Lean Innovative Connected Vessels (LINCOLN)

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Abstract

The European vessel industry is traditionally leader in the sector. In the last decades, to stay competitive worldwide, it has repositioned on the high-end market, characterized by specialized design and production with high complexity and technological content. This implies new challenges in complex product creation with reduced costs, fast design and optimal production time. This is more valid for SMEs and for emerging maritime sectors, where traditional vessels can't comply with their requirements. A comprehensive approach starting from early vessels design stages can help to overcome those issues. In this paper is proposed an integrated solution based on lean design methodology, IoT (Internet of Things) tools, HPC (High Performance Computing) simulation and sustainability methods, such as LCA (Life cycle Cost Analysis) and LCC (Life Cycle Cost). This is validated towards three specific industrial cases, related to small and medium vessels and mainly coastal activities. The adoption of this approach along the maritime value chain can also foster the introduction of new business models.

Keywords: Lean Design; Internet of Things; HPC Simulation; LCA; LCC.

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1   Introduction

Several innovative technologies and solutions have been studied to propose resource-efficient, eco-friendly, safe and specialized vessels, anyway a comprehensive approach from design, to manufacturing and operational stages of ships life, including digital and Internet of Things perspective, is still missing. The comprehensive usage of design methodologies, sustainability (economic and environmental) analysis and Internet of Things pervasive usage introduce new approaches in the vessel design and along the value chain. This is what we call the Lean Innovative Connected Vessel (LINCOLN). This is relevant to understand how the maritime transports can benefit from those mature solutions, already applied in other transport and manufacturing sectors, and what next steps are needed to make them widely applied, overall by European SMEs.

The paper is structured as following. Section 2 presents the main marine and maritime challenges in Europe, in relation to the current research and innovation programme. Section 3 provides the theoretical background of the project, as basic requirement for the expected results. Section 4 introduces the main LINCOLN principles. Section 5 explains the LINCOLN methodology. Section 6 describes the current work and the expected results, as applied to three industrial use cases. Section 7 presents the future impacts of the expected LINCOLN results.

2   Marine and maritime transports challenges

Surrounded by 136,000 km of coastline, a blue economy of 5.4 million jobs and almost €500 billion a year of gross added value, Europe is traditionally a world leader in the maritime activities (Blue Growth (2017)). However, in recent decades, European maritime industry has been dealing with an increased competition, due to ports becoming strategic poles of distribution for maritime traffic to/from new emerging countries. The European vessel construction industry - in response to the fierce competition of the vessel builders of the Far East (especially South Korea, Japan and China) – has started a major restructuring, repositioning on the high-end market, characterized by specialized design and production with high complexity / high technological content. On the other end new activities and services in several maritime sectors are emerging in Europe, such as aquaculture, renewable energy, coastal monitoring, control and surveillance, with the need of specific requirements, which traditional vessels can't comply all the time (Ecorys (2009)) (European Commission (2013)). The Vessels for the FUTURE (VftF) Research Association declared at MIBE 2015, "By 2050, we will be using our maritime space and inland waterways for transport, food and energy production, mineral exploitation, but also for expanding urban development, leisure, tourism and manufacturing. The increased use of our ocean [and sea] space requires that it is well organized, secure and supported by safe and clean vessels." To overcome those challenges main vessel technological advances to be addressed are: i) Reduced energy consumption and emissions; ii) Reduced hull water resistance; iii) Improved vessel sea keeping and passage management; iv) Increased automation and remote monitoring of vessel performance; v) Improved structural integrity; vi) Advanced adoption of digital technology across design, production and operation; vii) Weight reduction through use of novel materials and new manufacturing processes; viii) A paradigm shift in propulsion through the introduction of multi-fuel options; ix) A new safety era designed by considering all safety aspects including human aspects; x) New IT tools to support research and test new systems in vessel demonstrators; xi) Prototyping new hybrid vessels (VftF (2015)).

