IN 4.0

ADAPTATION OF INDUSTRY 4.0 MODEL TO THE NAVAL SECTOR

WP 6.1- COST SAVINGS AND BENEFITS OF THE ADOPTION OF INDUSTRY 4.0 TECHNOLOGIES FOR SHIPBUILDING SMEs

Executive Summary

Over the last two decades, the shipbuilding industry in the EU has experienced global competition especially from countries with lower wages. EU shipbuilding has managed to maintain a leading position in specialised vessels where high quality is a sales claim. Developing on this, Industry 4.0 (IN 4.0) has been identified as crucial in order to guarantee the continuity of the sector in an increasingly demanding market, where innovation is a key factor. The European shipbuilding industry is composed of around 400 shipyards, of which most are "small and medium" shipyards (1). Moreover in Europe, SMEs account for 67.1% of jobs in the private sector, a figure that has risen to over 80% for industrial companies (2). As major players, SMEs have to meet even more complex customer needs, hence IN 4.0 presents a valuable opportunity. Studies have shown that there is a relation between Industry 4.0 implementation and the size of firm (2, 3). Two of the reasons cited for the lack of adoption of IN 4.0 by these SMEs is lack of finance and lack of information concerning the cost/benefit ratio (4). However, there is a scarcity of research that looks into adoption of IN 4.0 technologies by shipbuilding SMEs.

The purpose of this report is to outline a transnational methodology with the aim of making SME shipbuilders aware of the various options available to save costs but more importantly to add value by adopting IN 4.0 technologies. The way to escape having to compete on costs -for which EU-based shipbuilders are always at a disadvantage- is to compete on value. The automotive industry is used to contrast and compare with regard to cost savings and adding to the value proposition for the shipbuilding industry.

The report focuses on answering four questions:

1. What are the key risks that encourage the adoption of IN 4.0 in the automotive and shipbuilding industries?
2. What kinds of capabilities do IN 4.0 technologies enable?
3. Which IN 4.0 technologies are impacting the automotive and shipbuilding industries today?
4. How can uptake of IN 4.0 by shipbuilding SMEs be encouraged?

Overall, our findings suggest that a risk-based methodology is useful for the various options available to save costs and add value related to the adoption of IN 4.0 technologies. Risk is the overarching methodology for this report. Firstly, the adoption of IN 4.0

technologies can be seen as a means to manage or mitigate risk. Secondly, adopting IN 4.0 technologies has its own specific risks. Thirdly, not adopting IN 4.0 can lead to the risk of competitive disadvantage. The report (i) identifies economic, environmental and social risks as parallels between the shipbuilding and automotive industries, which can be managed or mitigated with IN 4.0. Our study of the automotive industry highlights capabilities of monitoring, control, optimization and autonomy enabled by IN 4.0 technologies such as cloud computing, Internet of Things (IoT), big data analytics/ artificial intelligence, advanced robotics, additive manufacturing, augmented reality, and virtual reality to mitigate economic and environmental risks. Although IN 4.0 can be seen as a risk management strategy, it also opens up risks for shipbuilding SMEs particularly those related to economic and social risks. These concern for instance, affordability and the lack of competence of the existing workforce. However, overall the advantages of adopting IN 4.0 clearly outweigh the risks and IN 4.0 technologies enable mitigation of risks. In particular, IN 4.0 has the potential to transform organisational structures, the design function, the role of IT, cooperation patterns and overall business models within the shipbuilding industry. Cloud based computing is recommended as a first step into IN 4.0 for SMEs because they are an affordable, accessible and simple means by which SMEs can mitigate key economic, environmental and social risks in IN 4.0. Cloud-bases computing can be tailor made or off-the-shelf to suit an SME’s immediate needs to initially drive down costs and reduce risks and can serve as a platform for further adoption of IN 4.0 technology.

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SECTION 1. INTRODUCTION

1.1 Options for Saving Costs Related to The Adoption of IN 4.0 Technologies in The Shipbuilding Industry

With the advent of the Internet-of-Things, Big Data and Servitization, we now stand on the verge of the fourth industrial revolution—Industry 4.0. Industry 4.0 was first coined in Germany in 2011 during the Hannover Fair and became part of the German government's agenda for trade and industrial development (5). Since 2011, interest in IN 4.0 has increased and the topic has gained global significance as it has become part of the World Economic Forum's agenda since 2016 (6). The fourth industrial revolution after mechanization, electrification and automation is labelled as Industry 4.0. The term Industry 4.0 refers to cyber physical systems and describes the vision of intelligently automated factories in which workers, the production system, products and even services are connected. Industry 4.0 is a strategic initiative and it represents the synonym for the transformation of today's factories into Smart Factories, promising to overcome the challenges of the product lifecycle, highly customized products and to stay in the race with ubiquitous competitors (7).

The fourth industrial revolution is based on data flows and builds on the increasing number of ways in which it can be gathered, analysed and used to make the right decisions and contribute to competitive advantage. Shipbuilding is a complex industry, with a complex structure composed of a large number of suppliers located in different locations, and of different sizes, and types. Within the shipbuilding industry, there are two distinct fields of work, one dedicated to the repair, maintenance, or improvement of ships already built and the second dedicated to building new ships (8). Building new ships could be considered as a case of distributed manufacturing, where the different components that constitute a ship are made in different locations, to be eventually assembled in a ship yard (8). If this involves different firms, then supply chain management is required to bring everything together at the right time and costs for final assembly. Therefore, shipbuilding is a complex manufacturing process that looks an ideal candidate for adopting IN4.0 in order to progress. Furthermore, the whole process from contract and design to build and usage happens concurrently (9). The cycle of design/manufacturing/maintenance is repeated, where through each stage, more information becomes available. Gathering, processing, and disseminating the right information at the right time is difficult. The way to overcome the existing limitations and reduce the lead-time of the process from design to manufacturing is through the capabilities of IN 4.0. While IN 4.0 is rapidly gaining headway in many manufacturing industries, it is still not widely considered for heavy engineering. There are only limited examples of IN 4.0 applications in shipbuilding (7).

1.2 Risks Influencing the Adoption of IN 4.0 Technologies by SMEs

In Europe, SMEs are defined as firms employing fewer than 250 persons and that have a total turnover that does not exceed 50 million euros(2). Implementing IN 4.0 may require a large financial investment and a high level of expertise (10-12), which can be problematic for SMEs(4). Yet, because the strategy of SMEs is often based on flexibility, reactivity and customer proximity, IN 4.0 appears appealing with regard to potentially providing a more streamlined flow of information and thus better planning and control processes that add to this flexibility (4).

Risk is the overarching methodology for this report. Risk can be defined as "the level of exposure to uncertainties that the enterprise must understand and effectively manage as it executes its strategies to achieve its business objectives and create value" (13).

Firstly, the implementation of IN 4.0 technologies can be seen as a means to manage or mitigate business risks.. Secondly, there are specific risks related to the adoption of IN 4.0 technologies Thirdly, lack of implementation of IN 4.0 can lead to the risk of competitive disadvantage. The shipbuilding industry presents a fragmented value chain with companies of different size and capability, from SMEs to large undertakings, with a variety in technological capabilities. The vertical as well as horizontal value system is fractured between highly equipped large shipyards and traditional but low-tech SME suppliers. Studies have shown that there is a relation between IN 4.0 implementation and the size of the firm (2, 3). Therefore, it is necessary to explore the risks related to the adoption of IN 4.0 technologies by SMEs.

However, since these are still the early phases of the IN 4.0 era, the real benefits and requirements for SMEs are still not fully known (4). We will explore technology, employees, internal and external risks that are crucial to the adoption of IN 4.0

technologies by SMEs. Figure 1 gives an overview is the risks that need to be managed while adopting IN 4.0.

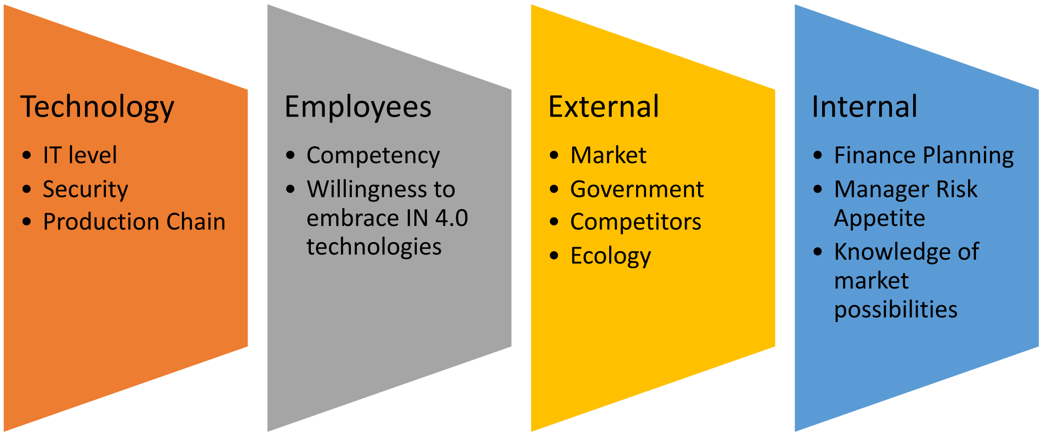

Figure 1: Risks appearing with the adoption of IN 4.0 technologies by SMEs

Employees

Studies have identified that existing employees may be unwilling to embrace IN 4.0 for fear of the potential loss of jobs (14). This is because the shift to digitisation can lead to redundancies if employees are not able to adapt quickly enough and satisfy the new requirements. Furthermore, repetitive tasks, planning and decision-making could become automated. Therefore, employees need to be able to develop new competencies, which is a major risk in the social dimension of adopting IN 4.0. Additionally, based on the shift of competencies and the reduction of process steps, the adoption of Industry 4.0 can lead to a widening of the social gap. Part of the workforce will be able to meet the changed requirements and prepare adequately for the challenges of the future through further training and education. It is unclear what will happen to those who do not succeed in this development—either because they do not want to, or because they cannot. It can be assumed that this will lead to social tensions within enterprises as well as in society.

- **Technology**

A prerequisite for the adoption of IN 4.0 is the availability and service speeds as well as the availability of data center services. The essential requirements for its use are the digital security of systems and the security of data processing in enterprises. Most SMEs tend to deal with security and maintenance by outsourcing (3). The costs of safety and maintenance have to be taken into account when considering whether or not to adopt IN 4.0 technology.

- **Internal Factors**

Know-how: Know-How includes ideas, market opportunities and integration opportunities. Both tacit knowledge and key employees play major roles in creating innovation and introducing new technologies. There is a risk of the organization culture not supporting new ideas and thoughts, creating impediments to have them subsequently developed. Another risk to innovation is to inefficiently process market information, preventing the firm to respond with agility to new trends and customer needs. The know-how of a firm is seen both as a competitive advantage due to the possession of patents and utility models, and as a gateway to technology, improving the supply chain as a consequence of information sharing (3).

An aspect that is often raised by the representatives of SMEs is that management also has to be aware of the developments and necessities that are associated with IN 4.0 (3). In particular, the shift from traditional organizational structures, i.e., the integration of IT-related expertise and their influence on decision-making, is named to be a major risk in this context. Furthermore, if the company seems to be running well, resistance against change can be encountered.

Financial Planning: Financial factors are arguably the most critical aspect preventing adoption of IN 4.0 technologies by SMEs. In a recent study (3) involving a sample of 1081 firms, it was identified that large firms are better prepared for IN 4.0 than small firms. More medium-sized firms (around 59%) are considering introducing digitization and robotic automation elements in the next 5 years, compared to less than half of the micro-enterprises in the sample. The reasons put forward for the lack of adoption of IN 4.0 by SMEs are financial constraints, and the lack of understanding of the value and cost-saving advantages of IN 4.0 to their business practices. Most SMEs have limited investment capacity which inhibits their access to new technologies. While large companies can invest in new technologies, most SMEs lack the financial clout to (2).

It is therefore necessary to assess whether firms have sufficient access to financial resources. The subsequent decision-making process deals with the question of whether to use external or internal sources of funding. A decisive factor influencing whether or not IN 4.0 is introduced is its return on investment and recovery rate. A necessary part of the investment process is risk analysis. The critical stage of the risk management process is the choice of the optimal solution. After that, the decision on the implementation of the risk mitigation measures and the decision on its further monitoring in the case of a high degree of uncertainty will follow. Risk management use the principle of feedback compared to the current situation and an assessment of possible threats to provide the fullest possible information about the likely course of their fulfilment. Without this analysis, the implementation of new technologies in connection with the introduction of IN 4.0 would be rather precarious.

Even if IN 4.0 is clearly seen as being optimal with respect to return on investment, the adoption in smaller firms will depend on the manager's risk appetite and the extent to which the manager is willing to take steps to mitigate or manage identified risks (15).

- **External**

The external risks that have a significant impact on the use of new IN 4.0 technology include technological development and the speed at which new technologies are adopted. Another important factor is the willingness of governments and communities of nations (e.g., the EU) to support the introduction of new technologies. This support can be both practical and financial (subsidies). Frequent drivers of introducing new technologies to lower costs and higher productivity are a competitive environment. It also includes market positioning of competitors, further trends in a competitive environment, and business mood. Thus, there is a risk of competitive disadvantage related to not adopting IN 4.0.

