such requirements, which will be tightened every five years and will substantially influence the power distribution and fuel consumption in the smart ships of the future.

Unfortunately, up to today, we are just in the early stages of implementation of such systems, and vessel builders and equipment manufacturers are starting to adopt new sensor technologies and to transmit data to land-based service centers. The HEalth MOnitoring System (HEMOS) by Rolls Royce and the Wärtsilä Propulsion condition monitoring service (PCMS) are a significant example of such developments. Most shipping companies in Italy and all over the are however in the early stage of implementation, and the establishment of an effective implementation strategy is a key-element for success. In order to support companies in the implementation of Industry 4.0 Industry Maturity Models (IMM) have been introduced. The shipping sector, however, is a service industry with very specific features, therefore it probably requires a customized approach. The paper reports a preliminary approach to the problem, and highlights the gap between the current state of the art and the future objectives.

2. The digitized shipping business model

The term "business model" Was introduced in the late 1990s as a network "architecture" with a focus on the different roles of the actors and their interactions and relationships [6,7,8]. Such definition has been reformulated in subsequent studies, and it is nowadays considered quite outdated. More recent definitions [9,10] make an explicit reference to the concept of "value", and highlight the importance of the dynamics of value creation and as an essential element of the business model. Referring to the concept of value creation, from a general economic perspective we can say that that value is created when a business earns revenue that exceeds the expenses. In modern times, however, we live in knowledge economy where value is increasingly being created by more intangible drivers such as research, innovation, branding, ideas, and networks, which usually provide indirect rather than direct benefits [11]. The modern dynamics of value creation, hence, are much more complicated and the basic economic view must be substantially revised.

The major challenge faced today by the security domain is developing the ability to identify patterns emerging within huge amounts of data, fused from various sources and generated from monitoring thousands of vessels a day, so as to act proactively to minimize the impact of possible threat

3. I40 Gap Analysis in shipbuilding sector

The concept of shipping 4.0, briefly discussed above, refers to a broad ecosystem and embraces an entire landscape of technologies and applications. In such context, two important question arise about what is the current level of technological advancement in the maritime shipping industry and how the new technologies and methodologies should be deployed to ensure a rapid transition to Shipping 4.0. Such questions are not new to the industrial world interested by the I40 revolution. In response to such questions, IMMs have been developed for the manufacturing industry as an instrument to conceptualize and measure the maturity of an organization or a process regarding some specific target state. In general, the term "maturity" refers to a “state of being complete, perfect, or ready” [12] and implies some progress in the development of a system. Accordingly, maturing systems (e.g. biological, organizational or technological) increase their capabilities over time regarding the achievement of some desirable future state. IMMs have been conceptualized with the goal to position companies towards the journey of digital transformation by defining how the adoption of digital technologies affects the whole organization [13, 14]. Indeed, several approaches have been presented in the literature in order to support strategy managers in understanding the current state of their organization. One of the most detailed I4.0 readiness model IMPULS – Industrie 4.0 Readiness [15] involves six dimensions: strategy and organization, smart factory, smart operations, smart products, data-driven services and employees. The readiness level is measured on the basis of predefined target requirements used for all self-assessing companies. Several maturity model concepts can be found in the literature based on different components [16,17, 18]. Most of the IMMs developed so far, however, are developed for the manufacturing industry, and hardly adaptable to the shipping context, which is a service industry with specific peculiarities. Recently, maturity models for the service industry have also been proposed [19], but the shipping industry is a peculiar sector, which differentiates substantially from general services. In this paper, after reviewing the above reported models, in order to perform a preliminary gap analysis, we concentrated on two main dimensions: have been analyzed: “Strategy & Organization” and “Infrastructure/Technology”. Such dimensions are discussed referring to the shipping industry in the following sections.

3.1. Strategy & Organization

The Strategy dimension concerns the overall business strategy and focuses on how the business transforms or operates to increase its competitive advantage through digital initiatives. The paradigm of Industry 4.0 involves a substantial innovation to the value creation approach thought the entire supply chain, as the result of a substantial innovation process. At a general level, the chain of maritime shipping basically consists of a sea voyage and two land based transportations. The transportation begins at the production site, where goods are stored before being transported to the port and loaded on a ship. The ship carries the goods to the port of arrival, where it is discharged and usually stored before being transported to their final destination[20].

Fig. 1. Shipping supply chain.

Although this is an extremely simplified supply chain model, which does not highlight many significant differences from, e.g. liner shipping to bulk shipping, it gives a good starting point for analyzing the various actors within the chain. In the maritime chain of transportation the most important carrier is the shipping company or shipping operator. Many shipping companies have, nowadays, integrated their supply chain and thus being also engaged in port operations and land based transportation. Concerning the dynamics of value creation in a shipping company, the general economic reference models [20] report three key variables that contribute to the creation of value: the revenue received from chartering/operating the ship, the cost of running the ship, and the method of financing the business. Such costs include the ship operating cost, the voyage costs, the Capital costs (which depend on the way the ship has been financed) and the Cargo handling costs. The general incidence of such costs is around 45% both for the operating expenses and voyage costs, and the remaining 10% for the capital costs.