The European Agenda 2020 also covers many sustainable aspects with long-term goals, waste management, renewable energy development, sustainable manufacturing, critical raw material efficiency, and the blue growth (Blue Growth (2017)). The Blue Growth initiative wants to be a joint initiative, where the EU countries will work across the burdens to increase safety and security, promote sustainable blue growth and jobs, and preserve ecosystems and biodiversity. One of the main principle of the Blue Growth is the Sustainable Consumption and Production of maritime transport, ports, maritime and costal tourism, and marine aquaculture. This principle is in line with the Principle 12 of UN Global Compact, where the Sustainable Consumption and Production (SCP) is the goal to support the sustainable development in manufacturing (European Commission (2017)). International Maritime Organization (IMO) contributes to SDG 12 through the reduction of waste generation, both operational waste from ships and dumping of wastes under the London Convention and Protocol (LC/LP) (IMO (2017)). For garbage and several other types of waste generated on board ships, MARPOL (International Convention for the Prevention of Pollution from Ships) requires ports' States to provide adequate reception facilities for the safe and sound management of wastes. (International Navigation Association (2013)).

3   Theoretical background

The Lean Innovative Connected Vessel bases its vision and activity on a strong theoretical background in relation to three different research streams: Lean Design methodology, Digital and IoT developments, Environmental and Economic assessment studies. The state of the art of those topics is the starting point of the project activity and it

provides the scientific, technical, economic and environmental context for the project principles and the framework, where the project results will be developed in.

3.1   Lean design: Set-Based Concurrent Engineering (SBCE)

The concept of set based design was first introduced by researches from the Massachusetts Institute of Technology and University of Michigan in the 90's to combat delays and complications being faced in product development (Sobek II, Ward and Liker, Jeffrey (1999)). In many regards, there is a strong resemblance/correlation between Toyota's internal development process and the Set-Based Concurrent Engineering (SBCE) methodology developed by Allen Ward. SBCE is understood as a tool employed by engineers and product designers for "reasoning, developing, and communicating about sets of solutions in parallel and relatively independent" (Sobek II, Ward and Liker, Jeffrey (1999)). This understanding is based on three principles, *principles of exploration*, *set based communication*, and *convergence* (Sobek II, Ward and Liker, Jeffrey (1999)). This definition reflects the main traits of SBCE, which relies mainly on the use of design sets as alternative options in a design space; independent development of such sets from sub-functional teams; intensive communication of these sets between design teams; and progressive elimination of weak alternatives until a final robust solution is achieved. All these processes are supported by a strong use of formalized knowledge in the form of trade-off curves, limit curves, checklists, and standards (Kerga et al. (2014, 2015); Levandowski, Raudberget and Johannesson (2014)). For many working to advance the product development process SBCE is a highly enticing approach, particularly during the early design phase of a project (Singer, Doerry and Buckley (no date); Kerga et al. (2014)). Part of the reason for this resides in the fact that they understand the design and development process is highly specific, generating not only products but also knowledge that can be used for future development. SBCE, when properly implemented has shown the ability to resolve a lack/limit of innovation, project delay, overruns, quality, waste reduction.

The maritime industry is one of the most recent industries that has been working to apply unique solutions capable of improving their development performances (Milanovic (2016)). To facilitate the optimization of this initiative, an evaluation of diffused strategies was undertaken, and a Set Based Concurrent Engineering (SBCE) was identified as a tool to use in product development (PD). Currently there are two challenges that have reduced the ability for this approach to be adopted (Rossi et al. (2011); Kerga et al. (2015)). The first is related to the awareness level of SBCE by practitioners in the industry. SBCE as a tool is not well understood or practiced by most all designers and managers in the maritime sector. Therefore, there is a need for a method to introduce and to increase the awareness level of SBCE in the maritime sector. The second challenge is related to low diffusion, and is in part due to the extensive nature of SBCE, and complications associated with unconventional products. This second challenge is grounded around the SBCE process, which requires designers to go through series of extensive phases (exploration of alternative sets, communication of alternative sets, test of alternative sets and converge to optimal sets), all of which have shown to be problematic in practice for complex products such as the maritime sector ones. The principles of SBCE are derived from large automakers (particularly Toyota) which are set in a distinctly business context than that of maritime and in the literature there is a lack of systematic methods for introducing and guiding practitioners in the successful application of SBCE for complex systems in maritime sector.