In summary, employee, technology, external and internal risk may act as deterrents to the adoption of IN 4.0 by SMEs. On the flip side, IN 4.0 presents a way of managing certain risks. The remainder of the report will be structured as follows. Section 1.3 introduces common risks in both the automotive and shipbuilding industry that can be managed by IN 4.0. In particular, we will propose that economic, social and environmental risks are common challenges faced by both automotive and shipbuilding industries which may be overcome by IN 4.0 technologies. The similar challenges faced by both the automotive and shipbuilding industries make the automotive industry a useful benchmark for the shipbuilding industry for the purposes of our investigation. Sections 1.4 and 1.5 identify IN 4.0 capabilities and technologies. In section 1.6 we will explain the context of our study for investigating how economic, environmental and social challenges can be overcome by IN 4.0. Section 2 presents the key findings in two steps. In step one (2.1), key risks faced by the vehicle manufacturers in the automotive industry are identified and linked to IN 4.0 capabilities and technologies. In the second step (2.2), key risks faced by the shipbuilding sector are introduced, highlighting areas where the best practices observed in our automotive case study can be applied. The report is concluded in section 3 with final comments and recommendations.

1.3 A Risk Methodology for Investigating the Value of IN 4.0

The decision to adopt IN 4.0 can be explained from a risk perspective. In business, each process and decision is affected by risk and uncertainty, with many consequences for a company (16). In addition, risks are not limited to the boundaries of a single enterprise, but rather are spread across an ecosystem, leading to interdependencies between suppliers, customers, competitors, and the company itself (17). Therefore, a careful understanding of particular risks inherent in a business and how they can be managed by adopting IN 4.0 presents a rationale for investment in IN 4.0 technologies. For this study, a qualitative analysis of risk is used to make SMEs aware of options available to save costs -and more importantly to increase value -related to the acquisition of IN 4.0 technologies. The way to escape the relentless competition on costs for which EU-based shipbuilders are at a disadvantage, is to compete on value.

Society has recently become aware of the environmental impacts of industrial value creation, particularly since the “Brundtland Report” of the World Commission on Environment and Development (18). As a result, a corporate philosophy that exclusively aims to maximize profits and completely neglects other stakeholders is no longer accepted

(19). This change in awareness has helped Corporate Social Responsibility reach its current and ongoing relevance (20). The Triple Bottom Line of sustainability includes the three dimensions of profit, planet, and people, which represent economic, environmental, and social aspects (21). Economic success is the basis of a company's profitability and liquidity, which ensures its existence (22). From an environmental point of view, companies act sustainably if they exclusively use resources that can be reproduced and if they only produce emissions that can be managed by the natural ecosystem (23). The social perspective includes economic action that respects the human and social capital of a society, and complements the Triple Bottom Line (22).

Due to the interdependencies between the economic, environmental, and social aspects, the different dimensions of sustainability should be taken into account within strategic and organizational considerations in the implementation of IN 4.0. Fig 2 represents these interdependencies.

Figure 2: Risk Methodology for Investigating the Value of IN 4.0 technologies

In this report, the UK shipbuilding industry will be explored.

1.3.1 The UK Shipbuilding Industry

The UK is the fourth largest shipbuilder in Europe and the third largest in boatbuilding (24). This important sector directly employs nearly 90,000 people across the UK. The shipbuilding sector has been in a long decline in the UK, particularly in terms of merchant ship builders (25). UK yards tend to concentrate more on niche markets and vessels with a high technological content. The biggest yards are still heavily dependent on building new ships. Between 1997 and 2006, the number of firms in shipbuilding and repair had fallen by a third, and as at 2006, there were 700 firms still active, most of which were small firms with less than 18 staff. By 2016, the global market share for commercial orders had fallen to 0.4%. The problems associated with demand and output of shipyards has compelled increased state intervention (26).

The UK's expertise in maritime systems, equipment, design, manufacturing, engineering and architecture is recognised internationally. The UK shipbuilding industry is a sector that is still thriving, with plans to grow even stronger in the years ahead, building on competitive strengths that have been developed over many years. The industry spans six subsectors that include: shipbuilding and repairs; shipbuilding equipment; shipbuilding renewable energy servicing; leisure and small commercial boats; shipbuilding science; and shipbuilding consultancy. Therefore, to remain truly competitive, the UK needs not only to provide innovative market leading products and services but has to ensure that skills and technology is being developed for the longer term. Overall the overarching transnational methodology of High Value Manufacturing (HVM) informs UK manufacturing industries. Generally, the term HVM refers to the resolution for UK manufacturing firms to avoid price competition. High value manufacturing is based on value rather than costs. IN 4.0 is a means to do HVM. Although the case for IN 4.0 may be well established, plans for Shipbuilding 4.0 are less advanced. For organizations already using high levels of automation, IN 4.0 and digitalization of operations can be a relatively small step (27). However, in sectors like the shipbuilding industry where investments are larger (28) and life cycles significantly longer and more challenging(7, 27), IN 4.0 becomes a more complicated issue.

1.3.2 The UK Automotive Industry

It is difficult to isolate IN 4.0 analysis to a single country. For example, The UK automotive industry benefits from a diverse mix of manufacturers bringing German, Japanese and US perspectives on IN 4.0 (29).The UK now is the second largest vehicle market and the fourth largest vehicle manufacturer in the EU. It is also the second largest premium vehicle manufacturer after Germany. The UK has the most productive automotive factories in the EU. A recent report by KPMG (29) indicates that the UK automotive industry is well positioned to benefit from IN 4.0. The study highlighted that although many vehicle manufacturers recognise the importance of digitalisation, so far only a few had initiated a series of pilots. Some suppliers, notably SMEs had not begun any significant digital pilots. Manufacturers and suppliers both forecast substantial benefits from digitalisation including productivity gains, shorter lead times, more personalised vehicles and enhanced services for customers. A key barrier to implementation of IN4.0 by SMEs was found to be a lack of knowledge and the necessary skills to design and execute a companywide digitalisation strategy.

As explained earlier, this report will draw on an industry different from the shipbuilding industry in order to identify cost-saving strategies and value adding opportunities of IN 4.0, which are applicable to the shipbuilding industry. The automotive industry is selected for benchmarking because they seem to be more advanced in their adoption of IN 4.0 technologies compared with the shipbuilding sector. However, there are differences between both industries. For example, the supply chain of the automotive industry consists of companies of larger sizes compared to the supply chain of the shipbuilding industry which has mainly SMEs. Some suppliers to the automotive industry like Omnium Plastic, Farina, and Mecharome have separate units dedicated to specific car manufacturers, a phenomenon that does not exist among the many shipbuilding suppliers. Nonetheless, with respect to IN 4.0 both industries can be compared with respect to risk.

Risk drivers are crucial to determine a relevant IN 4.0 strategy. Therefore, a case can be made for adoption of IN 4.0 technologies by carefully linking risks with IN

4.0 capabilities and enabling technologies. Environmental, economic and social risks are defined as common interrelated risks across both the automotive and shipbuilding industries.

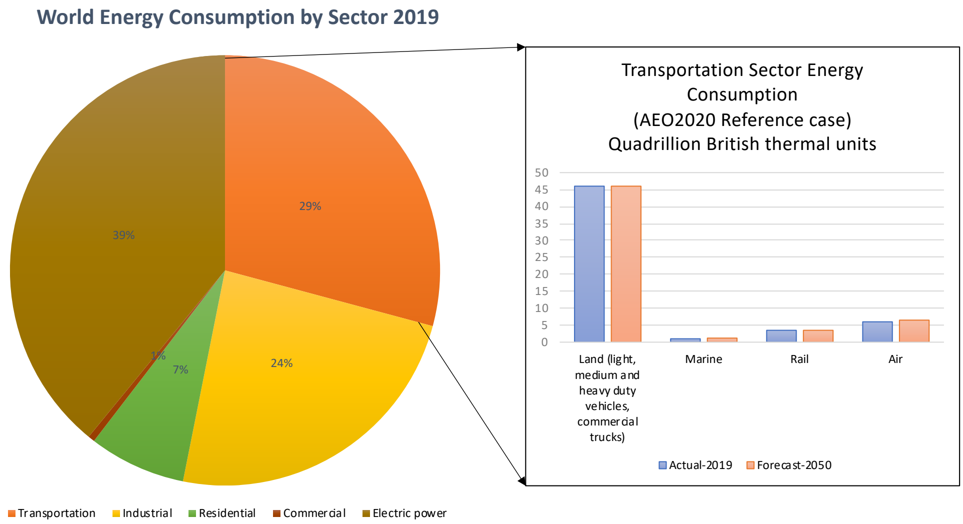

Figure 3: World energy consumption (2019) and breakdown by transportation sector

- ***Environmental Risks***

From the chart presented in Figure 3, one can observe that marine vessels have lower energy consumption rates than land, rail or air modes of transportation (29). One of the main reasons for this can be attributed to more stringent environmental regulations that are being introduced in the shipbuilding industry to reduce energy consumption and carbon emissions. Ships currently transport 90% of international trade (30). Ships are built to customised specifications such that the design and manufacturing processes are highly individualised (7). Ongoing changes in environmental regulations have an impact on how ships are designed, manufactured and operated. For example, in 2013 the International Maritime Organization (IMO) introduced the energy efficiency design index (EEDI), which defines the energy efficiency standard for new ships (IMO 2016). As part of the energy efficiency design index (EEDI) regulation implemented by the International Maritime Organisation (IMO) in 2013, ships built after

2025 will have to be at least 30% more fuel efficient (31). The Ship Energy Efficiency Management Plan (SEEMP) was introduced by the IMO to provide guidance for fuel-efficient ship operation. As part of the recommendations, measures such as the use of weather routing to optimise efficiency will help to significantly reduce fuel consumption and, consequently, carbon emissions (7).

Consequently, green requirements and energy efficiency are now key design criteria for the construction of new ships (32). These regulations include controls on exhaust emissions, installation of fuel-saving devices and the push for more efficient hull designs (32). Therefore, systems and processes need to be more flexible and adaptive to customisation and production changes. Hence it is important to consider temporal aspects by paying attention to the various design and manufacturing aspects and how these impact and are impacted by the entire lifecycle of a ship in order to improve the overall energy efficiency (7).

Similar to the shipbuilding sector, all major global automotive markets have in place increasingly stringent legislation focused on controlling carbon dioxide emissions and exhaust gas emissions- such as particulates and nitric oxide (NOx) and improving fuel economy, with the EU forcing car manufacturers to limit emissions during the life cycle of a car. Automotive manufacturing industries are facing new challenges in the multi-faceted context of economy, technology and environment. Increasing energy prices and environmental issues mean that energy is now one of the major costs in automotive manufacturing industries and also responsible for a significant proportion of Green House Gas emissions (33). The development of energy efficient techniques in automotive manufacturing operations is crucial to reduce energy consumption, Green House Gas emissions and also production costs. The amount of energy consumed in manufacturing systems accounts for a significant proportion of carbon emissions which has a major impact on climate change. More specifically, electricity is the major source of energy in manufacturing, and more than 60 per cent of all electricity is produced from fossil fuels. For these reasons, carbon emissions are a crucial component of energy efficiency particularly in the automotive industry. Machine processes and tools consume a significant amount of electrical energy. Thus, one solution is to improve the efficiency of machines and equipment such that carbon emissions can be reduced.

- ***Economic Risks***
- This most basic assumption underlying business strategy is that a business is set up to make a profit. Therefore, managing economic risks are key to the survival of the shipbuilding industry. Different strategies channelled towards becoming leaner and making more efficient use of resources are to be encouraged.

Energy efficiency is an important factor in the shipbuilding industry and can be linked to reduction in manufacturing and operational costs. Energy efficiencies and lower amounts of fuel consumption in turn leads to greater cost-efficiencies as fuel is the single highest expenditure for ship operations and accounts for 65%-75% of overall costs (34). Therefore a 1% reduction in fuel consumption can result in annual savings of up to $3,000,000 for a large container vessel (7). In short, a capability to reduce fuel and energy consumption can help to improve the shipyard's value proposition, as it improves a ship operator's competitiveness through maximizing operational and constructional cost savings as well as reducing harm to the environment through greener ships. In addition to reducing operational costs or efficiencies through reduction in fuel consumption, there are other avenues for cost efficiencies with regard to ship operations, e.g. improving quality of machines, reduction in labour, faster turnaround periods, nad the reduced cost of maintenance, that all add to the shipbuilding value proposition.

As mentioned earlier, the marine sector can be distinguished from other industrial sectors because of highly individualized and short production series. This explains the lack of automated production, with most technical tasks still manually accomplished, and the arrears in manufacturing innovation compared to other sectors such as aerospace or automotive, whose manufacturing processes are highly innovative and automated (27). Unlike consumer products where the components are mostly homogenous (low mix) and manufactured in large volumes, ships are considered engineering structures that are highly customised (high mix) and constructed in low quantities (low volume) (7). Yet, in the face of new regulations, global competition and cost-effectiveness, IN 4.0 presents a means by which shipbuilders and operators can overhaul the overall lifecycle of a vessel from ship design, manufacturing and operation process to achieve energy, cost and innovation goals, especially with regard to high mix and low volume production and usage..

- ***Social Risks***

IN 4.0 is also expected to have benefits with respect to the social dimension. For example, employee job satisfaction can increase if more dangerous tasks are allocated to robots, and greater flexibility and the option of working from home is also identified as a key advantage (35). Additionally, IN 4.0 encourages partnerships across sectors and increased cooperation which enables more productive working environments.

1.4 What kind of capabilities are enabled by IN 4.0?

Managing and mitigating risk requires investment in different IN 4.0 capabilities. In identifying the different capabilities of IN 4.0, we draw on a framework proposed by Porter and Heppelmann (36) to establish a list of four distinct capabilities aligned with the concept of IN 4.0. The capabilities of IN 4.0 can be grouped into four areas: monitoring, control, optimization, and autonomy. Each capability builds on the preceding one; to have control capability, for example, a product must have monitoring capability, and to have optimization capability, a product must have both control and monitoring capabilities. The value drivers for IN 4.0 are embedded within these capabilities. Figure 4 is a representation of IN 4.0 capabilities. It is important to realise that these capabilities are relevant for both shipbuilding as well as vessel operation. While IN 4.0 will have the potential to reduce costs for shipbuilders, its biggest impact is with regard to the increased efficiency of operating a vessel. If shipbuilding is recognized as pivotal for the whole life cycle of a vessel, designing and building ships with this in mind will add to a shipbuilder's value proposition.

