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Maritime 4.0 – Opportunities in Digitalization and Advanced Manufacturing for Vessel Development

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Abstract

Maritime vessels are complex systems that generate and require the utilization of large amounts of data for maximum efficiency. The successful utilization of sensors and IoT in the industry requires a forward-thinking approach to leverage the benefits of Industry 4.0 in a more comprehensive manner. While processes and manufacturing processes can be improved and advanced through such efforts, in order the industry to be able to benefit from data generation, integrated approaches are necessary. In order to develop truly value-added vessels, we introduce a descriptive approach for understanding Maritime 4.0.

Keywords: Maritime 4.0, Digitalization, Maritime Vessel Development, Industry 4.0

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1. Introduction

Digitalization and the dynamics of the maritime industry are driving a need to rethink how connected systems and IoT can be leveraged to create the next stage in vessel development. The maritime industry is critical to social and economic development, accounting for roughly 90% of the EU's external freight trade with more than 400 million passengers embarking and disembarking in European ports each year [1]. Surrounded by 136,000km of coastline Europe has been a world leader in maritime activities for the past century.

In an effort to facilitate and increase the competitiveness of the European maritime sector, lessons learned from the manufacturing and vessel industry have served as a key element in future development. This includes the incorporation of new technologies, materials and optimization processes into the engineering and design practices of the greater industry [2,3]. Through the integration of reporting and real time tracking technologies in vessels the amounts of data being collected and generated over the past 5-years has grown exponentially [4,5]. Despite a rise in the amount of data being generated, a challenge remains in how to leverage it in the most efficient manner to support the next phase of development.

Within the field a lack of clarity is evident from the multiplicity of descriptions and terms used with respect Industry 4.0 (I4.0) and even more complicated in the field of maritime. Based on this, this paper consolidates principles that reflect the objectives of Maritime 4.0 (M4.0). In an attempt to address this, this paper incorporates industry technical literature, published cases and common figurative usage to present an initial basis that aims to support the formalization of M4.0. Highlighting critical research areas and presenting current research that has been performed to support the digitalization in maritime development.

1.1. RESEARCH APPROACH

As digitalization grows in importance as a consideration in the design, production and operation of vessels there is a need to have a well-defined basis for 4.0. To this point the incorporation of digital technologies has been user driven, however due to opportunities for improvement the producers can now also leverage technology for their own means.

The characteristics and principles introduced in this paper were developed out of a series of interviews performed with industry experts, literature and industrial materials. In the first instance, a series of interviews was conducted on “4.0” in the maritime industry. It was found that there is a general lack of consensus regarding what the term means and how it relates to the industry. That raised the research question – ‘What is 4.0 in relation to the maritime industry?’

Through a rigorous, empirically grounded, and contextually relevant means the main contribution of this paper is the provision of an organized set of characteristics related to 4.0 and introduce a practical definition.

2. OVERVIEW OF INDUSTRY 4.0

The technological basis for the I4.0is the Internet of Things (IoT), first proposed in 1999 by the MIT [6]. Since its inception, I4.0 has gained tremendous interest worldwide, since its origin in 2011 by the German government to address and bring forth advancements in data management, device communication and digitalization. I4.0 refers to the fourth industrial revolution, characterized by the incorporation of IoT and IoS in the manufacturing industry. The industrial transformation leverages Cyber-Physical Systems (CPS), internet and future-oriented technologies and enhanced human-machine interaction paradigms to deliver value added processes [7–9]. I4.0 has been operationalized through different national initiatives, some examples are “Industry 4.0” in Germany, “Industry 2025” in Switzerland, “Smart Manufacturing” in USA, “Industria 4.0” in Italy, “Norge 6.0” in Norway, “Usine du Futur” in France and “High Value Manufacturing” in UK. Illustrating that its name has not been consolidated even at an International level.

Considering these efforts, many studies have been undertaken to describe how syncretistic components function and identify enabling technologies needed for successful I4.0 implementation. For this, it has been determined that it is essential to understand the relationship between physical objects used to control and improve the integration between the physical and digital world [10]. This utilizes intelligent manufacturing technologies to communicate and deliver large amounts of data in to allow for better predictability and optimization capabilities [11,12]. This in effect merges historically separate worlds, creating a synergy between operational technologies and information technologies.