3.2   Digitalization and IoT solution

LINCOLN digital and IoT background comes mainly from previous European projects results, BOMA (BOMA (2017)) and HighSea-Fortissimo (Wellsandt et al. (2015)), and the Norwegian national project ECO-boat MOL (Røstad & Henriksen (2012)). In ECO-boat MOL the initial idea of the Fact based design has been introduced into the maritime sector. HighSea project in the Fortissimo experiment has integrated sensor-based usage information in the design decision-making, in order to validate simulation models for boat hull behaviour, ran on a High Performance Computing (HPC) platform. It has developed the first prototype of the Universal Marine Gateway (UMG) black box (von Stietencron (2017)). BOMA has introduced the concepts, explained below, of Product Lifecycle Management (PLM) and Intelligent Maintenance (IM) establishing Intelligent Products (IP) and Service Extensions(SE) for the marine sector. It has also exploited its results in the HOLONIX iCaptain commercial IoT solution, based on the Marine Gateway (MG) black box, a market available model, for the leisure boats sector (i-Captain (2017)).

3.2.1   Fact-based design in the maritime sector

According to Rostad's studies on the leisure boat market (Rostad (2012)):" boat industry lacks of data on how customers actually use their products resulting in product design based on experience (looking backwards), subjective to judgments and input from certain customers or key persons. This often results in too high or wrong quality standards and consequently over-processing". Combining the knowledge from people that know the customers' demands and operational requirements with facts about the usage of the vessel during its service, brings new knowledge into the product development process. This is today seen, coupled for instance with the lean design

methodology, as a competitive advantage in the vessel domain (Henriksen (2016)). In the Internet era, facts come also from the Internet of Things capabilities to capture, transmit, analyse and reuse, in short and even in real time, product usage information, providing a huge time and quality advantage.

3.2.2   *Product Lifecycle Management*

Product Lifecycle Management (PLM) considers the life of a product as a lifecycle made of three main phases: beginning-of-life (BOL), middle-of-life (MOL) and end-of-life (EOL). The BOL comprises the traditional manufacturing steps: product development, production and distribution. The MOL represents the phase when the product is used. For a vessel corresponds to its operative and service life in water, including side activities, like the maintenance one. The EOL includes the reconditioning, dismantling and recycling. (Terzi (2010)).This vision of product life is the baseline of extended products, product service systems, functional products concepts and fosters the need for an extensive management of the product's lifecycle (von Stietencron (2017)).

Moreover, along this lifecycle the product information originating from any phase can also be reused in another one, generating the closed-loop PLM. The knowledge about the products can come from different sources and with different methods (Henriksen (2016)). Anyway, this is based not on real time information nor on real customer product usage and it also mediated by end-user involvement and perception. This can be overcome through the adoption of the new digital technologies inside the process. The Intelligent Products, enabled by the Internet of Things (IoT), allow the seamless closed-loop PLM, overall from the MOL to the BOL phase. In particular in the Fortissimo experiment it has been demonstrated that product's real use data availability reduces the number of design-simulation iteration (von Stietencron (2017)). The combination of closed-loop PLM and Intelligent Products brings also new business models to life, as such the "Intelligent Maintenance", introduced by BOMA.

3.2.3   *Internet of Things and Intelligent boats*

The "Internet of Things" concept was first mentioned by the Massachusetts Institute of Technology in the year 1999. Here, it was used in the sense of a "[…] information-technologically networked system of autonomously interacting things and processes, characterized by an increasing self-organization and leading to a merger of physical things with the digital world of the Internet" (Brand et al. (2009)). The things, to interact in this kind of system, need to have their own digital identification, a knowledge to share and a communication capability. To fulfil those requirements sensors, able to measure and gather product data, data storage and processing unit, and communication devices, such tags and bus systems, need to be installed or even better embedded into the products. In this way, the things become Intelligent Products. To this scope the Product Embedded Information Devices (PEIDs) (Jun et al. (2007)) can be used. They are categorized according to their capabilities of data storage and data processing from the smallest, like barcode and RFID, to largest, such as servers and data enterprise and PLM systems. The PEID gathered information is then integrated into the network of systems by a data integration or middleware mechanism (Främling & Nyman (2009)) and communicated over the Internet to activate the Internet of Things. Intelligent products have been initially applied in the logistics sector (Främling & Nyman (2009)), but they are also used for closed-loop product lifecycle applications, servitization and product avatars (Hribernik et al. (2012); Wuest et al. (2013)). In the BOMA project the installation of a modular data acquisition and integration device for PLM purposes, the UMG, connected to the iCaptain cloud platform, has introduced the Intelligent Vessel towards the concept of the Internet of Boat ecosystem .