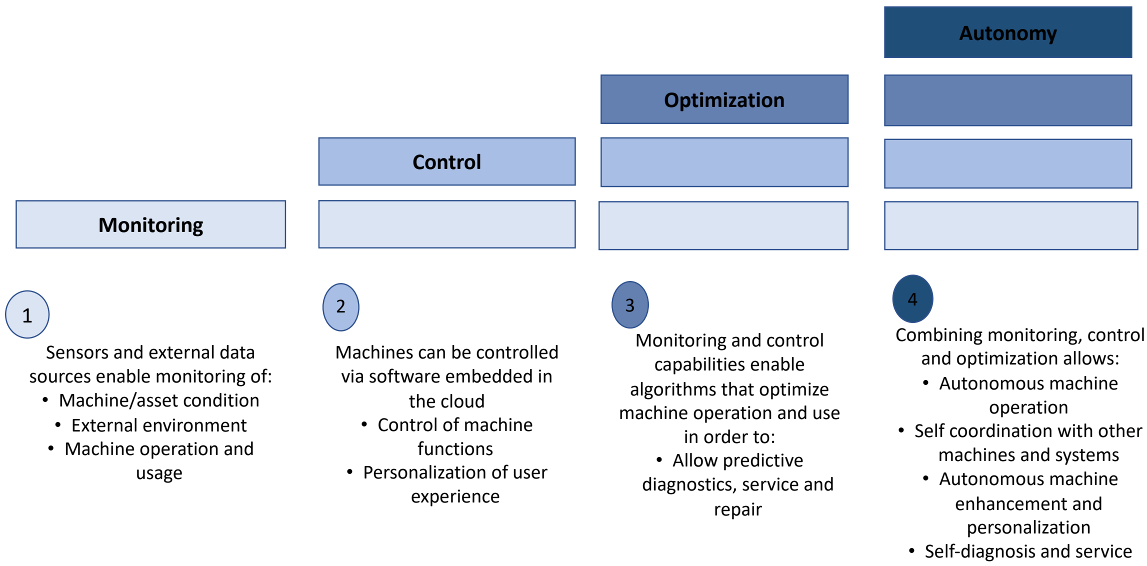

Figure 4: IN 4.0 Capabilities

- ***Monitoring***

Firstly, connected devices and sensors using Radio Frequency Identification (RFID) technology enable the comprehensive monitoring of a product's condition, operation, and external environment. Using data, a product can alert users or others to changes in circumstances or performance. Monitoring also allows companies and customers to track a product's operating characteristics and history and to better understand how the product is actually used.

- ***Control***

The data collected through real-time monitoring leads to control capability. Control favours the interaction of humans and systems through the use of historical data and predetermined thresholds. Predictive analytics, cognitive computing and artificial intelligence improve the collection and transmission of information throughout the entire system thus enabling better control of machine operation, processes and systems and energy usage. In this way, performance levels can be defined, and modifications can be made accordingly. Remote commands or algorithms that are built into the device or reside in the product cloud. Algorithms are rules that direct the product to respond to specified changes in its condition or

environment (for example, “if temperature gets too high, shut off the valve” or “when temperature gets too low turn on the valve”). These algorithms allow temperature to be managed and controlled accordingly such that energy is consumed at the possibly lowest rate.
Real-time control is becoming more critical in improving system efficiency and responsiveness and also in reducing breakdown periods (37).

- ***Optimization***

The capabilities of monitoring data from smart, connected products, coupled with the capacity to control product operation, allows optimization of product performance in a variety of ways, most of which has not been previously possible. Real time monitoring, and control enables information transparency as the data collected through interconnection needs to be made available to all key members of the value chain which results in optimization of production and services. An energy efficiency system has a great potential in reducing energy consumption in manufacturing (38). In automotive manufacturing, energy consumption can vary depending on various factors such as the size of the cars being produced. Recently, it has been estimated that the energy demand in manufacturing plant range between 1.39 MWh and 3.42 MWh with an average of 2.5 MWh per car. Optimisation of energy consumption is likely to reduce this rate. The monitoring and control capabilities also enable predictive diagnostics, service and repair.

- ***Autonomy***

Monitoring, control, and optimization capabilities combine to allow smart, connected products to achieve a previously unattainable level of autonomy. In this way, cyber physical systems are able to physically support humans by conducting a range of tasks that may be unpleasant, too exhausting, or unsafe for their human co-workers. Additionally, there are lower margins for error, and there are more consistent and verifiable results that are digital; enabling future access to machine learning and artificial intelligence options. This allows technical assistance as low value tasks can be shifted from people to cyber physical systems. In this way, decision making can be decentralised as the systems are capable of making their own decisions and taking autonomous action. All of these levels of IN 4.0 capacities are enabled through the implementation of various technologies, described in the following subsection.

1.5 IN 4.0 Enabling Technologies

IN 4.0 represents technologies that enable connectivity and interaction between all parties involved in manufacturing. There are many studies that describe the basic components and technologies of IN 4.0. Ang et al. (7) summarised IN 4.0 as a collaborative network that combines seven key enabling technologies, namely intelligent robots, automated simulations, Internet-of-Things, cloud computing, additive manufacturing, augmented reality and big data analytics. Figure 5 provides an overview of IN 4.0, depicting the development timeline of the four Industrial Revolutions with their key features as well as core technologies for IN 4.0.

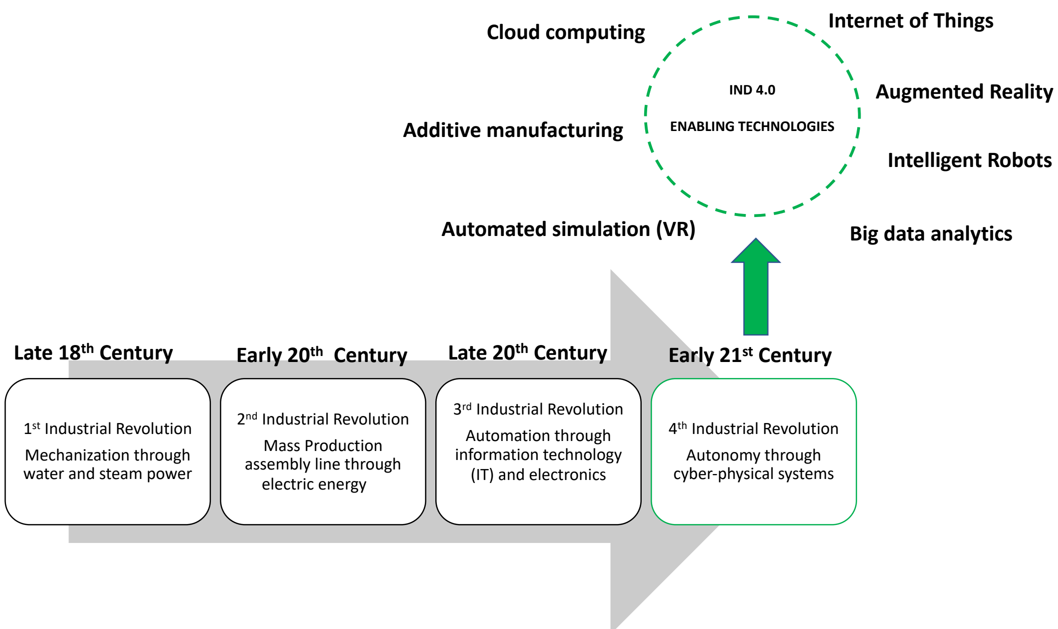

Figure 5: IN 4.0 development timeline and enabling technologies

The enabling technologies can be summarised as follows:

- ***Internet-of-Things (IoT)***

IoT can be described as the concept of gathering information from physical objects through the use of computer networks or accelerated wireless connections (39). IoT is used to link any object (thing) in the physical world by being connected over the Internet. It allows field devices to communicate and interact with one another and helps to decentralise analytics and decision-making, thereby enabling real-time responses (4).

Cloud computing (CC) and cloud manufacturing

Cloud computing can be viewed as a way to deliver IT enabled services in the form of software, platforms and infrastructure using internet technologies. Cloud computing is defined as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. The major driver for this widespread adoption is the economic benefit that cuts expenses for existing applications (Sandhu et al., 2010).

CC is a general term for anything that involves delivering hosted services over the Internet(40). Instead of a static system architecture, CC enables users to dynamically scale up or down leading to high reliability, rapid response times and flexibility to handle traffic fluctuations and demand. CC allows machine data and functionalities to be deployed in the cloud, thereby enabling more data-driven technologies and monitoring systems (7). Through the use of CC, communication and exchange of information can be expanded easily with the use of cloud computing technologies by providing easy means of network connectivity. With quick reaction time of milliseconds and large bandwidths, CC allows information to be shared across multiple systems and networks in real time, thus ensuring that data and applications are available everywhere, at any time and from any terminal(41) .

In this way, CC promotes an environment of digitally enabled collaboration and integration, driving efficiencies and enhancing risk management. The use of CC resources in the context of manufacturing is known as Cloud Manufacturing (CM). CM has many definitions, one of which defines CM as manufacturing focused on providing services based on resources from its pool of virtualized manufacturing material. CM provides scalability and flexibility at lower costs through sharing resources in the cloud. Information can be shared in the cloud via Internet access. Additionally, CM enables a manufacturer to provide access to equipment and production data to any Internet-connected device. This is actually the main advantage of the cloud concept, and the global availability of data has been beneficial to the manufacturing industry.

- ***Virtual Reality (VR)***

VR technology is designed to present the senses with a computer-generated three-dimensional environment that can be explored and interacted with to some degree. The illusion is created by activating many of the senses, including vision, hearing and feel. Traditional ways to present media are also designed to immerse the user, but these technologies do not strive to create an ever-improving illusion of another reality.

In practice, the illusion of VR is created by presenting visual data on screens within a headset that completely obscures the user's vision. VR enables the physical world to be mirrored in a virtual model(7). An example of this are digital twins which are already in use in manufacturing design processes. Digital twins are a virtual image of a component, product, or system, which reflects the status of the object in question. The integration of different computer tools allows users and designers to simulate the performances of all aspects of a production system(42). Digital twins can be used for a wide range of purposes, including design adjustments and diagnostics. Additionally, because they are accurate representations of physical assets, they can also be utilized to streamline and optimize the commissioning phase. Instead of commissioning a new system or robot cell in the physical world, virtual commissioning involves creating a digital twin and then testing and verifying the model in a simulated virtual environment. Automated simulations enable the physical world to be tested in a virtual model(7). An Example of this are digital twins which are already in use in manufacturing design processes. Digital twins are a virtual image of a component, product, or system, which reflects the status of the object in question. The integration of different computer tools allows users and designers to simulate the performances of all aspects of a production system(42).

- ***Additive manufacturing (AM)***

AM is the name used to describe technologies that are used to produce 3D objects by adding layer upon layer of material, often also referred to as 3D printing. AM methods can be widely used to produce batches of customised products that offer construction advantages such as complex and lightweight design(7). Due to the necessity for mass customization in the IN 4.0 era, non-traditional manufacturing methods need to be developed. Therefore, AM is a key technology for fabricating customised products due to its ability to create sophisticated products with advanced attributes(39). The concept of additive manufacturing requires that components be constructed from data files derived from three-dimensional (3D) Computer Aided Design (CAD) software and are manufactured by adding material together. This is in contrast to more traditional subtractive manufacture where material is removed through processes such as machining (Griffiths, 2002).

Advantages of additive manufacture lie in the ability to produce highly complex parts that require no tooling and thus reduce the costs of manufacture, especially for low volumes (Hopkinson and Dickens 2001, Griffiths 2002). As high volumes do not need to be manufactured to offset the cost of tooling then the possibilities for affordable, highly complex, custom parts becomes apparent.

Augmented Reality (AR)

AR is an interactive virtual interface of a real-world environment where real world objects are enhanced through computer generated perceptual information. AR provides employees with real-time information to improve decision-making and work procedures through AR devices. AR can also help create digitalised visual workflows that can is used for worker training(7). AR technology enables humans to access the digital world through a layer of information positioned on top of the physical world. According to the Mixed Reality (MR) framework, AR is positioned in between the physical and the virtual reality (VR). AR augments the real world without replacing it. This contrasts the concept of VR, where all the information is presented virtually. AR can be used for design and manufacturing applications, assembly operations, either in training or as an online guidance system for operators. In logistic, 'pick-by-vision' is a prominent concept utilising AR to indicate picking locations and quantities. Other areas where AR can also be used include warehouse operations. Another prominent field of applications includes quality assurance, maintenance, supervisory control and data acquisition (SCADA) tasks, through-life engineering services and visualisation of instruction.

Big Data Analytics

The extracted information from IoT technologies constitute substantial amounts of statistical data, i.e. big data. Big data analytics is used to describe very large or complex datasets and can be used to support real-time decision-making via the collection and evaluation of data from various sources within and outside of the organisation(7).

-
- ***Advanced Robotics (Human robot interaction technologies)***

In an attempt to follow the requirement for more customized products and smaller lot sizes, production and research engineers have turned to the concept of Human Robot Collaboration. The benefits of implementing such production cells lays in the implementation of flexible and highly reconfigurable production systems which can easily change their operation to accommodate different product families, similar to the way that a human operator would do.