Considering the numerous interpretations, I4.0 in this paper is understood to be a collaborative digital end-to-end integration process (socio-technical), operating through a vertical and horizontal integrated production system. This shift aims through the following enabling technologies to increase the availability of data for decision making.

- **Internet of Things** (IoT) refers to a global dynamic network, linking uniquely identified physical and virtual objects for the purpose of communication, configuration and actuation [13–15]. This includes autonomy and privacy for the management and collection of data.
- **Intelligent Robots and Automation** (IR) carry out and perform planed and unplanned operations while interacting with people or other systems [16–18].
- **Cloud Computing** (CC) is a computing technique or service that allows for the storage and processing of data or resources through computing units connected by IP networks [19–21]. CC provides accessibility to manufacturing data from outside of the facility.
- **Additive Manufacturing** (AM) is the process of joining materials to make and produce objects from 3D model data, as opposed to traditional subtractive manufacturing approaches. Reducing transport distances and stock on hand for the production of customized accurate and strengthened intricate objects [22–25].
- **Big Data Analytics** (BDA) enables the collection and evaluation of data from different sources to support real-time decision making, optimize production and improves equipment service. BDA provides the ability for data to be collected in real time to provide the right information for the right purpose at the right time to the right person [18,19,26].
- **Intelligent Simulation** (IS) leverages real-time IoT data in a virtual model, so that engineers, operators and managers to test and optimize systems before implementing a physical changeover. This reduces the down time of machines, the setup time, while increasing production quality [27,28].
- **Augmented Reality** (AR) supports a variety of services that support human workers respond to rapidly changing production environments, such as selecting parts in a warehouse and sending repair instructions through a networked and connected system [27,29,30].

The goals of these technologies are to provide for the mass customization of products; expand the use of automatic and flexible systems and to facilitate the communication between parts, systems, and humans. I4.0 enables the improvement of products, the creation of new services and ability to refine business models for better communication in the value chain.

3. DIGITALIZATION IN MARITIME

As the data and technologies continue being developed, M4.0 has become increasingly important to the European maritime. Given high dynamic pressures there is a need for improved efficiency; in design, production, and operation.

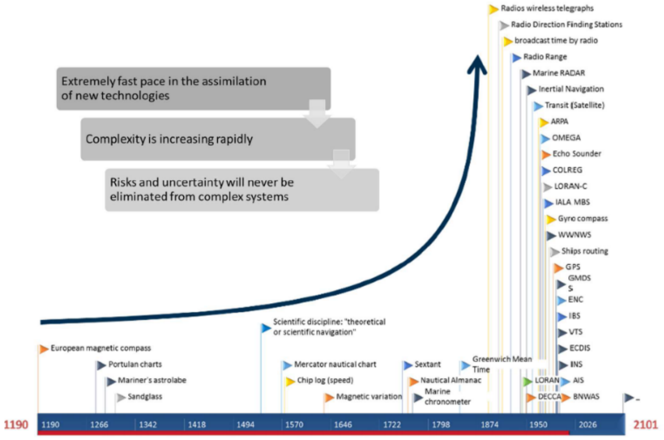

Figure 1: Timeline of in maritime navigation technologies [31]

The literature considered in this section is based upon the findings of academic publications that were found to have relevance to Shipbuilding 4.0, Shipping 4.0, Maritime 4.0, and Shipyard 4.0. Due to a wide disparity of 4.0 in the industry amongst academic publications, it was decided to include business reports, technical publications and white papers.

3.1. System Design and Construction

The world is getting more connected and the needs of customers are becoming more demanding and dynamic. From design, shipbuilding, and maintenance, to the optimization of cargo routes the maritime sector continues to evolve in response to economic, political, demographic, and technological trends. Accordingly the utilization of digital technologies allows these trends to be met in a preemptive and responsible manner.

Vessel design and construction continues to heavily rely on the utilization of knowledge from past projects. Consequently, the development and inclusion of digital technologies has been limited, with adoption taking many years before the full benefits of the technology can be realized. Recognizing this, the table below briefly illustrates the levels of implementation 4.0 technology currently in the industry, regarding; Vessel Design, and Vessel Construction.