3.2.4   *The Fact Based Simulation of boats*

Simulation is widely used in the industrial context especially for supporting strategic and tactical decisions. However, despite its potentialities it still faces several barriers: i) Lack of modelling and statistical competences; ii) Lack of reliable and updated data/information; iii) Big efforts, in terms of time, required for developing simulation models; iv) Lack of integration of simulation tools/models/results with enterprise management software and methodologies; v) Difficulty to translate simulation results into clear instructions to be applied throughout all the processes. In 2009, the VIRTUE project (VIRTUE (2017)) demonstrated the successful application of virtual tanks solutions, based on CFD simulation. Nevertheless, the still high costs of software (SW) licenses (Ponzini and Penza (2015)), make the simulation not an affordable choice for SME. To overcome this last challenge Open-source CFD SW can be adopted. However large validation campaigns are required to prove the reliability of the results for industrial-use cases of interest. Ponzini and Penza (Ponzini and Penza (2015)) report a successful experiment done on Luna Rossa, America's Cup Sailboat, Hull design. The simulation work has been built on OpenFOAM (Open Source Field Operation and Manipulation) toolbox running on the HPC environment of the CINECA, LINCOLN partner (Bassini (2015)), exploiting simplified scenarios based on half hull only. The results show consistency with full hull simulation, with a 43% reduction of computational time and consequently in total

activity costs. The High-Sea-Fortissimo experiment, using the Fact Based Design, with the UMG as data collector unit, has achieved the reduction of the design-simulation iterations (von Stietencron (2017)). Furthermore, LINCOLN scope is to create a user-friendly environment for the boat designer, where the necessity of having a deep knowledge of Computational Fluid Dynamics or handling a HPC environment is hidden.

3.3   Environmental and economic assessment

Life Cycle Thinking is an innovative approach to prevent the negative situation of shifting boundaries where it reduces the impacts in some lifecycle stages to postpone in other downstream stages (ISO 14044 (2006)). The Life Cycle Thinking approach can be applied to the three pillars of sustainability: environmental, economic and social. Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardized (by ISO) method. It quantifies all the relevant emissions and resources consumed, both directly and indirectly, and the related environmental and health impacts and resource depletion issues that are associated with the entire life cycle of any goods or services (in general terms, of a product). LCA is a vital and powerful decision support tool, complementing other methods, which are necessary to help effectively and efficiently make consumption and production more sustainable (European Commission (2010)).

The ISO 14044 defines the steps in how to conduct an LCA. In details, it identifies 4 phases to take into account during an LCA study, where each phase shall not be considered distinctly from the others, but it works in an iterative process (ISO 14044 (2006)).

- Scope and Goal definition: planning phase where the goal and the scope, including system boundary and level of detail, are identified.
- Life Cycle Inventory: is the second phase, but the most important one, because it lists all the input and output that may cause an impact during the lifecycle of a product. It is possible to conduct a Life Cycle Assessment only after this phase and investigate only the energy and materials flows involved into the product life.
- Life Cycle Impact Assessment: the analysis of environmental impacts is carried out. The purpose of LCIA is to provide additional information to help the assessment of LCI results so to better understand their environmental significance.
- Life Cycle Interpretation: is the final phase of the LCA procedure, in which the results of a LCI or a LCIA, or both, are summarized and discussed as a basis for conclusions.

The Life Cycle Costing (LCC) accesses the direct and indirect costs of the product life cycle, but also for the external environmental costs due to the environmental impacts. This methodology has been developed by the Society of Environmental Toxicology and Chemistry (SETAC) that has published a code of practice for environmental Life Cycle Costing (LCC) (T.E. Swarr et al. (2011)). The SETAC code of practice proposes to structure the LCC following the four phases defined by the ISO for the LCA, in order to facilitate definition and application of consistent system boundaries for complementary LCC and LCA studies of a given product system. Goal and scope definition is similar, but different parts of the product system may fall below relevant cut-off criteria for the separate LCC and LCA components. For example, the early research and development may impose significant costs but little environmental impact. The key is that both studies refer to a consistent definition of the product system, and that cut-off criteria do not conflict with the intended goal and scope of the study (T.E. Swarr et al. (2011)).