Referring to the competitive advantage, the “shipping 4.0” business model builds upon the above described value chain, and aims at promoting advanced analytics to strengthen the value chain. As the organizations evolve in their digitization process, their analytics capabilities will move from basic and anticipatory to predictive analysis. This process will also involve port logistics, and just-in-time shipping services will be possible with the spread of Big Data and networking of technologies. The revolutionary vision on industry 4.0, however, is not only the implementation of its core technologies (which in some cases are not even recent) but it must be rather be found in the effectiveness creating new value from digitized information. Consequently, the big challenge is to design and implement appropriate processes to improve and optimize decisions and performance taking advantage of the information extracted by big data. In such view, decision support is arguably the most important element of the industry 4.0 paradigm, and the significant driver for value creation. In this regard, the economy of a shipping company is based on some well established microcosmic model such as the relationship between actual annual cost for operating the ship and the ship size [21]:

$$C = \frac{OC+PM+VC+CHC+K}{DWT} \quad (1)$$

Where: C is the cost per deadweight (dwt) per annum (p.a.), OC the operating cost p.a, PM the periodic maintenance p.a, VC the voyage cost p.a, CHC the cargo-handling costs p.a, K the capital cost p.a, DWT the vessel’s deadweight, t is the year and m stands for the ship.

Some additional simple empirical models also included for cost modelling, such as the fuel cost related to the fuel consumption which is normally assumed as a function of the actual speed:

$$F = F^{*}\left(\frac{S}{S^{*}}\right)^{\alpha} \quad (2)$$

Where F is the actual fuel consumption (tons/day), S is the actual speed, F* is the designed fuel consumption and S* is the designed speed. The component α has a value 3 for diesel engines and 2 for steam turbines.

The basic revenue results from how much cargo the vessel can carry in the financial period measured in tons, tonmiles etc., and the price or freight rate the ship owner will receive per unit transported. The revenue per dwt can thus be calculated as:

$$R_{tm} = \frac{P_{tm} \cdot FR_{tm}}{DWT_{tm}} \quad (3)$$

Where R = Revenue per dwt/p.a, P = the productivity in ton miles of cargo p.a, FR = Freight per ton mile of cargo transported, t = time period, m = ship type

Finally, the Profit is calculated by taking the total revenue earned by the business during an accounting period and deducting the costs. The approach towards tactical management by the ship-owner, consists in determining the operating speed of his vessel(s) as an optimum tradeoff between ship's speed and fright rates. In addition, the ship-owner must take into account the effects of depreciation to estimate how much profit the company is making and that depends on how much depreciation is deducted. The ship is written off in equal proportions over its expected life 'straight line' depreciation.

The decision processes of the traditional shipping industry, hence, involve historical internal data and external data, which, in the traditional literature are classified as: Structured, when a well-defined decision-making procedure exists, Unstructured, when a well-defined decision-making procedure does not exists and the experience and creativity of the manager are required, Semistructured, when the decision-making procedure is partly defined and so it is also required the manager's creative intervention.

There is no strict correspondence between types of decision and levels of decision making processes, however, at the operational level decisions tend to be more structured, at the tactical level decisions are mainly semistructured and at the strategic level decisions are typically unstructured. The employment of information or mathematical models to facilitate a decision process originates a decision support system (DSS). The DSS can be broadly classified into two main types: model-driven, to take structured or semistructured decisions, or data driven to take unstructured decisions [22]. Model driven decision support is typically implemented manually through spreadsheets or "what-if" simulation models, and the effectiveness of the results obtained clearly reflects the quality of the underlying mathematical models. Data driven systems involve more sophisticated models, including Advanced Analytics and artificial intelligence. Such systems require a large amount of data and complex calculations, therefore they are typically built on top of ICT infrastructures involving data warehouses and data processing. With the technological advances, the data mining capabilities of ICT systems have increased, and, with a consistent amount of operational data accumulated over time, they have become capable of extracting "knowledge" from information and creating value from knowledge, by means of Artificial Intelligence (AI). The data warehouse has thus become a knowledge warehouse, and the recent category of knowledge-based decision support system has been defined. To become actionable, knowledge should also be closely integrated with an organization's business processes.

In the context of the shipping industry, hence, the replacement of manual noon-record based reporting with automated sensor-based monitoring, involved in the Shipping 4.0 paradigm, leads to a significant increase the amount and the quality of information generated, thus preventing human operators to perform individual calculations based on mathematical model. The shift towards digitized information thus requires a substantial revision of the decision processes in the shipping industry, and an epochal shift from model based to knowledge based decision support.