1.6 RESEARCH CONTEXT

We applied a two-step methodology in our investigation. First, we conducted interviews with staff from Ford Motors UK to investigate the risks that are general to the automotive industry and to Ford in particular, the IN 4.0 technologies they currently use, and the value or advantages they realised by using these technologies. We gathered information from staff of Ford in order to investigate costs and benefits of IN 4.0 technologies that are transferable to the shipbuilding industry. We used a large company as our case company because SMEs in the automotive sector have not begun any significant digital pilots. A key barrier to implementation was found to be a lack of knowledge and the necessary skills to design and execute a company-wide digital strategy. Another key barrier is the trust needed between supplier and manufacturer to share data electronically. SMEs identified funding for investment as a concern as well(29).

In the second step, we also conducted expert interviews with IN 4.0 software vendors such as Aveva, Hexagon, and suppliers like SKF, all working within the shipbuilding value chain to gain deeper insights into the potential of IN 4.0 tools as well as their uptake within SMEs or larger firms. During our research we found risk to be a common thread used to explain the value and adoption of IN 4.0 technologies. Additional to conducting interviews, we attended webinars and embarked upon desktop research. These webinars were mostly organized by the aforementioned software vendors. In addition to webinar attendance, we also interviewed a number of experts from Aveva, SKF, Hexagon and Relianeering. The purpose of interviewing the software vendors was to understand their product offerings and the extent to which their services and technologies for digital manufacturing for shipbuilding can be adopted by SME shipbuilders. Adoption of IN 4.0 by SME shipbuilders is rare, which is why we were unable to interview SME shipbuilders on their experience with adopting IN 4.0 technologies.

HEXAGON PPM

Hexagon is an established leader in information technology and solutions. Hexagon has offices in Stockholm and London. Hexagon has over 20,000 employees in 60 countries and service a broad range of industries. The PPM (process, power and marine) division is the awarded solution provider of engineering software for design, construction, fabrication and operation of major industry segments such as oil and gas, chemicals, electric power, marine and mining and metals.

AVEVA

AVEVA is a British multinational information technology company headquartered in Cambridge, with over 4,400 employees across 80 countries. AVEVA grew out of the government-funded Computer-Aided Design Centre, which was established in 1967. Across shipbuilding, ship operations, and shipyard operations, AVEVA's solutions for the shipbuilding industry offer complete and up-to date engineering and operational data throughout the lifecycle of the ship.

SKF

SKF is a bearing and seal manufacturing company founded in Sweden in 1907. The company manufactures and supplies bearings, seals, lubrication and lubrication systems, maintenance products, power transmission products, mechatronics products, as well as condition monitoring systems or services globally. SKF is the world's largest bearing manufacturer with 17,000 distributor locations encompassing 130 countries, one of which is the UK.

RELIANEERING

Relianeering is a technological consultancy company with employees with extensive experience in Reliability and engineering. The company was founded in 2015. Relianeering has developed an innovative and revolutionary platform called ReSES.net used to support a simple, easy and affordable approach to IN 4.0.

1.6.1 Data collection and Analysis

Using the collected data, data analysis followed both relying on theoretical propositions and developing case descriptions to employ pattern matching and explanation as primary tools in our investigation. During our research we found risk to be a common thread used to explain the value and adoption of IN 4.0 technologies. Our analytical framework, as shown in Figure 6 illustrates the risk methodology that we used to guide the analysis of our research findings. Each of these elements is described further in section 2. IN 4.0 introduces new possibilities that may disrupt traditional approaches to manufacturing. Smart connected machines enable capabilities that allow different types of risk to be managed. Hence, it is essential to classify IN 4.0 capabilities in terms of their desired risk management objectives. Additionally, IN 4.0 capabilities are enabled through implementation of various groups of IN 4.0 technologies. Each group represents different ways of implementing the desired capabilities. There is therefore a close relationship between the risk that an organisation faces, levels of IN 4.0 capability and the IN 4.0 technologies that are required to manage them.

SECTION 2: FINDINGS OF THE STUDY

2. IN 4.0 In the Automotive industry

As mentioned in the earlier section, IN 4.0 both the automotive and shipbuilding industry is largely understood to be driven on the basis of costs, energy usage, operational efficiency, and quality improvement. The findings from our desktop research and interviews highlight that economic, social and environmental risks drive the adoption of IN 4.0 in the automotive industry, hence IN 4.0 is used as a means of managing these risks. Monitoring, control, optimization and autonomy are key IN 4.0 capabilities that help the automotive industry to manage or address these risks and sensors and tracking technologies, augmented reality, virtual reality, additive manufacturing, big data analytics and advanced robotics are the key IN 4.0 technologies used to enable these capabilities.

2.1 IN 4.0 as a means of managing risk in The Automotive Industry

Our case study of the automotive industry identified economic, social and environmental risks as key to the adoption of IN 4.0 by vehicle manufacturers in the automotive industry. Fig (6) represents the IN 4.0 technologies which enable digital capabilities that allow automotive firms to manage economic and environmental risks inherent in their business operations

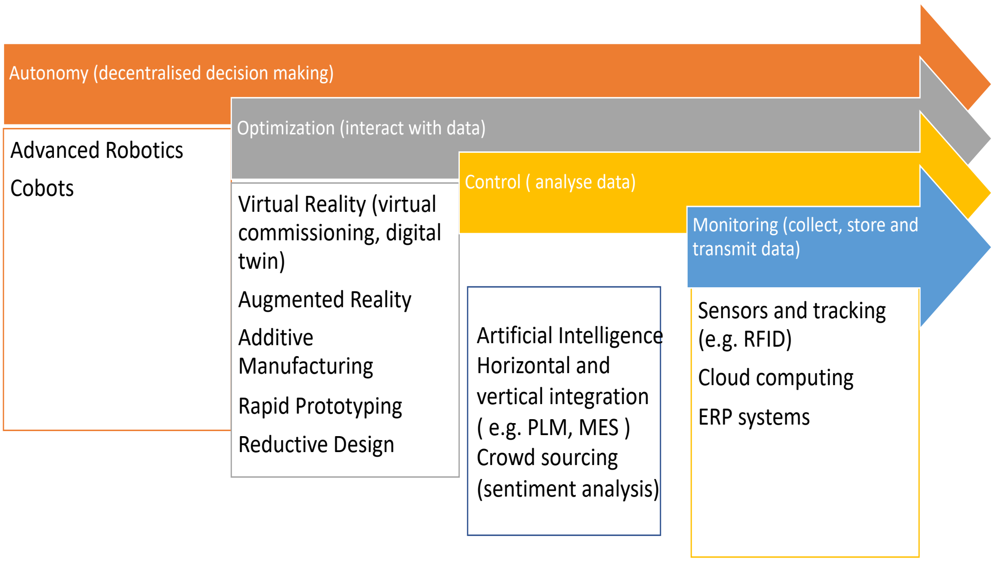

Figure 6: IN 4.0 technologies that enable digital capabilities for risk management

From a risk management perspective, IN 4.0 technologies enable capabilities that allow automotive companies to manage or mitigate economic, social and environmental risks. These findings will be explored in more detail below.

2.1.1 Economic Risk Management

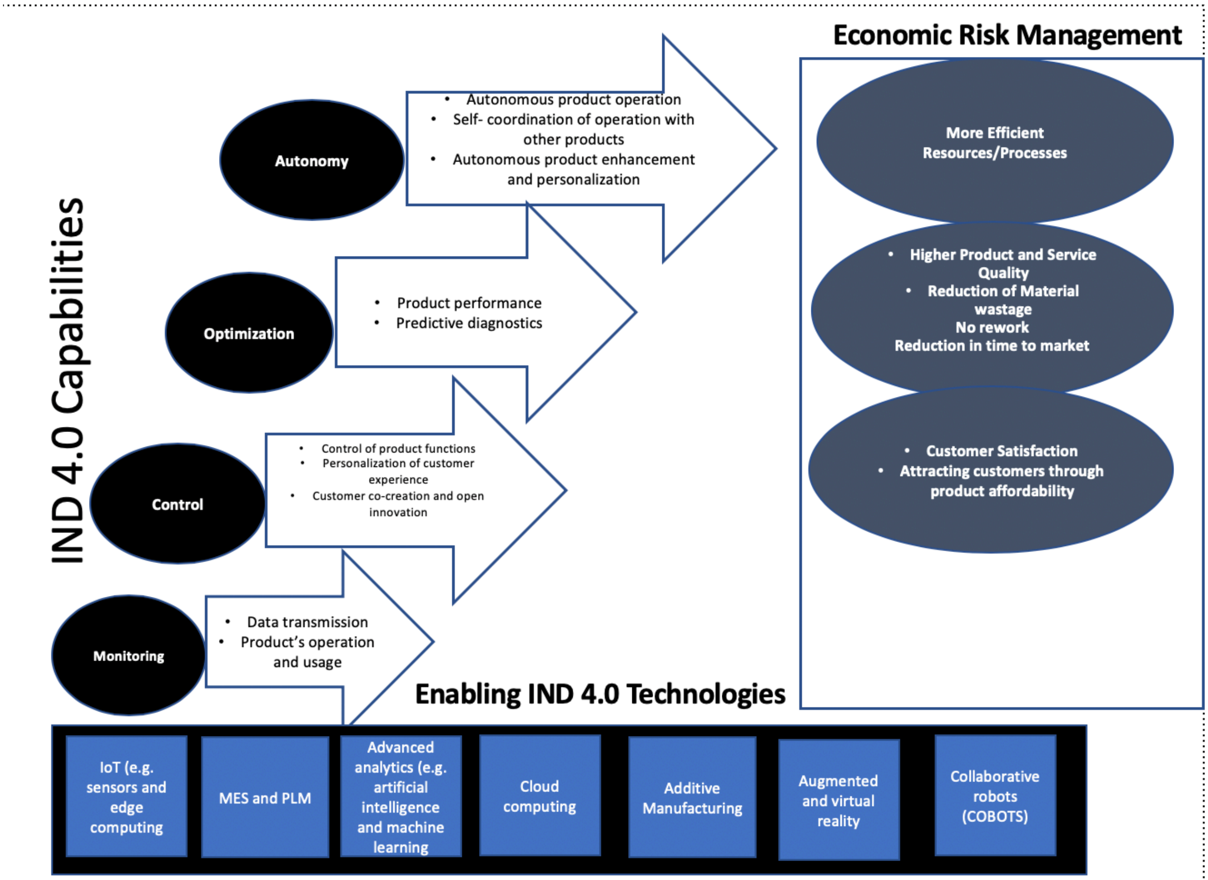

Figure 7: Linking economic risks, IN capabilities and enabling technologies in the automotive industry

- *Time to Market*

Time to market is the amount of time it takes to design and manufacture a product before it is available for purchase. Bringing a new product to market earlier creates benefits by increasing revenue and early mover advantages. Hence, IN 4.0 delivers in speeding up the development process to help to drive this value. Rapid prototyping saves the company money in not having to make several iterations of the same design and greatly reduces a component's time to market. The capability of control enabled through AR and VR, data analytics and cloud computing allow the customization of product performance to an extent that was previously not cost effective or even possible. For example, the use of cloud computing platforms has the potential to shorten design time through collaboration between all partners of a network in different locations. Additionally, the use of digital twins enables rapid experimentation and simulation with the overall effect of increasing team productivity and speeding up the manufacturing processes as a whole. Furthermore, AR and VR are useful for better design accuracy when designing equipment for the future. Flaws detected in machines can be communicated to the manufacturers who then remedy this in future designs. Additionally, customer co-creation and open innovation is enabled which is a useful part of the design workflow for the future. For example, when customers send parts list, they are able to import the information into software, which very quickly transforms the data to something that can be used for future design thus considerably shortening the design phase.

- *Inefficient Resources and Processes*

The pressure to be more environmentally sustainable as well as to drive down costs has led to increased efficiency in every possible manner. This has driven vehicle manufacturers to work towards resource productivity and minimisation of waste. Due to ever new product variants expected by customers the product lifecycle is considerably shortened, so work on product and process innovation is kept up to date. Labour and production development optimisation are key means of driving down operational costs.

- Labour

Improving labour productivity helps to significantly improve efficiency. This benefit can be captured through levers that reduce waiting time, increase speed of workers operation or even reduce the number of workers required to perform tasks. The capability of autonomy is useful in driving down costs and risks associated with human labour. The implication of autonomous systems is that the process ultimately can function with complete autonomy. Human operators merely monitor performance or watch over the fleet or the system, rather than over individual units. Monitoring and control capabilities using augmented reality can also help to decrease the costs of labour. Robots have been part of the automotive production line ecosystem for some years now and in the IN 4.0 era, a particular interest in collaborative robots- or cobots as they are familiarly known has developed. These machines are designed to operate alongside human workers and Ford has installed over 100 of them across 24 of its facilities.

- Product Development

Product development processes in the automotive industry have accelerated, due to the ability of designers to make 3D printed models of several different designs, which can then be tested by engineers simultaneously. The printing of 3D replacement parts helps to keep production running without having to wait for days or weeks for parts to be ordered and manufactured. Additionally, rapid prototyping saves the company money in not having to make several iterations of the same design, and greatly reduces a component's time to market.

- *Customer Satisfaction*

The current trends in a firm's competitive environment and business mood play a role in shaping customer expectations. For example, the success of companies like Apple who are constantly updating their operating systems features has led to higher customer expectations which spills over to the automotive industry as well. Customers now expect regular updates or new features. In order to overcome this challenge, the car manufacturers are under pressure to change the way they use more agile software that enables them to update their systems multiple times a year in order to keep their customers satisfied. It is one thing to build safe and sustainable vehicles, it is another thing to understand exactly what the customer wants. Being able to understand customer behaviour and needs is key to increasing profitability. For example, data is collected from the car and the customer through onboard diagnostic units, sensors and cameras. This enables vehicle manufacturers like Ford to use a "reductive design" approach, which is the ability to eliminate all those items that buyers do not use, need or care about but end up adding to the cost of the vehicle. For example, using monitoring and control capabilities vehicle manufacturers like Ford has recently taken out CD players from cars because they were hardly used by customers. By doing so, they have taken out a few hundred pounds worth of kit in the vehicle. This enables vehicle manufacturers to give the customers more what they wanted. In the future, this data will allow car manufacturers to provide monitoring services of vehicle health, wear and tear and malfunctions. Using data analytics, the driving style of the user and distance travelled can be used to predict energy consumption, vehicle maintenance etc.