3.1.1. Vessel Design

Vessels are complex systems that designed through an iterative and multifaceted process, influenced by a number of factors (both internal and external) [32]. Depending on the requirements set forth by the customer, designers are required to develop cost efficient vessels capable of performing specific tasks, while maintaining strict adherence to both international and national rules or regulations [33]. However, finding the best balance within these restrictions is a challenge for the designer/engineer, system integrator, and shipyard.

Determination of the basic design type is a critical factor when determining the parameters and processes that will be undertaken from conception to delivery. Historically, new vessels are based on existing designs that integrate minor breakthrough innovations, which dates back to when ship design was often determined based on experience. This prescriptive allows for quick and straight forward to application. Managing the specific requirements, stakeholder interests (builders, cargo owners, customers, ports operators, classification societies, environmental matters, comfort of the crew/passengers, etc.), optimization criteria and technical feasibility. In addition when designing a “standard” vessel, this conservative approach reduces the risk for failure and ease for verifying compliance to national and international legal regulations [34].

- IoT: Recognizing the traditional vessel design approach and subsequent processes, the incorporation of data into the design process from sensors and Personal User Information (PUI) is limited [35,36]. While the utilization of such data is to this point limited there are several examples of vessels being produced that have utilized incremental improvement for the improvement of fuel efficiency [36].

  The prescriptive incorporation of PUI data could result in the mitigation of subjective design decisions, and thereby allow for increased performance and value of the vessel for prospective stakeholders. Despite the acknowledged potential benefits of using PUI and sensor data in the design process there are challenges that must be considered in insure that relevant, accurate and reliable data is articulated to those involved. Due to the relative newness of integrating data streams into vessel design decision [37]. This can facilitate the incorporation of data beyond 5rweather and location information to be used in the generation of new designs. Providing designers with not only PUI and performance data but also structural and mechanical data.
- Intelligent Simulation: Regarding design, data integration and machine learning coupled with CAD and CAE solutions provide the ability to reduce cost and improve key areas quality of vessels based on real data. According to several authors in the field this data optimized simulation system goes beyond the traditional virtual prototyping techniques used in vessel design, allowing for existing designs to be optimized according to operational and environmental conditions [38–40]. In relation to design and vessel development the ability for designers to be able to analyze and reuse, in short and even in real time [41,42]. Through increased data generation from vessel sensors and IoT devices vessels could be allowed to test and optimize the best design and significantly reduce the design time and user dependencies that currently exist in vessel design [40].

3.1.2. Vessel Construction

Shipbuilding (construction) is most closely aligned to I4.0 with several shipyards creating plans for implementation, including Navantia in Spain [43]. Globally the competitiveness of the industry has made it vital for the adoption and implementation of new technologies. The shift to adopt 4.0 is expected to change the way that operators perform their daily tasks and how materials are stored, processed and ordered. This includes how shipyards handle the integration of machines into the human environment and augmented reality.

- IoT and Intelligent Robots: Due to the nature of the maritime vessel construction industry, it has become increasingly important to reduce the time needed to build and develop vessels while improving the safety conditions for workers. IoT in relation to the shipbuilding process provides the ability for shipyards to improve their production schedules by improving the distribution of relevant data across its supply chain. This will help to not only in the material side of construction but also through the shipyards ability to better collaborate with support personal and subcontractors. Traditionally, shipbuilding has been closely related to the processing and conversion of sheet metal into panels, and hulls. Though with diminishing use of steel construction, and the development of new materials many new opportunities have emerged for improvement [40,42,44]. Robotics and automated production are promising areas, offering to improve the quality and reliability of vessels.
- Additive Manufacturing: Vessel construction is an expensive and extensive process, involving many individuals, processes and materials. Research into the viability of additive manufacturing for maritime has been ongoing for over 25 years, and looks to be well suited to

provide for large savings in ship-building and maintenance [45–47]. Additive manufacturing has for the past 10 years been described as a disruptive technology that promises to have profound implications for the entire supply chain. Fueled by the rapid development of new technologies, and materials the costs for development continue to decrease. Additive manufacturing looks set to not only replace several traditional manufacturing technologies but also eliminate not value-added stages of production (assembly) and ultimately simplify production. This supports adoption, competitiveness and facilitates the development of parts that have intelligent properties, including integrated sensors.