3.2. Infrastructure/Technology

The technological dimension of shipping 4.0 refers to the complex issues related to the digitized "smart" ships and to interconnection infrastructure. The achievement of an appropriate digitalization level is a mandatory pre-requisite for shipping 4.0, in order to develop an effective business model capable of creating additional value from knowledge. Building an adequate interconnection infrastructure requires an overall system understanding and analytic skills able to model and estimate the system performance. Because of the improvement in information systems and advanced sensing technologies, abundant sensing data provide a feasible way to study this analytic process with a data-driven approach. As stated before, the building blocks of such infrastructure are represented by "smart ships", which must be capable of interacting in real with the decision process providing relevant information about their state of operations. Achieving such a result requires a substantial innovation effort, considering that a ship is a complex engineering system, composed of many subsystems and components (e.g. propulsion, command&control, ship automation, etc.) devoted to specific functions, and their operational status contributes the overall functioning of the entire system. A ship is also equipped with some mandatory data gathering and transmission devices such as the Automatic Identification Systems (AIS), the Voyage Data Recorders (VDR), and the Automatic Radar Plotting Aids (ARPA). The shipping industry could thus potentially generate a huge amount of data from different sources and in different formats, including traffic data, cargo data, weather data machinery data, etc. Currently, the monitoring functions of each subsystem or equipment, when available, are provided by each single manufacturer, and analyzed in a non-structured manner, by human operators with elementary analytics. In such situation, important features in the data can hardly be detected and this prevents the exploitation of information for value creation. When referring to the cliché of the "digital ship" promoted by shipping 4.0, the issues related to the complexity of the system, the significant amount of data, and the lack of structured data processing procedures, must be addressed. The digital ship must thus be linked to the notion of cyber-physical systems. Such systems are not just large-scale and complex, but they are also characterized by decentralized, distributed, networked compositions of heterogeneous and (semi)autonomous elements, actively cooperating to strengthen the value chains of collaborative enterprises. Enabling monitoring and communication capabilities by integrating sensing and communication devices into a complex system allows to link its physical dimension with the virtual world of information processing. To achieve such objective a ship information system must be properly designed and deployed in the ship. Such consists of two main elements: a monitoring system and an on-board data storage infrastructure. Choosing the most appropriate communication technology for transmitting data from one device to another in a ship is a complex task, considering in the vast landscape modern wired and wireless data transmission system. As a starting point we consider that standard industrial sensors provide 4-20mA (or 0-5V) analog output signal on 2-wire or 3-wire cable. Such signal must be processed through an appropriate measurement chain in order to become the digital value of a physical measure. The measurement chain generally involves an A/D converter, which transforms the analog signal to a digital value, an amplifier, a filter to reduce the noise, and a microcomputer to perform scaling and linearization tasks. In industrial automation systems the measuring chain is generally performed by specific devices known as Programmable Logic Controllers (PLC), which can also perform control tasks, like activating relays and triggering alarm when threshold values are established. Once digitalized, the information gathered from several sensors can be conveniently transmitted into a structured protocol over serial lines between electronic devices. Such technology known as fieldbus has been introduced almost 30 years back in industrial digital communication networks to replace the existing 4-20mA (or 0-5V) analog signal standard. Controller Area Network-BUS (CAN Bus) is one of the most common fieldbus implementation, capable of ensuring data integrity and data rates of up to 1 Mb/s (less than 40 meters). Modern heavy-duty marine diesel engines, for example, come with several pre-installed digital sensors to assess their "health". On board data transmission however is not a simple task because all the materials and equipment employed must meet the restrictive maritime standards and must be watertight and robust enough to withstand severe environmental conditions. Also the wiring layout must be accurately considered taking into account ship compartmentation and the problems related signal attenuation and Contamination of the signals with Electromagnetic noise. An alternative is to use the power line communications (PLC) technology, which uses the existing shipboard mains power wiring for communication, or to use fiber-optic networks technology, which is free from Electro-Magnetic Interference (EMI) and jamming, and assures a much higher data rate. In addition, a wireless communication system can be considered an alternative to traditional wired transmissions. The motivation behind wireless sensor network is due to fully mobile operations, flexible installations, and rapid developments, although the feasibility of wireless sensor network on board vessels during realistic conditions must be carefully analyzed. Metallic bulkheads, watertight doors and multipath effects can limit the wireless communication on board [23]. Since the wireless sensor network can not transmit sensor data at the environment surrounded by thick steel walls, hybrid wired/wireless infrastructure have also been proposed in the literature, involving wired networks in the specific regions to avoid any hindrance caused by the inherent nature of ship. In such regard, also introduced a real-time monitoring system which combined PLC and Zigbee technologies in a full-scale ship has been investigated [24]. In this system, wireless sensor network was distributed in several areas and the collected data were transmitted to middleware by using PLC. Other researchers [25] proposed a wireless sensors system where ships hulls acted as wireless medium for data transfer among spatially distributed sensors. This kind of through-the-hull acoustic communication technology, provides a new direction for the research on the communication type and method in SIS.