Most new cars manufactured are now connected to the Internet. Cars collect increasing amounts of data from onboard diagnostics units, sensors and cameras.

Sensors and modems installed in cars enables vehicle manufacturers to monitor what customers are using their vehicles for. For example, a customer pays for the potential of the battery so the bigger the battery, the higher the cost of the battery and a battery-operated electric power train is much more expensive than the standard combustion engine power train. The monitoring allows optimization in the design of future products. For example, vehicle manufacturers are able to fit the vehicle to customer usage as much as possible, thus giving customers the best value products. Big data is used to manage and mitigate the products in the future and what to offer customers. Without real-time feedback of how customers are using their vehicles through the modems with the cloud, vehicle manufacturers would have to resort to very old-fashioned things like surveys or interviews. So monitoring, control and optimization capabilities helps to mitigate the risks and basically making sure the customer gets the product they really want.

- Quality

Improving quality is another benefit as products requiring rework lead to extra costs (for machine time, material and labour). The optimization capability enables continuous improvement in the quality of machines. Additionally, digital twins are also used to enable increased transparency regarding the status of energy systems. Data is used to compute accurate predictions of industrial energy consumption and generation. By reducing uncertainties in the forecasting of industrial energy consumption and generation as well as in the identification of technical failures, security of energy supply can increase significantly although power generation is increasingly dependent on the weather conditions. It is about continuous improvement of the product, whether it be the machinery what it was originally or there is a built defect.

IN 4.0 technology also has an impact on the conceptual phase of automotive production, and augmented reality (AR) and virtual reality (VR) technologies are used in the design stage. The digital environment enables engineers to create virtual production lines, run test case scenarios, identify potential hazards, and fine-tune the manufacturing process before the vehicle is assembled. Additionally, specialised gaming equipment is used to configure VR production lines with real world potential. AR overlays and VR simulations allow them to identify potentially hazardous manoeuvres and fine tune production workflows, long before the assembly lines are constructed. With Internet connectivity, the design process is now both collaborative and global.

Additionally, vehicle manufacturers now offer a VR feature allowing customers to 'sit' in and personalise car models as part of the purchasing process.

2.1.2 Environmental Risk Management

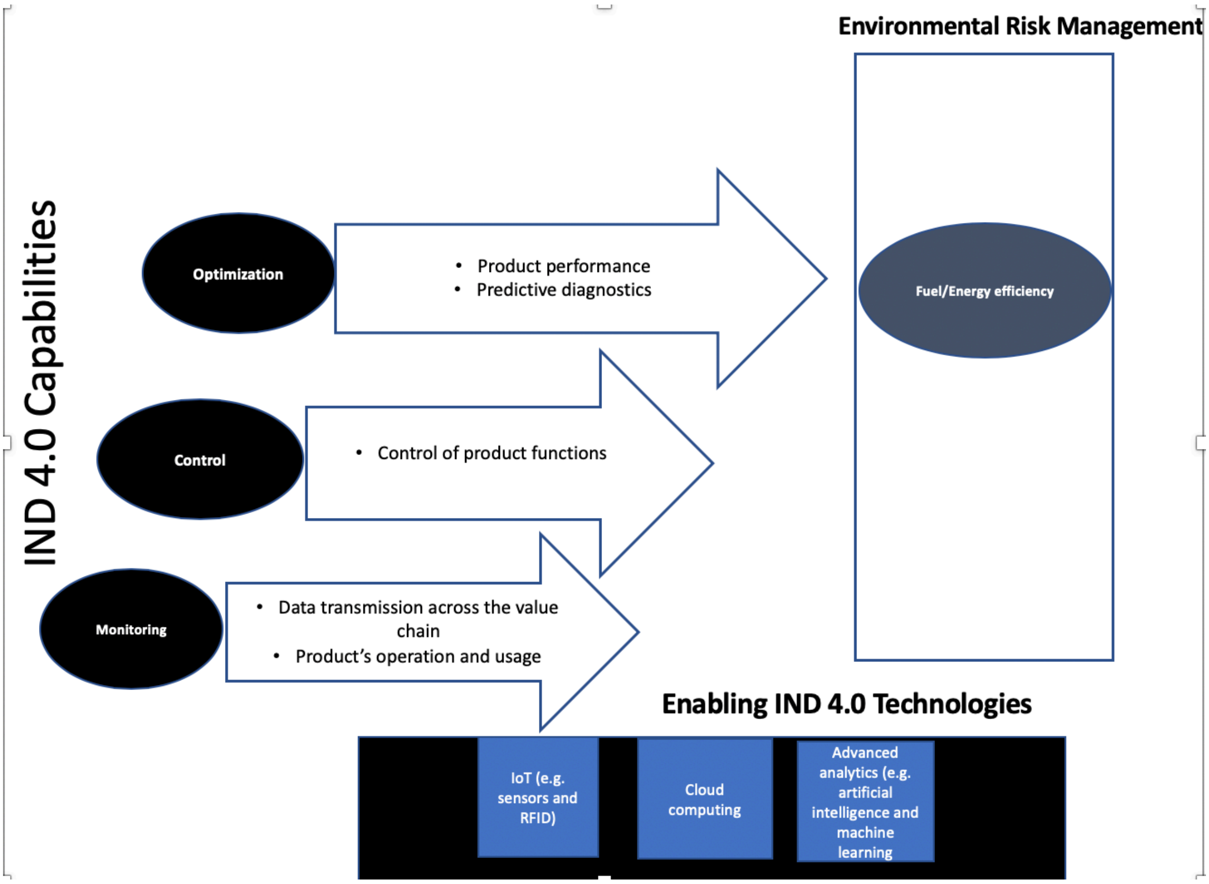

Figure 8: Linking environmental risks, IN 4.0 capabilities and enabling technologies in the automotive industry

From the 1980s onwards, the vast majority of automakers have adopted a pro-active attitude towards the reduction of the environmental impact of their production processes. Every major high-volume car manufacturer has worked towards increased levels of environmental performance and there are no doubts that improvements have been made. Firms within the automotive value chain are pumping in billions of dollars into making connected, autonomous, shared, and electric vehicles (EVs) a reality.

In a bid to manufacture safer and environmentally sustainable vehicles, there have been significant increases in new-car prices over the past couple of years. This creates the risk of prices rising to the extent that most customers will be unable to afford new cars or even unwilling to pay for them. This unwillingness to pay for more expensive electric vehicle technology in particular is part and parcel of a more general lack of willingness among consumers in developed economies to spend extra for other types of advanced automotive features(43).

At the moment regulation, especially in Europe is forcing the automotive industry to move towards more zero emission powertrains. From 2025 onwards in Europe, the emissions legislation is getting stricter; forcing automakers to produce more electric vehicles EV's. There is increasing customer demand for electrified powertrains as well. There is a big difference between an electric drivetrain and a standard internal combustion drive train with range being a big issue, leading to range so-called 'range anxiety'. This poses the question how much range a customer wants or needs. This creates a need to understand how people are actually using their vehicles. User data gives invaluable insight into how to navigate the electrified world.

2.1.3 Social Risk Management

Improvement in employee working conditions

IN 4.0 technologies has been useful in making certain jobs easier to do. For example, historically, before the advent of connected vehicles and connected services and capabilities like monitoring enabled by IN 4.0, employees typically had to do lots of surveys and interviews, visits. The capabilities of IN 4.0 enable access to customer and vehicle data a lot quicker and faster.

Better job satisfaction

Augmented and virtual reality spaces accessed via the Internet empower manufacturing teams around the world to collaborate on training or assembly techniques, sharing the same virtual experience simultaneously. Augmented reality helps to improve the efficiency of maintenance tasks by delivering instructions and information to technicians in real-time, saving time and money while increasing quality. This creates an efficient system where skilled technicians can execute their work more efficiently, cutting out travel time to and from different locations and freeing up their time to focus solely on work. This allows for the compression of production timetables, enabling technicians to unlock solutions in real-time, and for the optimization of manufacturing workstations for each location locally.

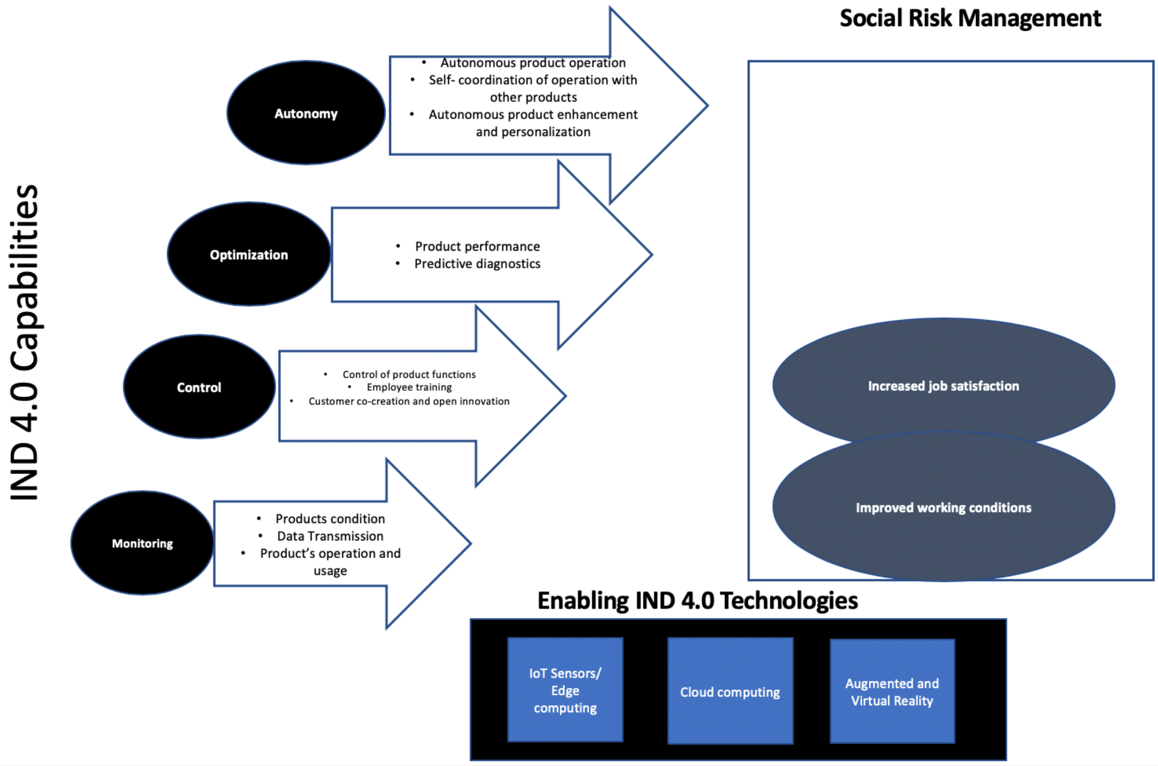

Figure 9: : Linking social risks, IN 4.0 capabilities and enabling technologies in the automotive industry

2.1.4 Returns on Investment from Implementing In 4.0 Technologies

A business model is defined by two things; how the organization creates value for its customers (the customer value proposition) and how it captures that value (how it makes money from the value proposition). Digital transformation changes both. Traditionally, vehicle manufacturers had dealerships as their main customers, who essentially bought their vehicles and sold them on to end users. The advent of IN 4.0 has opened up new ways of value capture, allowing vehicle manufacturers to tap into multiple ways of monetizing the different separate areas of the vehicle. With connected vehicles, connected growth and connected services and cloud computing, there has been a rise in subscription-based customer relationships. Consequently, instead of one transaction, vehicle manufacturers could be looking at several transactions. One could be for a lease on the vehicle, another could be subscription-based on what customers want from their car, allowing manufacturers to come up with a more sophisticated electrical car architecture as well. The customers can get better quality data from the vehicle manufacturers than from third parties. Hence this opens up avenues for vehicle manufacturers to expand their business transactions.

For vehicle manufacturers, the approach to achieving competitive advantage from IN 4.0 is based on a differentiation strategy- the ability to differentiate itself and thus charge a price premium but also to operate at a lower cost than its rivals through its unique reductive design approach. Value is created for customers by collecting data to help improve the functioning of vehicles, providing add on services for customers while also modifying future design. Value is captured by operational efficiencies, customer satisfaction, increasing sales of their vehicles (through reduction of cost of vehicles), charging for add on services, optimising production processes, and shortening time to market.

The monitoring and control and optimization capabilities enables vehicle manufacturers to make some immediate changes. Vehicle manufacturers have seen definite improvements and large gains and benefits in the product design phase. There has been a shortening in time to market and in making sure that the products are the best they can possibly be.

Additionally, there is more immediate feedback as they go from one product design phase to another. The success of the digitized design phase is seen during the vehicle manufacturing as well with design and manufacturing becoming a reiterative cycle of continuous learning and improvement.

However, on the other side of the spectrum, putting all these modems and sensors in a vehicle and putting the network systems or cloud infrastructure in place comes at a cost. So, the return on investment on some of these takes years to appear, so a long term perspective is needed. In terms of the benefits from cloud computing with regard to vehicles it is in its fairly early stages. Paybacks or actualised benefits are not expected to be realised for at least another five years. However, a differentiation(44) approach based on an understanding that the IN 4.0 infrastructure enables manufacturers to seamlessly talk to the vehicle, thus opening up new business models like subscriptions where customers buy apps or they can buy new software for the vehicle or new features increases monetization opportunities. And then, once the infrastructure is in place, the business model changes because again additional revenue streams will be appearing.