- Intelligent Simulation and Augmented Reality: The role of CAD/CAE has a long and established roll in vessel development, enhancing the various phases of the design process to assure shorter lead times. In today's digitally driven environment and the increasing complexity of system integration, production and operation CAD/CAE tools and AR are becoming more important than ever. As they can support those involved in the construction process perform tasks such as; assembly, context awareness, data visualization and Human-Machine Interface integration. This marks a decided shift in simulation development, from analytical/optimization oriented models, to integrated models that recurrently from other decision tools and simulations [27].

3.2. Operations and Shipping

The intelligent navigation of vessels has been greatly improved through digitalization efforts that allow for the real time tracking and positioning of vessels in transit. These systems provide collision avoidance, information display, monitor, alarms, satellite communication, and ship management which are useful for the crew the port and other stakeholders to operate and optimize the vessel.

Although the international shipping industry is responsible for the carriage of around 90% of world trade[48], its approach towards technology has been always followed very slowly other industrial sectors. The compulsory Automatic Identification System (AIS) used, as tracking system, on-board of ships and by vessel traffic services (VTS), was adapted to maritime use from aviation industry in the 1990s.

Today digitalization in shipping is mainly linked[49,50] to cost and capacity optimization, operations and navigation performance management, value beyond the vessel, such as better engagement with customers and more informed decision making, efficient use of transport infrastructure and new operating models, with applications in the following areas [4,51–53]: Innovative transport of goods, Remote operations, real-time tracking, Warehouse optimization, Asset maintenance, Route optimization, Collision avoidance, Asset Tracking, Equipment monitoring, Hull Monitoring, Seafarer training, and Market management.

4. Defining Maritime 4.0

The maritime industry is in the process of developing collaborative platforms to improve the lifecycle of vessels that can leverage the connected capabilities of digital systems. Facilitating the delivery of greater performance, lower ownership cost, increased safety and security, and reliability. However to this point, there remains a lack of consolidated principles and characteristics for M4.0. Based on a series of interviews conducted with industry practitioners and academics Maritime 4.0 refers to;

- The automated integration of real data into decision making;
- The adoption and implementation of connected technologies for design, production, and operation;
- Reduction of vessel environmental impact, related to production, operation, disposal (including emissions, underwater noise, and material utilization);
- Affordable and sustainable operation; and
- Reduction of risk, increasing safety and security.

These principles reflect the output of both interviews and literature. Where it was confirmed that there is not a comprehensive understanding for what intelligent vessels or 4.0 entails in respect to the maritime industry. One problem identified was that given the large variation in understanding the scope of 4.0 it was difficult to frame and propose solutions according to new customer needs. The desire for "M4.0" stems from the fact that we are embarking on the next phase of digitalization in the industry, both in reality and perception. This section draws from established principles, to merge I4.0 with maritime to create a descriptive explanation of M4.0.

4.1. Descriptive View of 4.0

Clearly, there are similarities between I4.0 and M4.0, particularly in regard to technologies. However the difference resides in how each of the technologies interacts and intersect with one another across multiple areas of the maritime sector. M4.0 can be defined as the integrated implementation of digital processes and technologies in the design, development, construction, operation and service of vessels.

Figure 2: Descriptive Representation of M4.0

This descriptive representation of M4.0 (systems of systems) considers forces and outcomes for achieving digitalization by integrating technology into the entire system of systems. This is due to the position of this paper being that independent connected systems fail to provide for comprehensive and integrated improvements for the industry.

4.1.1. Drivers for M4.0

Since I4.0 emerged there are several drivers that have affected the growth and interest of the concept. Drivers for

M4.0 represent external socio variables that influences the development of the concept of 4.0 in different disciplines. Based on a review of the literature and white papers related to I4.0 the four major drivers of are:

- **Dynamic Policy**: represents regulations mandating some aspect of the system (initiative established by Governments). Effected by the market though customer needs, this includes national initiatives such as those being pursued though I4.0 in Section 3.
- **Dynamic Marketplace:** market pressures require the development of vessels able to deliver value while maintaining a high level of responsiveness. Businesses must stay ahead of competition during design, construction, operation, while being maintained to satisfy market and customer needs.
- **Technological Evolution:** the ability to meet specific market and customers' needs requires the ability to efficiently change the vessel to accommodate new, novel technologies. Technology influences all aspects of the system and is an enabler for new and advanced systems.
- **Variety of Environment:** Indicates the number of embedded systems, integration of diverse technologies, or number of operational contexts. Interrelated elements and embedded systems.