The other fundamental element of the sipping 4.0 ecosystem infrastructure is related to the systems providing ship-to-ship and ship-to-shore communication. According to the paradigm of industry 4.0 ensuring a seamless information flow through the "interconnection" of the production resources involved in the value chain is a basic requirement for an effective digitized business model. The concept of "interconnection" not only requires the possibility of activating a bi-directional data stream among the production resources, but also to achieve an adequate level of abstraction where they can interact in a synergistic and intelligent to effectively contribute to value creation, in an extended view of "Interoperability". Referring to the maritime industry, hence, enabling 24/7 broadband ship-to-ship and ship-to-shore connectivity is a necessity for a digitized shipping industry, in order to leverage the efficiency of a globally networked business model. Differently from a standard "smart" production environment, where this is mainly a problem of ontologies, when referring to the maritime sector, this challenge must be faced primarily in the "realm" of technology. In fact, although specific communication systems and devices are required onboard ships under the SOLAS (Safety Of Life At Sea) Convention, since 1999, the functions of such systems, as defined by the Global Maritime Distress and Safety System (GMDSS) are based on MF, HF, VHF radios which makes them inadequate to support the a digitized shipping business model due to several restrictions. Maritime wireless communication is, however, differentiated from its terrestrial counterpart, because service environments are distinctly different. Global maritime communication between sea users and the rest of the world is technically developed and provided, but at a high cost. In general terms, communication from ship to ship or ship to shore is either with line of sight (LOS) type communication or communication via a "relay station" which almost always is a space satellite. LOS communication is based on radio systems and can be used for short-distance due to the significant limitations in bandwidth or coverage. Wi-Fi, for example, is merely applicable for on-board purposes and close to shore (e.g. in harbors) due to its limited range. Recently WiMAX technology has been considered a viable option for medium- to long-range broadband maritime communications, being theoretically capable of providing data rates > 20 Mbps at ranges up to 50-100 km [26], However, problems with licensing and frequencies make this technology less relevant.

Up to today. Satellite communications, are the only viable alternative for long distance sea data transmission. Mobile satellite communications for maritime industry were first provided more than 30 years ago by Inmarsat with Geostationary Orbit (GEO), at an almost prohibitive cost, subsequently with advent of Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) the costs have significantly reduced. Nowadays the Iridium NEXT system constellation, using a constellation of approx. 80 cross-linked satellites in near polar orbit provides global coverage and adequate bandwidth (up to 10 Mbps) at affordable price. However, considering that the data rate required for real time monitoring of a ship can easily reach more than 1Mbps, which makes current satellite technologies still too expensive.

In conclusion, although several technologies are available for enabling ship to ship and ship to shore communications, none of them is fully suitable to enable a shipping 4.0 interconnection requirements, due to their limitations in the coverage or their expensive cost. Recently, a system based on visible light transmission using LEDs and photo diodes for the transmission between shore and sea [27] has been proposed. Other researchers [28] demonstrated how a cloud computing enabled optimized exploitation of sources of information, significantly reduces the costs of shipping companies. In conclusion, novel maritime communication technologies are being researched, and it is expected that before 2025, many ships, systems, and components will be linked to the Internet, making them accessible from almost any location in the world. Maritime connectivity will advance significantly, and will dramatically affect how the industry manages information,

4. Conclusions

Cyber shipping constitutes the evolution of traditional shipping business into the digitized industrial paradigm envisioned by industry 4.0. With the objective of creating value from digital information, traditional shipping companies who are approaching such production paradigm necessitate new technologies and novel methodological approaches to manage their infrastructures, workforce and operations, with a substantial change in their corporate culture and decision-making processes. In this paper, we propose an analysis of the preparedness of the current shipping industry to face the fourth industrial revolution, while indicating the most significant open challenges and managerial insights. The result of the study is that there is a significant gap between the current state of the art concerning the implementation of a new digitized business model, both from a technological and an organizational point of view. In particular, although it is true that on vessels, more and more information is gathered and stored as data, their involvement in the decision making processes is still very limited, therefore such knowledge contributes only to a limited extent to strengthening of the value chain. Whether the fourth industrial revolution will succeed in achieving such objectives, it is still hard to say, considering the digitization journey is still in the early days, however a trend towards digitalization is evident. Nevertheless, the current implementation level is uneven and fragmented, and outdated operational practices like manual data reporting, are still a common industrial practice. In addition, a global standardization of the implementation process would be advisable to support industrial players in moving towards a unified direction and goal.

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