Additionally, vehicle manufacturers rely on economies of scale. For example, the more modems are installed in vehicles, the lower each unit will cost. Besides, an increase in uptake of IN 4.0 by other manufacturers is expected to drive down costs.

From a value capture perspective, return on investments in Industry 4.0 technologies calculated with a the short to medium-term investment horizon can often appear negative. This is due to several reasons. First, high initial investments are required, which come along with complex implementations. Second, the benefits only occur with a time lag. Third, the total benefit cannot be easily measured in pure monetary terms. Ultimately, this leads to a balancing of high upfront costs and growing benefits, which can only be decided on a company-specific and case-by-case basis. It should also not be forgotten that pressure can be built up from outside the company, for example by important customers and long-standing partners, forcing the company to digitize and link its value-adding process to IN 4.0 requirements coming from elsewhere. The latter case requires a decision based on more strategic considerations, rather than one the basis of its immediate effect on profitability.

2.1.5 Conclusion: IN 4.0 as a Risk Management Strategy in the Automotive Industry

In summary, this section explains how IN 4.0 technologies and the capabilities they enable serves as a means of managing economic, social and environmental risks in the automotive industry.

Risks that drive the adoption of IN 4.0	IN 4.0 technologies used in risk management	IN 4.0 Capabilities enabled by IN 4.0 technologies	Outcome of adopting IN 4.0 technologies
Economic	• Rapid prototyping/ additive manufacturing • Advanced analytics • Augmented reality and Virtual reality • Cloud computing • IoT	Monitoring Control Optimization Autonomy	• Efficient resources/ processes • Customer satisfaction • Improved quality • Better integration across the supply chain • Reduction in time to market
Social	• AR and VR • Cloud computing • IoT	Monitoring Control Optimization	• Better employee working conditions • Access to flexible training options
Environmental	• Cloud computing • IoT • Advanced analytics	Monitoring Control	• Reduction in carbon footprint • Fuel/ Energy efficiency • Compliance with regulation/legislation

Figure 10: IN 4.0 as a Risk Management Strategy for the Automotive industry

2.2 Transnational Methodology for The Implementation Of IN 4.0 By Shipbuilding SMEs

This section utilises a risk methodology to outline a transnational methodology for implementing IN 4.0 in shipbuilding SMEs.

2.2.1 What Are the Key Risks That Drive Adoption of IN 4.0 In the Shipbuilding Industry?

Similar to the automotive industry, in the shipbuilding industry risk is a key motivator for the adoption of IN 4.0 technologies. The following are more specific key risks that drive the adoption of IN 4.0 in the shipbuilding industry.

- Inefficient resources/processes
- Less attractive to younger talent
- Need for quality improvement
- Legislation

However, social risks such as demographics and lack of IT expertise and economic risks like access to capital are an added layer for the SMEs in the shipbuilding sector as well. Cloud technologies were identified as a means of managing, economic, environmental and social risks in a more affordable and assessable manner for shipbuilding SMEs.

- ***Economic risk Management***

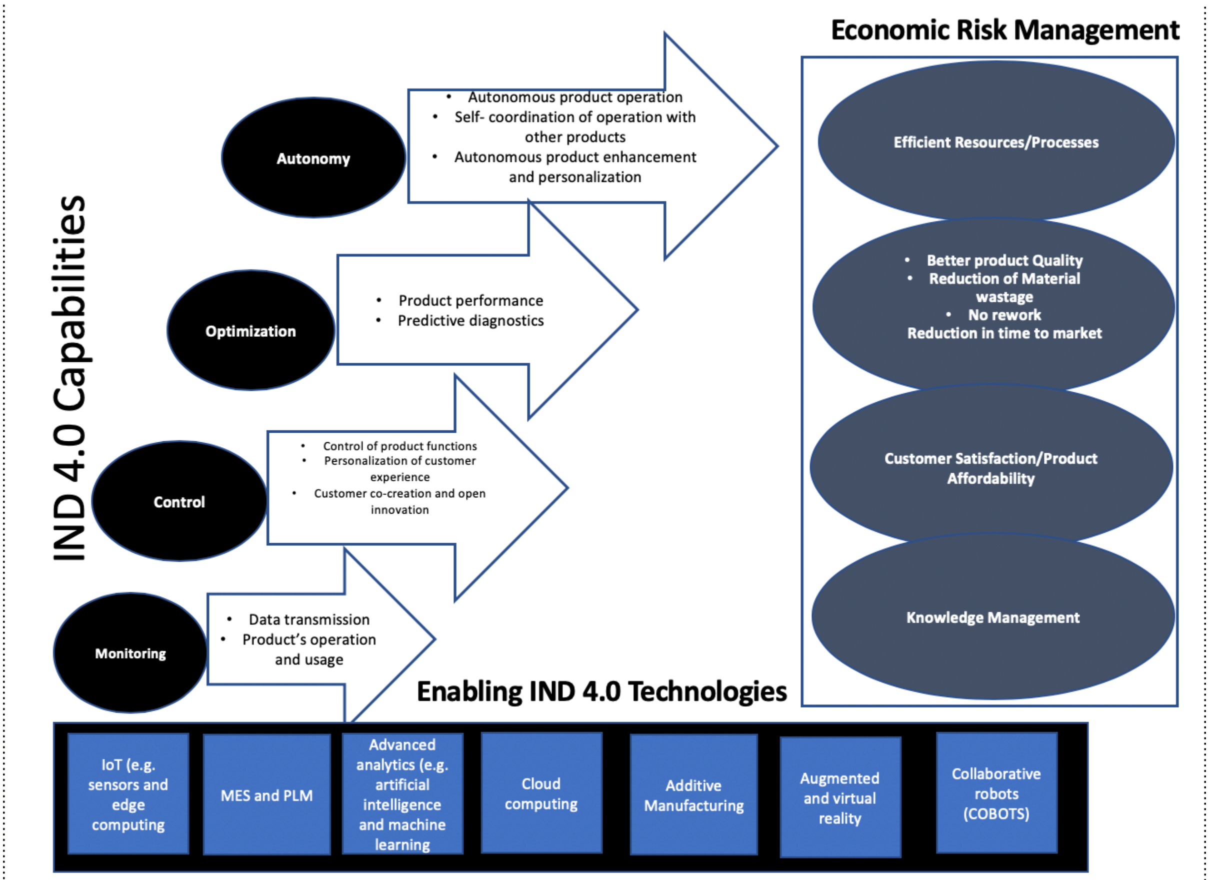

Figure 11:Linking economic risks, IN 4.0 capabilities and enabling technologies in the ship building industry

- **Data integration**

Shipbuilding increasingly requires coordination activity with most of the core engineering taking place outside the shipyard or design office. For instance, a lot of the design work takes place outside of the core CAD system inside the shipyard. There is a large increase in the effort and the value that goes into the procurement part as well. Consequently, a huge amount of the business that goes through the shipyard is effectively controlled by the enterprise resource planning system (ERP). Shipyards are traditionally organised along functional lines, so the design and engineering department, the materials or procurement department, project controls department and manufacturing or shipbuilding department make up the organization structure. In the past separate departments demanded separate IT infrastructures and tools that supported their business processes. The result of this was functional silos where each department was effectively supported by its own IT infrastructure. So, CAD and to a lesser extend ERP are two of the cornerstones of any shipbuilding IT infrastructure as well as document management, a manufacturing execution system (MES). Quite often, Excel spreadsheets are the backbone of the IT landscape of traditional shipyards.

The result of this is that integrating data today has become a challenge because each of these siloed IT applications only support part of the shipbuilding process. This, combined with a lot of the work being done by sub-contractors and external parties outside of the shipyard, leads to a situation where there is a massive amount of unstructured and uncontrolled data supporting the manufacturing process. Altogether such a siloed organisation results in core processes not being properly managed, therefore the overall optimisation of the shipbuilding process becomes very difficult if not impossible. Consequently, the shipyard organisation relies on poor quality data for the production and potentially the operation of the vessels.

Digitalizing shipbuilding potentially enables several functions such as design, work preparation, material storage, logistics and management to exchange information almost in real time. Digitalized shipbuilding enables three types of IT applications to be put in an IT system that allows seamless data gathering and sharing. This results in a reduction in errors and inaccuracies due to sub-optimal resource planning, avoidable wastage of materials by managing remnants, a lack of workload optimization of workforce be it human or machine to ensure that none is idle. Additionally, accessibility to transparent and complete, timely information helps to increase the quality of products as well as ensure that the production processes are completed on time.

- ***New servitization business models***

There are more shipyards evaluating a strategy of providing post-delivery services for ships they have built. By using IN 4.0 technologies, large shipbuilders have achieved a high level of efficiency as their design, manufacturing and production processes are already lean. In contrast, many SMEs still have to reach the same level of efficiency. Also, with regard to ship operations, reducing the number of crew onboard, maintaining equipment more efficiently, and less downtime pose opportunities for ship operators to cut costs, which in turn offer vallu-adding opportunities for shipbuilders. Suites of software exist, which monitors, controls but also does asset management for ship operators. One way for shipyards to survive and to go onwards is to look at delivering maintenance, repair and operations (MRO) services to make ship operations more efficient. Currently, this service is hardly offered by shipyards although there are one or two examples in Germany and Finland but premised on a close relationship between the shipyard and a particular ship operator. So, there currently is very limited application of this new model. However, there is possibly very good potential for shipyards to offer this as new source of revenue.

From a shipbuilder's perspective it makes sense to extend their services for a product that they create. If they already have a significant portion of the ship in a digital representation as well as the best knowledge of the design and the decisions and compromises that were made during the design and manufacturing, then this can be leveraged for MRO work. In many cases the shipbuilder who initially built the ship is in a better position to bid for MRO contracts. This potential was also discussed in the automotive industry and can have a significant impact on the future of the business of shipbuilding.

- **Knowledge Management**

Knowledge management is an extremely important topic because shipbuilding is a very complex engineering discipline. Losing knowledge is a large risk. Efficiency in shipbuilding is often achieved by specializing in one type of vessel. However, this also increases risk as a shipyard becomes more dependent on a limited number of customers, while simultaneously losing the knowledge required to build other types of vessels. As a response, shipyards are trying to be more flexible in order to be able to switch product types more quickly. A lack of agility therefore presents a risk. Across the board for both large and smaller shipyards, IN 4.0 technologies have started to address this risk.

For example, the ability to capture how people do things can be programmed into CAD software these days. It can start to look at the patterns of how people are using a software tool and that information can be saved for the company. Additionally, shipyards can retain knowledge by recording and building a library of YouTube-type instruction videos. Key information can be recorded and stored in the cloud. PLM (product lifecycle management) is an important topic related to knowledge management, however it is quite complex and very expensive for many shipyards -even large ones- because the implementation of PLM usually costs about 25 million pounds.

Cloud computing provides a cheaper alternative as vendors use the cloud to deploy a standard shipbuilding knowledge management solution. And that is very much part of the strategy for most of the shipbuilding software vendors in trying to attract SMEs to the market. The strategy is to reduce the price of the software to make it easier to acquire and deploy, and to make sure the shipyard needs less IT people to run the system, which is a major thing especially for a smaller shipyard. In smaller shipyards, IT competency is a big issue.

- **Time to Market**

The use of design technologies offers a means of becoming more agile and bringing new products to the market faster. Similar to the automotive industry, the capability of control enabled through AR and VR, data analytics and cloud computing allow for the customization of product performance to an extent that was previously not cost effective or even possible. For example, the use of cloud computing platforms has the potential to shorten design time through collaboration between all partners of a network in different locations. Additionally, the use of digital twins enables rapid experimentation and simulation with the overall effect of increasing team productivity and speeding up the manufacturing processes as a whole. Furthermore, AR and VR are useful for better design accuracy when designing equipment for the future. Flaws detected in machines can be communicated to the manufacturers who then remedy this in future designs. Additionally, customer co-creation and open innovation is enabled which is a useful part of the design workflow for the future. For example, when customers send parts list, they are able to import the information into software, which very quickly transforms the data to something that can be used for future design thus considerably shortening the design phase.

- **Efficient processes**

Many smaller shipyards still have to move from 2D to 3D CAD technology. This in itself can result in a significant saving in material wastage because 3D CAD allows for a more accurate design. In terms of design shipbuilding is not very advanced using other Industry 4.0 technology. For instance, generative design machine learning is not widespread in shipbuilding. A number of very large shipyards e.g. BAE systems have some machine learning and artificial intelligence research programs. And there is a current trend towards refreshing MES technology by connecting it to PLM and connecting it to technologies like radio-frequency identification (RFID) on the shop floor. There is a large initiative, for example, in BAE where they are looking at that. Software vendors like Hexagon are providing enabling platforms for this. However, smaller shipyards do not have the budget for something like this and many are still using mainly 2D CAD. They manage with 2D technology because of the scale of their businesses and the cost of upgrading to 3D design software.

However, cloud computing is starting to have an impact in this regard. Currently, small shipyards and design agencies are moving their documents onto the cloud. Cloud computing is also opening up opportunities for collaboration between equipment suppliers and design agencies and shipyard design departments. To a lesser extent, robotics is used to optimise production processes. However, robotics tends to be much more heavily invested in by larger shipyards.