A primary motivation for LCC studies is to fully account for the financial costs of life cycle environmental aspects and impacts that ultimately result from a decision. This can be achieved by internalizing the costs, namely by applying the polluter pays principle, or by using information to make the impacts visible at the time of the decision.

4   Main LINCOLN principles

The objectives of LINCOLN are:
- The introduction in the maritime sector, overall towards SMEs, of Set-Based Concurrent Engineering, where the design will be executed with a lean methodology, based on real field data coming from IoT devices, using supercomputers to run the simulations.
- The improvement of the digital tools and IoT solutions needed to support vessel design and operations, to explicitly enable, even SMEs, to use simulation, running it on supercomputers, to provide services for their vessels through i-Captain professional platform and to record and manage testing data from prototypes.
- The use of Lifecycle Thinking to support the design phase in terms of materials and technologies with a less impact on the environment, such as to reduce emissions, liquid and solid waste and resources consumption.

Those three LINCOLN principles will be applied to three industrial cases described here below:
- A multiplatform catamaran will serve as: a) Service crew vessel (Business Case operation activity 1); b) Multipurpose survey vessel (Business Case operation activity 2). It will develop, among other features, a new

people transfer system based on new hull form and a mechanical system integrated in the ship structure, able to improve safety during people transfer from/to the vessel to/from facilities located in the sea (wind farms, aquaculture fishing cages, marine platforms, coastal remote areas and others). Thanks to the great load capacity, the enhanced stability of the double hull and the introduction of hybrid diesel-electric propulsion, this vessel will reduce operations costs and will be eco-friendly.

- A module based high-speed patrol boat platform will be a reconfigurable boat platform adaptable to the different operational requirements of patrol and security operators (Business Case operation activity 3). The company will develop one design platform, where several different vessels can be designed for various markets, built as low cost production series. The innovation here is to use the standardization and modularity approach of the Lean Design and the real-life data for fact-based improved design, which is the core concept of LINCOLN vessel design and production process, as described below. This approach will enable the introduction in this market segment of the innovative "Vessel as a Service" business model, granting lower after-sales costs and new market segments to the vessel producers and additional services to the end users and maritime operators.
- An Emergency Response and Recovery Vessels (EERV) series for coastal rescue activities (Business Case operation activity 4) will integrate multiple electronical systems and IoT connection. It will develop an enhanced automatic and low cost Integrated Dynamic Position System, which will help rescue operators during the ship-wreckers rescuing and will reduce operative costs, since it works with high pressure water, allowing being in middle of the sea with great fuel economy.

Along the design and development characteristics and details of the three vessels series, which is out of scope of this paper, the research objectives towards LINCOLN are:

4.1 Lean Design for Maritime Vessel Design: research objectives

Organized to have a comprehensive view of the design process and simplify the execution of the steps for designers,the first research aim is the addressment of the low awareness levels of concurrent engineering practices in the maritime industry. The level of awareness is designed to address three currently unresolved features: 1) the principles and key enablers of SBCE in the sector, 2) the diffusion of best practices, and 3) the advantages and obstacles confronted through the implementation of SBCE in a new industry. The methodology developed will allow small and medium sized shipbuilders to obtain the advantage of Lean Manufacturing, to increase their competitiveness and to offer a product with a high value added.

The second methodological aim is related to the lack of an optimized methodological approach that can identify and prioritize areas within the maritime industry that SBCE can be implemented (at a product level). To optimize the SBCE process for maritime industry, the adoption and implementation process will be undertaken once possessing an in depth understanding of the sector and corporate behaviours. This address the technological capabilities and methodological readiness as well as the resources available to support the adoption of SBCE. To accomplish these aims three base principles are applied:

- Map the design space, or the principle of exploration. The first aim of SBCE is to develop an in-depth understanding of sets of designs. This principle is realized through its three subprinciples: (i) defining feasible regions; (ii) exploring trade-offs by developing sets; and (iii) communicating sets of possibilities (Sobek II, Ward and Liker, Jeffrey (1999); Kerga et al. (2014)).
- Integrate by intersection, or the principle of set-based communication. Guaranteeing that through inter-team communication, that the outlined design sets are feasible and compatible with all functional groups involved. This principle relies on three subprinciples: (i) looking for the intersection of feasible sets, (ii) imposing minimum constraints, and (iii) seeking conceptual robustness (Sobek II, Ward and Liker, Jeffrey (1999)).
- Establish feasibility before commitment, or the principle of convergence. This allows for the progressive elimination of inferior design solutions from sets and ensures the identification of high-value system solutions. This last principle can be explained through its three subprinciples: (i) narrowing sets gradually while increasing details, (ii) staying within sets once committed, and (iii) establishing control by managing uncertainty at process gates (Sobek II, Ward and Liker, Jeffrey (1999)).