4.1.2. Elements of M4.0

In this context, M4.0 elements represent industry aspects (sectors) that operate together to address and respond to the primary drivers. M4.0 is built around four elements that respond and intersect to create a comprehensive system: (1) design, (2) construction, (3) operation, and (4) service.

- **Vessel Design**: Reflects the incorporation of data from existing and previous vessels for improvement and optimization of the vessel.
- **Vessel Construction:** The process of construction describes production process used to deliver the vessel to the customer, including consideration of the supply chain, manufacturing technologies, representing both time and money, incurred from design to delivery.
- **Operation**: Marine transportation systems, diving operations, ports, dredging and waste disposal. The operation and usage is the actual conditions and behaviors of the vessel, generating and producing vital data used for decision making regarding navigation, fuel consumption, and operating environment.
- **Service**: Manufacturers, engineering consultant firms in marine electronics and instrumentation, machinery, telecommunications, navigation systems, special-purpose software and decision support tools, ocean research and exploration, and environmental monitoring.

The objective of M4.0 is for the delivery of a high quality, optimized, and reliable vessel that leverages the latest technologies for the maximization of customer value.

4.1.3. Principles Guiding M4.0

In considering the close link to I4.0 the basic principles discussed in the literature considering; interoperability, virtualization, decentralization, real-time capabilities, service orientation, and modularity can be extended. Recognizing the elements and drivers of M4.0 shown in Figure 2 it is possible to understand how each intersect and behave towards one another. The four principles of M4.0 to be discussed are: (1) innovation, (2) sustainability, (3) safety and security, and (4) connected and automated operations.

Innovation: the integration, adoption and inclusion of technology, that allows for and supports syncritic data. Through consideration of the innovative data solutions, information relating to the vessel can be used to evaluate varying options and iterations for decision-making activities. When considering the necessary processes for data to be integrated from vessels across different elements of M4.0.

Sustainability: Designers, shipowners, and operators have in recent years requested the retrofitting of existing vessels and the development of new energy-efficient vessels with better performance and lower operating costs. Sustainability therefore represents a mechanism that describes value considerations and can be reflected through either materials, noise generation, or other quantifiable matrices relating to sustainability. The expectations and effects of this principal relates to the continued optimization need to meet the shipowner expectations to have rapidly modernized the fleet with the energy efficiency systems solutions on the ship.

Safety and Security: Determination of the appropriateness of data sources in relation to design parameters and application is critical to maintaining and delivering a reliable and safe vessel. The challenge for how to deliver this principle to the vessel requires consideration of how data is utilized and effectively integrated with other data sources. Insuring that the information being generated and collected is of paramount importance in order for proper decisions making taken. Failure to meet this can result in a negative value for those involved if the "context understanding" during data collections is unclear. Integrating and merging the data into viable and manageable virtual systems allows for 4.0 to deliver operational data protection that cannot be tampered or molested and improves upon the vessel as a system.

Connected and Automated Operation: through a desire for optimized vessels this principle refers to the actual level of digitalization and integration of the vessel. Leveraging data so that it can deliver the greatest value requires not only the information generated by the systems, but also recognition of the industrial business being served. This data-driven approach considers that under the current conditions there are many sensors that can be used to provide and generate many types of data. The challenge therefore is not directly linked to this first stage, the challenge rather is in the ability to understand and develop new sensors and data streams that provide more value to the entire industry. Redundancy and modularity can be powerful together, because it allows a module to be taken away without the system losing a critical function of the vessel.

4.1.4. Characteristics

Characteristics are distinguishable features of M4.0 proposed in order to create realistic operating profiles and to improve the maritime industry. In recognizing the potential value of digitalization and M4.0 regarding vessel systems and stakeholders, vessels must not only meet current needs but also be able to interact with one another so that they can accommodate the needs of tomorrow. A preliminary list of characteristics has been developed from the literature that was, these characteristics seek to illustrate M4.0 systems in a pragmatic manner.