- ***Environmental Risk Management***

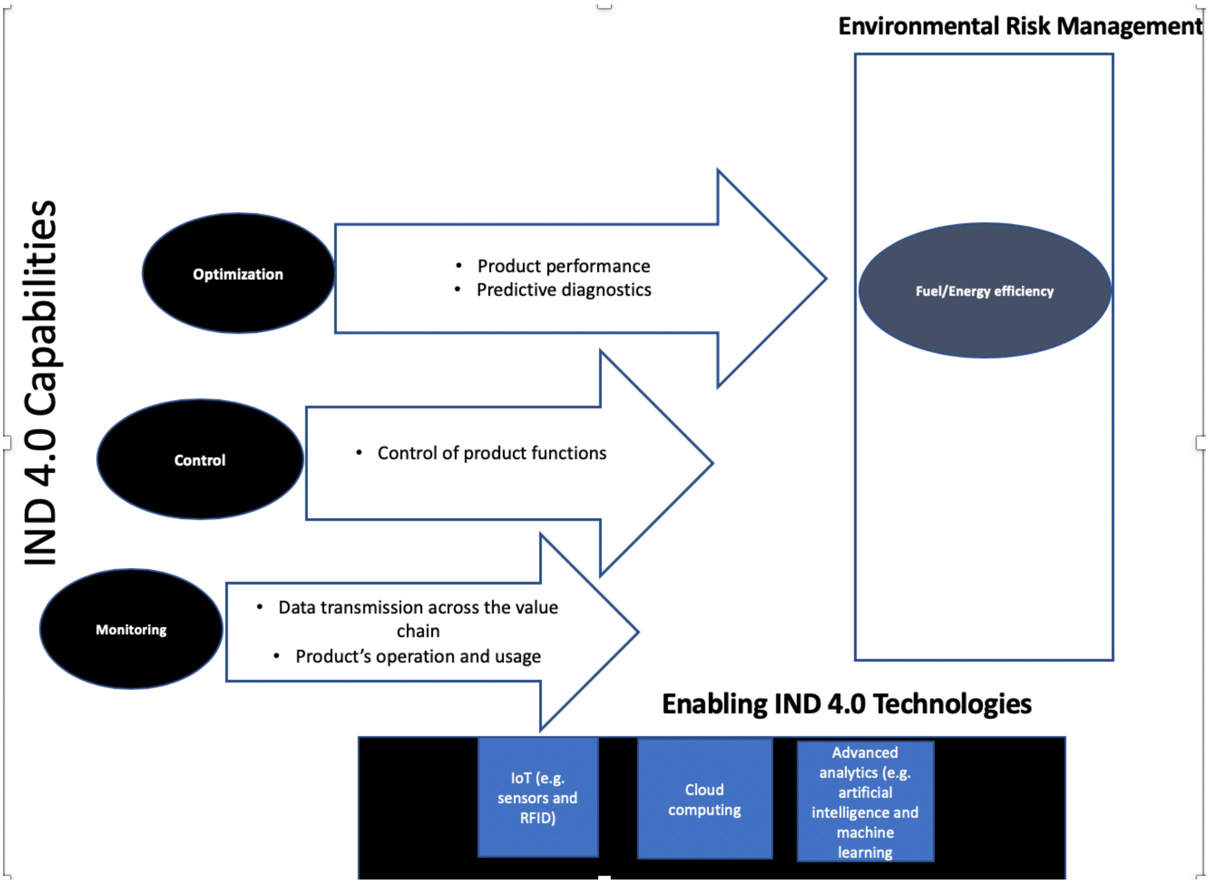

Figure 12: Linking environmental risks, IN 4.0 capabilities and enabling technologies in the shipbuilding industry

- **Ensuring energy and fuel efficiency in ships**

Monitoring and controlling through artificial intelligence and big data analytics is useful for ensuring energy and fuel efficiency in ships. There is a trend a shipyard being commissioned to build a number of similar ships to be asked to guarantee later built vessels will be more efficient than the first ones, based on shipyards monitoring and learning from the data from the earlier builds. Gathering and processing big data can enable them to change the design as well as operational procedures to ensure that subsequent ships are more efficient, greener and have less of a carbon footprint. An example of this is Qatar Petroleum ordering 100 ships. The benefits of scale from operations is huge. According to our expert from AVEVA, "this is where shipyards are heading, they're saying, "OK, we'll do 50 ships and will offer you progressively less operating costs across them. But it's new. They haven't built up this experience yet and that's exactly where the shipbuilding industry is just now."

- ***Social risk Management***

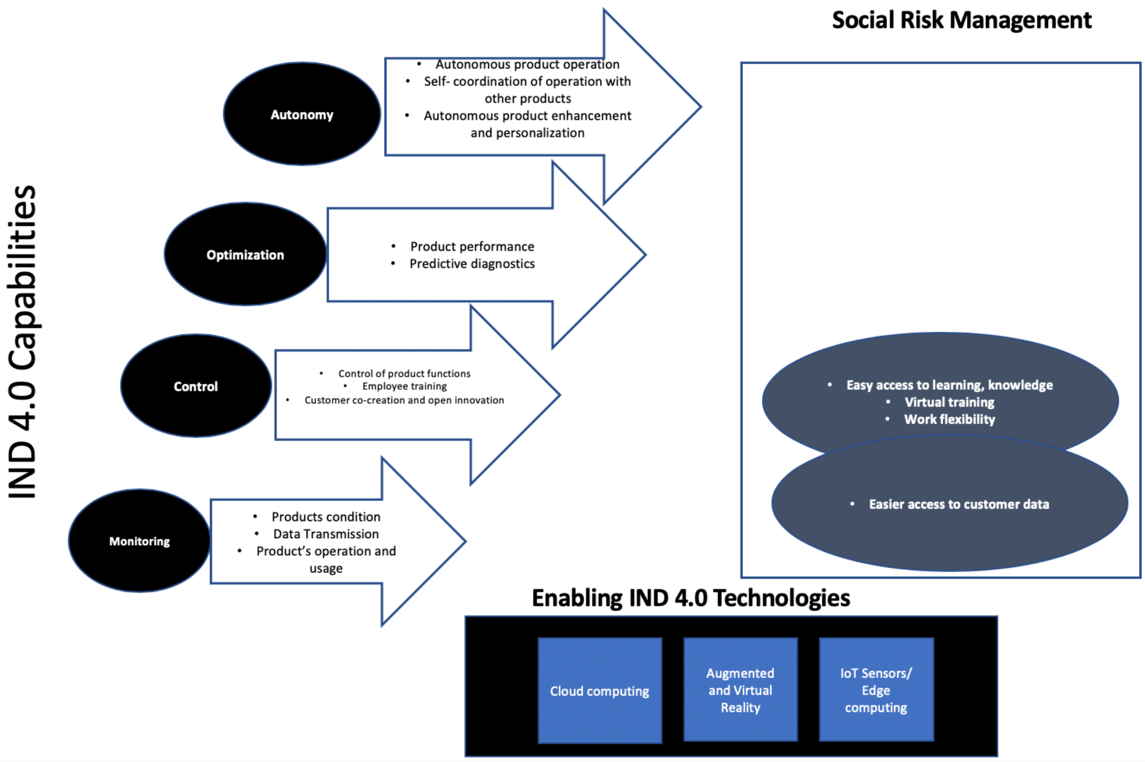

Figure 13: Linking Social risks, IN 4.0 capabilities and enabling technologies in the shipbuilding industry

- ***Attracting young talent***

A key issue raised by all our interviewees is the unattractiveness of the shipbuilding industry to young people. Additionally, there is also a huge turnover with the few young people who join as they stay only two to three years to then move on. There are two reasons: location and the cyclic nature of the shipbuilding industry. Shipyards are generally located in heavily industrialized areas that are not usually attractive for younger people who prefer to live in more vibrant cities. Secondly, the cyclical nature of the industry is very off-putting for people, as the shipbuilding industry is hardly surviving around the world; making very low margins everywhere. Traditionally, luxury cruise ships were the only healthy segment, but this is now under threat. IN 4.0 technologies such as the cloud provides a means of managing the risk of attracting talent because it allows people to work from far away much more easily.

Currently due to Covid-19, AR/VR Technology is used mainly across larger shipyards as a form of communication and as a means to enable remote collaboration. Additionally, cloud computing is one of IN 4.0 enablers that is very important just now in a post covid-19 world because most shipyards around the world have sent their employees home or they are very much limited as to how many people they are allowing into the shipyards. The cloud is allowing them to have access to software that they need to do their work. Therefore, everything from design software through material management software and can be done from home. According to our interviewee from AVEVA, there has been a huge increase in demand for cloud technology from shipyards immediately after the lock-down, because people could not access their enterprise software from home. Therefore, the cloud was useful to enable remote desktop work. Furthermore, this has served as an inducement to attract younger talented people, as they have been told they can work from home and still contribute to the design. This is something that is having a big impact and is expected to become even more important in the future.

- **Lack of IT skills**

Smaller shipyards tend to have less specialized people working in IT. They also rely more on standard software. Additionally, they may lack the time and the resources to make the software really fit their processes, so they are looking for software which has a lot of the shipbuilding knowledge built into it. In order to address this challenge, software vendors provide standardised software specified for the shipbuilding industry, which can be navigating with a few clicks; saving significant time and effort. This solution is useful even in extreme cases where especially smaller shipyards lack some knowledge, skills or expertise with regard to every aspect of the shipbuilding process and are looking for some of that knowledge to be baked into the software.

2.2.2 Which IN 4.0 technologies are impacting the Shipbuilding industry today?

The bigger shipbuilders utilise similar IN4.0 technologies as those used in the automotive section. However, SME shipbuilders as still slower to catch up due to cost of implementing these technologies as well as a lack of expertise and knowledge of these technologies.

2.3 Conclusion: Transnational Methodology for The Implementation of IN 4.0 By Shipbuilding SMEs

In particular, IN 4.0 has the potential to transform organisational structures, the design function, the role of IT, cooperation patterns and overall business models within the shipbuilding industry.

The **organisational structures** that supports the shipbuilding processes are changing from functional silos that is kind of a relic from the industrialisation of the shipbuilding process to more networked approach where the shipyards take on the work but allow subcontractors to contribute what that they are very good at and work together with partners and other companies who are able to add value in the ship building process.

The **design function** in shipbuilding is moving away from treating every vessel as being purely bespoke towards vessels being more configured products. This related to the agility in terms of bringing more products to the market while simultaneously reducing design man hours in order to deliver the required variety of products to the market. In terms of shipbuilding production, we are seeing more – and this is of course dependent on the size of the shipyard- of the traditional workshop type of fabrication being replaced by highly digitized, highly automated ship building factories. This is happening where there is more consolidation of ship building groups where they can afford to make that kind of capital investment in highly automated panel lines.

The **role of IT** in supporting shipbuilding is changing from simple file and document management towards cloud-based information platforms that support the transfer of information across the shipbuilding network through application programming interfaces (APIs).

And ultimately the **business model** is generally moving away from the shipyard being a generator of information to make products to being able to offer products to the market based on the information that the shipyard is able to gather and sell on it. These best practices demonstrate that better collaboration during the overall lifecycle of a vessel that includes the design, build and operation phases is the major trend. This is reflected in more the vertically integrated shipbuilding companies- where they combine ship design capability, ship building capability and the capability to build major pieces of equipment to integrate them into the vessel in a more meaningful way to then work closely with ship operators to learn for the purpose of improving shop designs, build practices, and to offer maintenance services.

Cooperation patterns: There is an increased importance of information being the common currency of interaction between all the partners involved in designing, building, and operating ships. This is afforded by the digital transformation that are currently happening. To reap the benefits, all the participants in the shipping ecosystem need to develop a common language and this has been one of the major stumbling blocks of cooperation and truly digitally transforming the industry. There currently is an inability for partners to communicate and transfer data to one another because of the lack of communication standards but also a lack of recognition of a common purpose.

Leveraging cloud computing is key to facilitate the emergence of a value proposition that spans the lifecycle of a vessel. Previously, there would be a hand over from design to build, to operations. Using the power of the cloud, the dynamics of the network is changed from subsequent and somewhat disconnected phases to more integrated network delivering the complex functionality of maritime transportation. **Cloud technology** will enable that in an effective way.

SECTION 3. CONCLUSION AND RECOMMENDATIONS

In this report, a risk analysis was used to demonstrate cost savings but more importantly provide enhanced value propositions in relation to the adoption of Industry 4.0 technologies in shipbuilding. For this we made a comparison with the automotive industry and consulted with firms who are already active in providing Industry 4.0 solutions to shipbuilders. Overall, the learnings provide profound evidence of success, weaknesses and demonstrate cost savings and value propositions that come with the adoption of Industry 4.0 technologies that are relevant for shipbuilding SMEs.

We started the report by asking four questions:

1. What are the key risks that encourage the adoption of IN 4.0 for the shipbuilding and automotive industries?
2. What kinds of capabilities do IN 4.0 technologies enable?
3. What IN 4.0 technologies are impacting the automotive and shipbuilding industries today?
4. How can uptake of IN 4.0 by shipbuilding SMEs be encouraged?

Overall, we identified that both automotive and shipbuilding industries have in common economic, social and environmental risk that can be managed/mitigated by IN 4.0.

This risk management is accomplished by four IN 4.0 capabilities: monitoring, control, optimization and autonomy. These capabilities are enabled by a number of IN 4.0 technologies such as AR and VR, IoT, advanced analytics, additive manufacturing, advanced robotics, and cloud computing.