4.2 Digitalization and IoT solution: research objectives

The LINCOLN research is based on the following open questions: i) how the collected data and the fact based approach can impact the vessels design? ii); what are the general features an IoT solution must have to satisfy the needs of different vessels?; iii) What technological improvements are needed to reach the functional business requirements?; iv) What are new business opportunities introduced by the IoT for the three targeted use cases? According to those research questions LINCOLN addressed results are: i) the definition of specific tools for vessel design; ii) the development of appropriate HW tools for data collection; iii) the evolution of a specific SW platform

able to satisfy the business requirements; iv) the definition of prospect new business models enabled by the technological solutions.

4.3   *Environmental and economic assessment: research objectives*

One of the objectives of LINCOLN is to understand the environmental implication of vessels with a focus on product life cycle. The methodology to assess the environmental impacts of product life cycle is applied to the three case studies. The research on environmental impacts is based on the three following questions: i) what are the environmental impacts of the three selected vessels?; ii) what are the vessel life cycle steps with the main impacts?; iii) how the life cycle steps can be optimized in order to reduce the vessel environmental impacts? The three main research question help to better identify the environmental objective to fully achieve the LINCOLN goals about the investigation of product life cycle in terms of environmental impacts and economic costs. We have identified the three following objectives: i) definition of the environmental impacts of the three selected vessels; ii) identification of the critical life cycle steps of the vessels sector; iii) definition of the optimal product life cycle management.

5   Methodology

The LINCOLN approach is based on the Lean Fact Based Design methodology. This is a complex process linking several methodologies to close the loop of information between product design and usage, including information of real product usage into the design phase and providing tools to support continuous products improvement cycles through HPC based simulations (Rostad (2012)). Fig. 1 shows the main process. Designers are usually not aware of the behavioural strengths and problems of the vessels in their operative conditions and overall technical
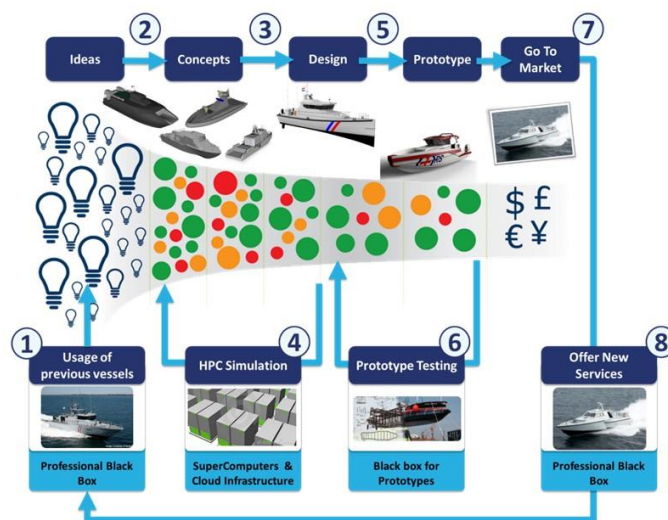