- The vessel shall operate with or interact with some autonomous decision-making process, while generating data relevant to a common basic set of attributes.
- The vessel has a stable core functionality but aims to be optimized through secondary functions.
- The vessel has a long lifecycle.
- The M4.0 architecture and vessel are subject to a dynamic marketplace with strong competition.

5. Digitalization Case for Design and Construction

According to the described characteristics and elements of M4.0 the incorporation of usage-data and vessel information requires that the relationships between data-analysis, filters and the system dependencies be well established and documented. Thus allowing for the transferring of usage-data into reliable parameters, in turn facilitating the successful inclusion of data streams into vessel design for advanced decision making.

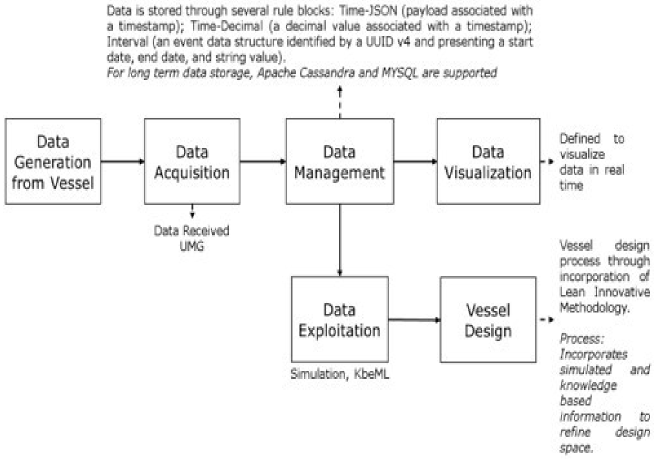

Figure 3: Data Oriented Data Oriented Design Structure (data visualization representative of real-time feedback interface)

Sensor monitoring data and Product Usage Information (PUI) requires the setup of related analysis capabilities, such as filters dependencies between usage-related parameters and design parameters or component attributes on the other. In addition, usage-information can be utilized to test varying configurations to make vessels faster (according to material and design parameters) while reducing risk, due to improved decision-making processes that are based on real-time data. Thus allowing new vessels and different product generations, to leverage the collective outputs generated from PUI data to strengthen the whole vessel family.

Through the framework and in line with the safety centric design approach of the industry, a data-oriented that combines multiple elements of M4.0 was developed [54]. This framework seeks to enhance the resources available to designers and engineers throughout the development process and allow the testing of designs based on real vessel data and not only experience (subjective knowledge). This could reduce the cost and time required throughout the design and development process in a comprehensive, long-term, improvement methodology. This information will be utilized for future vessel design and simulation, as well as for verifying the quality of the data being collected. The information available to the designer is accessible via the UMG (Universal Marine Gateway) operating on the vessel.

5.1. Data Generation

According to vessel characteristics and stakeholder requirements, sensors were incorporated into the hull to measure slamming forces and strain. Sensors were selected according to the:

- Vessel's environmental and operational context;
- Vessel's characteristics and core parameters (e.g., vessel displacement, length at waterline, keel-line);
- Feedback intent, and purpose of data acquisition (design, maintenance, etc.);
- Technology suitable to context and intent

Each selected data type is based on its ability to deliver data suitable to meeting the vessel's purpose, ability to integrate into the on-board monitoring system and relevance to the intelligent simulation platform.

5.2. Data Acquisition

Data acquisition regarding vessels tends to focus more on the facet of collection information from different on-board systems such as the NMEA2000 and NMEA0183 networks. These networks are sources of information like geographical location of the vessel, engine parameters, environmental characteristics in and around the vessel etc. The analyses of generated data streams can be utilized for various assessments according to the needs of the designers/engineers.

Data acquisition is performed through an on-board computer and network NMEA connector, to store information to a database with timestamps. This provides an overview of boat's physical attributes over a specific period of time or during voyages. However, from a vessel design perspective, it is more crucial to obtain specific information from specific parts of the vessel e.g. hull. A practical consideration from a design perspective is how the hull reacts during voyages. It is important to understand during the data acquisition phase for different data streams, where exactly the sensors installation takes place within the vessels.