Our key argument in this report is that the adoption of IN 4.0 is crucial for the shipbuilding industry. As with any new innovative opportunities there are risks involved with adoption. However, the benefits associated with adopting industry 4.0 far outweigh the risks. Importantly, IN 4.0 presents opportunities to mitigate and manage several crucial risks within the shipbuilding industry in such a way that it is likely to increase an organisation's competitive advantage. However, a lack of adoption of IN 4.0 opens a firm up to the risk of competitive disadvantage. These key findings are summarised in Table 1 below:

Table 1: Summary of key findings of the study

Risks	Risks associated with adopting IN 4.0	IN 4.0 Solutions	Risk Mitigation/ Advantages of adopting IN 4.0
Economic	• Cost of implementation	Cloud computing- low cost, pay-as-you-go format	• Customer Satisfaction • Efficient resources/ processes • Reduction in time to market • Improved quality • Operational efficiency
Social	• Widening of the social gap • Requirement for new competencies • Loss of jobs due to automated tasks	VR and AR opportunities for training	• Employee Flexibility • Customer satisfaction • Ability to attract young talent • Development of Partnerships in the supply chain
Environmental	–		• Reduction in carbon footprint • Fuel/ Energy efficiency • Compliance with regulation/legislation

In the following sections, we will reflect on the opportunities for value creation and value capture associated with IN 4.0 and then conclude with a few recommendations.

3.1 Value Creation and Capture within the Shipbuilding Industry

The distributed and connected nature of IN 4.0 also poses potential challenges with respect to how value is created and captured; how the vast amount of new (and sensitive) data is utilised and managed; who owns data; how relationships with traditional business channels are redefined; as well as what the role of individual companies is, as the boundaries become blurred due to the distributed nature of IN 4.0 applications. The distributed nature of IN 4.0 in the shipbuilding industry is represented in figure 12.

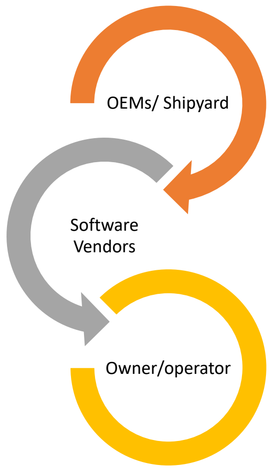

Figure 14: Distributed nature of IN 4.0 in the shipbuilding industry

The IN 4.0 capabilities of monitoring and control and predictive maintenance programs were traditionally driven by the equipment suppliers because it is their intellectual property. As mentioned earlier, a shift seems to be occurring where monitoring and control, which tended to be the domain of the equipment suppliers is now becoming something that the shipyards want to manage. Our interviewees explained that there are current discussions about the right business model to adopt, as it appears that a system of systems approach(36) is more likely for shipyards. There are a lot of discussions about whether the software vendors should provide all the services themselves like Apple. This will promote efficiency as they would have full control of the whole system. However, on the flip side, there are specific capabilities that exist within other domains which other participants in the shipbuilding network may be better off exploiting.

This is perpetuated by IN 4.0 itself, as its application requires firms to cooperate and connect to make it work. These connections, as we have reported, go beyond shipbuilding and also has to extend to ship operations. This means that the shipbuilding sector more than ever has to deal with three interconnected problems (3). The first problem is about value appropriation.

On the one hand, IN 4.0 requires investments, yet the added value and cost savings do not necessary accrue with the party who makes the investments. The second issue is the capability configuration. Adding IN 4.0 capabilities means that different stakeholders in designing, building and exploiting a ship might become involved in parts of the process where they traditionally had not been involved. The question becomes who is allowed to do what? Thirdly, all of this requires some form of governance, with some relationships between the various stakeholders taking shape as arms-length market exchange while others require a form of more intimate coordination. All of this needs to be coordinated in a context of simultaneous cooperation and competition.

As a consequence, it is effectively impossible to make a meaningful cost benefit analysis that applies to every ship building firm, or to provide one to serve as inspiration because it will work out very differently for each individual firm. Moreover, to make IN 4.0 work, it has to involve more than one firm. Costs and benefits in terms of value appropriation, capability configuration, and governance will be distributed differently across the whole shipbuilding sector as a consequence of adopting IN 4.0. It will be a matter of negotiation who will benefit the most.

3.2 Recommendations: How can the uptake of IN 4.0 by shipbuilding SMEs be encouraged?

IN 4.0 is highly applicable to the shipbuilding industry, as it combines heavy steel construction work with the most advanced electronics to produce technologically complex products. A well-thought-out strategic plan might be considered as one of the factors supporting the implementation of Industry 4.0. It would require a dedicated effort as well as assigning people who are made responsible for further deepening the principles of Industry 4.0 within individual firms (3, 45).

Ship design, manufacturing and operation are highly complex process and consume high amounts of energy throughout the entire lifecycle. To survive in this competitive market, shipyards need to design and build ships that are more energy-efficient and innovative(7). Shipbuilding SMEs seem to be lagging behind in their adoption of IN 4.0

technologies and in this report, we focused on showing how IN 4.0 is useful as a cost-saving and profit maximizing strategy because it helps to overcome challenges related to energy efficiency, cost efficiency and rapid innovation. More importantly IN 4.0 opens up a pathway for enhanced value propositions that allow for European shipbuilding to step away from this relentless competition on price. The findings of our study show that although there is knowledge of the potential benefits of all the IN 4.0 capabilities, currently the monitoring and control and optimization capabilities are starting to be utilized, whereas the autonomy capability appears to be underutilized. The reason for underutilization is the high cost attached to IN 4.0 enabling technologies especially for SMEs. We have identified a risk-based methodology that informs SMEs to come up with a plan for IN 4.0 adoption. As was highlighted earlier, although IN 4.0 technologies can be applied to each lifecycle stage of a car or a ship (design, build and operation), benefits related to economic, social and environmental risk appear by coupling various IN 4.0 technologies across a vessel's entire lifecycle.

3.2.1 Benefits of IN 4.0 For SMEs In the Shipbuilding Industry

In order to unlock the benefits of IN 4.0, SMEs in the ship building industry, firms should consider the following:

Tailor what constitutes an acceptable risk for the firm to an understanding of appropriate technologies to be implemented throughout to develop a bespoke solution for the company. Start with using cloud computing technology to develop a unified data platform designed to integrate data from different departments in the shipbuilder's organization and other participants in the value chain, which is able to ingest various types of datasets. It will be useful if such a platform is able to anonymise, normalise and enrich the data, thus enabling the creation of value-added applications. SMEs are the major category that can benefit from cloud services due its low cost and pay-as-you-go format. Additionally, technology vendors are commoditising IN 4.0 solutions more and more, making them more affordable. This includes much of the networking connectivity that is required. Some of the solutions even come with standard interfaces based on best practices that help to streamline some of the technical requirements for tying the various layers together. With cloud computing in place, additional IN 4.0 technologies can be added as a shipyard links the various design, building and operational activities together to deliver on the enhanced value propositions with regard to the complex functionality of maritime transportation.

References

1. Munin-Doce A, Diaz-Casas V, Trueba P, Ferreno-Gonzales S, Vilar-Montesinos M. Industrial Internet of Things in the production environment of a Shipyard 4.0. International Journal of Advanced Manufacturing Technologies. 2020;108(1-2):47-59.

2. Moeuf A, Lamouri S, Pellerin R, Tamayo-Giraldo S, Tobon-Valencia E, Eburdy R. Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research. 2020;58(5):1384-400.

3. Vrchota J, Volek T, Novotna M. Factors Introducing Industry 4.0 to SMEs. Social Sciences MDPI. 2019;8:1-10.

4. Moeuf A, Pellerin R, Lamouri S, Tamayo-Giraldo S, Barbaray R. The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research. 2018;56(3):1118-36.

5. Ghobakhloo M. The future of manufacturing industry: a strategic roadmap toward industry 4.0. Journal of Manufacturing Technology Management. 2018;29(6):910-36.

6. Hofmann E, Ruch M. Industry 4.0 and the current status as well as future prospects on logistics. Computers in Industry. 2017;89(23-34).

7. Ang JH, Goh C, Saldivar AAF, Li Y. Energy efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment. Energies. 2017;10(5):610-23.

8. Ramirez-Pena M, Abad Fraga F, Sanchez SOntano A, Batisa M. Shipbuilding 4.0 Index Approaching Supply Chain. Materials. 2019;12:1-18.

9. Kim L, Lee S, Park H, Lee J-Y. A model for a simulation-based shipbuilding system in a shipyard manufacturing process. International Journal of Computer Integrated Manufacturing. 2005;18(6):427-41.

10. Ruessmann M, Lorenz M, Gebert P, Waldner M, Justus J, Engel P, et al. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Boston Consulting Group. 2015;9.

11. Adu-Amankwa K, Attia AK, Janardhanan MN, Patel I. A predictive maintenance cost model for CNC SMEs in the era of industry 4.0. International Journal of Advanced Manufacturing Technologies. 2019;104:3567-87.

12. Radziwon A, Bilberg A, Bogers M, Madsen ES. The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions. Procedia Engineering. 2014;69:1184-90.

13. DeLoach JW. Enterprise-Wide Risk Management:L Strategies for Linking Risk and Opportunity. London, UK: Prentice Hall; 2000.

14. Birkel H, Veile J, Mulle J, Hartmann E, Voight K-I. Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers.

15. Wang Y, Wang Y, Yang Y. Understanding the determinants of RFID adoption in the manufacturing industry. Technological Forecasting and Social Change. 2010;77(5):803-15.

16. Heckmann I, COmes T, Nickel S. A critical review on supply chain risk- Definition, measure and modeling. Journal of Business Strategy. 2015;38:35-43.

17. Dellermann D, Fliaster A, Kolloch M. Innovation risk in digital business models: The German energy sector. Journal of Business Strategy. 2017;38:35-43.

18. Elkington J. Towards the Sustainable Corporation: Win-WIn-Win Business Strategies for Sustainable Development. California Management Review. 1994;36:90-100.

19. McWilliams A, Parkhankangas A, Coupet J, Welch E, Barnum D. Strategic Decision Making for the Triple Bottom line. Business Strategy Environmental. 2016;25:193-204.

20. Glavic P, Lukman R. Review of sustainability terms and their definitions. Journal of Clean Production. 2007;15:1875-85.

21. Norman W, MacDonald C, Arnold C, Voight K-I. Sustainable Industrial Value Creation: Benefits and Challenges of Industry. Business Ethics Quarterly. 2017;14:242-62.

22. Dyllick T, Hockerts K. Beyond the business case for corporate sustainability. Business Strategy Environmental. 2002;11.

23. Hubbard G. Measuring organizational performance: Beyond the triple bottom line. Business Strategy Environmental. 2009;18:177-91.

24. UKMarine. A strategy for growth for the UK Marine Industries: UKMarineAlliance.com; 2011 [Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31813/11-1310-strategy-for-growth-uk- marine-industries.pdf.

25. European Commission DFaMA. An exhaustive analysis of employment trends in all sectors related to sea or using sea resources: Country report- United Kingdom. 2006.

26. MaritimeIndustry. APPG Shipbuilding and Ship Repair: Inquiry into the National Shipbuiliding Report. 2019.

27. Stanic V, Hadjina M, Fafandjel N, Matulja T. Toward Shipbuilding 4.0- An Industry 4.0 Changing the Face of the Shipbuilding Industry. Brodogradnja. 2018;69(3):111-28.

28. Drobetz W, Haller R, Meier I. Cash Flow Sensitivities in an Asset-Heavy Industry: The Case of Shipping. Hamburg Finance Research Center Working Paper Series. 2015;14.

29. KPMG. The Digitalisation of the UK Automotive Industry. 2017.

30. InternationalMaritimeOrganization. http://www.imo.org/en/OurWork/TechnicalCooperation/ITCP/Pages/Default.aspx 2015 [

31. Hughes D. Shipping Commits to CO2 Roadmap. The Business Times. 2016;Singapore.

32. Ang JH, Goh C, Li Y, editors. Key challengs and opportunities in hull form design optimisarion for marine and offshore applications. In Proceedinfgs of the 21st International Conference on Automation and Computing; 2015; Glasgow, UK.

33. Katchasuwanmanee K, Bateman R, Cheng K. An Integrated approach to energy efficiency in automotive manufacturing systems: quantitative analysis and optimisation. Production and Manufacturing Research. 2017;5(1):90-8.

34. Stopford M. Maritime Economics. Third ed. Great Britain: Routledge; 2009.

35. Araujo B, Tureta C, Araujo DA. How do working mothers negotiate the work-home interface? Journal of Management Pyschology. 2015;30:565-81.

36. Porter M, Heppelmann JE. How Smart, Connected Products Are Transforming Competition. Harv Bus Rev. 2014.

37. Li J, Blumenfeld DE, Huang N, Alden JM. Throughput analysis of production systems: Recent advances and future topics. International Journal of Production Research. 2009;47:3823-51.

38. Fysikopoulos A, Anagnostakis D, Salonistis K, Chryssolouris G. An Empirical study of the energy consumption in automotive assembly. Procedia CIRP. 2012;3:477-82.

39. Dilberoglu U, Gharehpapagh B, Yaman U, Dolen M. The role of additive manufacturing in the era of Industry 4.0. Procedia Manufacturing. 2017;11:545-54.

40. Nazir M. Cloud computing: Overview & current research challenges. Journal of Computer Engineering. 2012;8(1):14-22.

41. Gupta P, Seetharaman A, Raj JR. The usage and adoption of cloud computing by small and medium businesses. International Journal of Information Management. 2013;33(5):861-74.

42. Caggiano A, Caiazzo F, Teti R. Digital Factory Approach for Flexible and Efficient Manufacturing Systems in the Aerospace Industry. Procedia CIRP. 2015;37:122-7.

43. DeloitteInsights. Who's going to pay for the future of mobility? Insights from Deloitte's 2020 Automotive Customer Study https://www2.deloitte.com/us/en/insights/industry/automotive/will-consumers-pay-for-automotive-industry-innovation.html2020 [

44. Porter M. Competitive Advantage: Creating and Sustaining Superior Performance. New York: Free Press; 1985.

45. Basl J. Pilot study of readiness of Czech companies to implement the principles of Industry 4.0. Management and Production Engineering Review. 2017;82:3-8.

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