Fig. 1: Lean Fact Based Design process

quantitative data are unavailable and unknown. With the LINCOLN approach those data are collected and used for improving previous vessel series and for creating new products (step 1). The vessel improvements or new boat concepts are then developed according to the results of the data analysis about ship performances and users' behaviours (step 2). The chosen concepts are designed (step 3) and tested through CFD (Computational Fluid Dynamics) and FEM (Finite Elements Method) simulation, in a High Performance Computing (HPC) environment, which uses real data to improve the fluid dynamics simulations datasets (step 4). This type of simulation is executed on datasets coming from field data in a very short time, enabling designers to run several design-simulation iterations, resulting in a detailed and accurate design. Steps 2, 3 and 4 are repeated several times for testing different design options, in order to evaluate the best concept and to increase the quality of the resulting vessel. Then the vessel prototype is built and tested in water (step 5). The Universal Marine Gateway (UMG) black box for prototypes (von Stietencron (2017)) enables a full recording of the tests, comparing different fine-tuning options and validating the simulated tests (step 6). The iterative design and testing approach completes when the vessel is optimized for the market (step 7). The new delivered vessel is then equipped with the Marine Gateway black box (i-Captain (2017)) , which will record the vessel behaviour during its operative life, starting once again the fact based design loop and providing also useful information for after-sales added value services to different stakeholders (step 8).

Along this closed-loop process, whose methodological foundations are explained in section 3, LINCOLN uses the

lean design methodology for the design and development of the vessels, represented in the figure by the funnel in the middle of the loop. Last but not least, the LINCOLN vessels are also assessed and evaluated about their environmental and economic sustainability, which is not represented in the picture to not overload the amount of information and make it easier to understand.

6   Expected results of LINCOLN

An initial LINCOLN concept refinement and assessment activity has been done in relation to: i) the functional and technical vessels use case requirements, which are out of scope of this paper; ii) the technological developments of the IoT and simulation tools; iii) the methodological approach, enhancements and customization for the maritime sector. Regarding the first two topics, the Business Effects Evaluation Methodology (BEEM) (Henriksen and Røstad (2010)) has been used to consider technological push perspective and market demand requirements. This activity has defined the following expected results.

6.1   Lean design: Set-Based Concurrent Engineering (SBCE)

The expected result of this methodology is to provide a toolset that enables for the identification and prioritization of areas (subsystems, components or design factors) that are critical to mission objectives. The Maritime Lean Design Methodology (MLDM) sets to enable for designers to evaluate options and choices to maximize system value and maximize benefits to the customer. MLDM advocates that design and development should proceed in an incremental manner, in contrast to a product level.

The methodological goals of this research reside in the needs identified within the maritime industry, based on a series of interviews and case studies conducted within the European Union (EU). Buttressed by three industrial cases under development, the tools and processes of MLDM will been allowed to evolve under real-time operating conditions as well as within an academic environment. This partnership between industry and academia has created a unique opportunity to deploy an action research project such as this improving the usage of SBCE in the maritime sector.

6.2   Digitalization and IoT solution

To enabled the connected vessel paradigm, an IoT service oriented platform will be developed and provided to the following, but not limited to, stakeholders: i) Designers; ii) Simulation centres; iii) Shipbuilders; iv) Vessel Operators; v) Third parties companies (i.e. equipment manufactures); vi) After-sales service companies (i.e. maintenance specialists); vii) Service providers (i.e Coast Guard, Insurance companies); viii) Sea-based business companies (i.e. wind park operators). The platform will be based on the HOLONIX i-Captain solution and it will integrate the Portweather (Stavros et al. (2015)), web-based Geographic Information System (GIS) application, collecting weather and sea conditions to monitor them in real-time, providing interactive maps, graphs and stats. This is pretty useful information, for instance, for captains, vessel operators and service providers in difficult sea conditions, like the coast guard. The main features developed and improved in the platform will be: i) warning and advice messages to vessel crew on the boat status and usage and sea/weather conditions, to correct the sailing approach (e.g to reduce fuel consumption); ii) vessel real life datasets to simulator experts for CFD analysis and simulation tools improvements, for instance in terms of accuracy; iii) simulation data, test runs results and simulation data comparison against vessel real life behaviour to designers; iv) claims analysis tool to manufactures, and other claim offices; v) vessel behaviour analysis for service improvements to vessel operators and fleet managers; vi) vessel maintenance reminders and reports for programmed maintenance and warnings for conditioned maintenance to captains, vessel operators, fleet managers and maintenance third parties; vii) third parties data visualization to system users; viii) after-market new services to the different stakeholders. For the different services and features the platform will provide specific visualization windows: i) the on-board gathered vessel data in real-time; ii) the historical data; iii) the vessel maintenance data; iv) selected vessel data based on filter options; v) the weather and sea conditions and short forecasts around the vessel position and service area.

Vessel data will be collected on board of the vessels using the UMG, in case of prototypes, and the MG, for commercial vessels. The main difference is that the UMG allows the acquisition of a large amount of vessel usage data and in a defined time window; the MG, instead, gathers a reduced but continuous set of data during the vessel operational activity. Both HWs will integrate Portweather algorithm. The UMG will be improved in its features and adapted to professional vessels by BIBA partner, while the MG is going to be redesigned from scratch by TOI partner, using the Zerynth development suite (Zerynth (2017)), to gain the needed flexibility in the initial firmware release and maintenance. This will allow the MG to be easily customized and adapted to various types of professional vessels and to be simply upgraded and reconfigurable in line with the new digital standards and novelties of the fast changing IoT world. In this way the entry gap in programming and managing the MG will be

reduced, in fact the innovative Zerynth technology will allow programming in Python, instead of using complicated and hard-to-maintain low level C code, which requires a long development time.

Finally the collected vessel data will be used by CINECA partner to develop inside their HPC environment and through the OpenFOAM toolbox, the LINCOSIM, an open source virtual towing tank web service. This will be integrated into the IoT platform and accessed through the web. It will enhance the simulation capabilities, defining a more precisely reliable design solution, before moving to prototyping the hull, and reducing the necessity to rely on costly towing tank analysis. Through LINCOSIM designers will define in an early design stage some key-parameters of the hull including: resistance curve, attitude, hull pressure distribution, waves distribution, wetted surface area and any other derived quantities. LINCOSIM will provide a simple and intuitive web interface to not expert simulation users (designers) enabling the usage of CFD automated and standardized simulations. Only synthetic hull design key parameters will be requested to the end-user, the CFD key parameters, instead, will be hidden to the end-user (no CFD case setup request). As result of the automatic simulation, all the synthetic hull performance outcomes will be automatically available to the end-user (no active post-processing request). In this way, LINCOSIM will facilitate the usage of complex and expensive CFD techniques to designers and SMEs.

6.3   LCC and LCA approach

The environmental and economic assessment has been implemented considering the three different vessel case studies with an action research approach (Hult and Lennung (1980)), where the scientific knowledge is supported by direct input from the industrial partners. At this stage of the research, the first phase of the life cycle thinking approach has been implemented with the definition of functional unit and system boundaries that will be used to perform the next phases of LCA and LCC. The first requirements definition phase is divided in the following steps: i) Functional group definition; ii) Goal and scope definition (with functional unit and system boundaries definition); iii) Data quality. The three vessels have been homogenized in a common structure following the functional group approach, already well known in different scientific papers (Luglietti et al. (2016)). Thanks to the functional group analysis we defined the following main group which helps to organized the results in a correct way: hull, deck, engine room, cabin, electric system, equipment and others. The functional unit selected in order to allocate the environmental impacts and costs, is defined different for the two main goals of the assessment: i) to evaluate the results for the three products, we selected 1 m2 of vessels, to help the evaluation of different scenario during the interpretation phase; ii) to evaluate the impacts of transport service using the three vessels, we selected 1 ton transported for 1 operating hour (or 1 ton transported for 1 km).

About the System boundaries, a full life cycle approach has been implemented especially in order to better investigate the end of life phase, which is one of the promises phase for improving the results (e.g. with the investigation of a product service system business model).

7   Future impacts of the expected LINCOLN results

The adoption of the LINCOLN solution aims to reduce of 20% the costs for vessel design and coastal operations activities. It will also demonstrate that including sustainability dimension since early vessel concept and design stage optimizes the vessel life cycle. The SMEs and the maritime sector, more in general, will get new tools to be used along the value chain to increase their market capabilities through the fact based knowledge. New business models, in fact, can arise from the availability of MOL vessels data, e.g. improving services, like maintenance and after-sales vessel features upgrades based on usage, personalizing insurance contracts, profiling customer for future sales and so on. The SME will also benefit from learning advanced design and sustainability methodologies, improving their professional skills. For instance, where SBCE has been properly adopted, the design engineers have demonstrated skill improvements according to internal corporate review. It has therefore been determined that this design methodology has the potential to help in developing new knowledge and efficiency, within the maritime sector at both a practitioner and corporate level. The final impact will be then an improved go to market of companies adopting the LINCOLN solutions, resulting in increased competitiveness.

Acknowledgments

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