To enable comparison and/or mapping between theoretical information based on simulations and practical information based on the trials, the model provided for CFD (Computational Fluid Dynamics) has to be aligned to the characteristics of the physical vessel used for the sea trials. Additional parameters such as the loads influence the boat's draft, waterline and other related performance parameters. The center of gravity has to be identified and provided for the mesh-model (spatial model) used for the CFD calculations. While a "theoretical" center of gravity can be calculated by CAD systems (indicated by coordinate origin in Fig. 4), the center of gravity under operating conditions can differ.

5.3. Data Management

Data management aims to handle and save data, in order to assure accessibility and compatibility with digital and knowledge-based interfaces. Whilst the Data Generation process determines the varying data types, the management process is responsible to merge data streams from different devices (or sources). Considering data aggregation, it was necessary to consider that certain simple devices tend to provide noise data that requires cleaning and post-processing in order to be converted into a usable form and reduce errors. Testing data manipulation, notifications, events or alarms generation is possible through some conditions recognized within the data inputs. A device abstraction layer is employed to provide a set of rules to carry out these tasks in a simple manner, reducing the burden of specific implementations.

5.4. Data Exploitation

The proposed approach refers to the leveraging and integration of real vessel data into the design process. This includes interfacing PUI and sensor generated data into secondary programs for decision-making and product development improvements based on the proceeding processes. Further, collected data through proper data management allows for integration with software (e.g. CAD, CAE, and CFD). The exploitation, of this data allows for the direct improvement of the vessels, since this enables real condition data for calculations, dimensioning and simulation, as well as the evaluation of design alternatives against different operational conditions.

5.4.1. Data Processing for Calculation Optimization

The approach for the coupling of PUI and sensor generated data is based on KbeML. The approach was developed as a formal extension of SysML, to facilitate a formal and neutral representation of engineering data independent from any other framework. KbeML functioned to capture codified knowledge, such as rules and equations to improve calculations.

- To provide of a neutral format (standard) to avoid the encapsulation of knowledge (rules & equations) in filters and applications.
- Enable post-processing of modeled dependencies, e.g. documentation or simulation.
- Support a common understanding among the different domain specialists. This objective refers to the circumstance that interdisciplinary teams of different domain specialists typically drive the design of complex products & systems.
- Represent product usage information and data in terms of sensors, components, or systems.
- Define elements that are utilizable through statistical functions, for specific post-process analysis related to the product-development.

Additional elements have been defined to describe the linkage between PUI and design knowledge. These elements support the idea that usage related information can be mapped directly to design related elements such as equations or rules.

Following a set of usage parameters the calculations were able to be performed based on the direct link between usage and design elements. Typically, the ABS rules expect the speed to be treated as a precondition (e.g., customer says the boat should allow a maximum speed of 20 knots). In reference to the approach, the parameter can be extracted from the usage phase and provided to vessel designers. Which allowed a broad range of calculations to be linked to PUI and sensor generated data.

Further, the formal notation and its underlying semantic meaning allowed the post-processing and linkage to the design and development related application. Exemplarily, the codified data can then be utilized within the the virtual towing tank application (intelligent simulation) [27]. Based on the successfulness of the codified data a support structure for future automated data transfer into programs beyond CAD (HPC virtual towing tank, LINCOSIM will be instituted.

6. Concluding Remarks

Managing large amounts of data is increasingly seen as a competitive advantage for companies and is viewed as a principal way to deliver and provide for autonomous operations in all elements of the industry. Recognizing the growing use of connected technologies, M4.0 aims to provide an introductory understanding of the principles and characteristics involved.

The framework described in Section 6, represents part of ongoing research that is being conducted to incorporate real time into intelligent simulations through the utilization of IoT, and Big Data to support decision making. Ultimately M4.0 is an integrated system of systems concept that requires the utilization of innovative technologies for the development of sustainable, secure and connected vessels. By bringing together not only the technologies and elements of it is possible to harmoniously synchronize efforts for industry improvement.

Even though I4.0 and M4.0 utilize the "same technologies" the value potential is by bringing the benefits of each together for an intelligent vessel. Providing a descriptive view of M4.0 allows for technologies, characteristics and 4.0 elements to improve the likelihood for the highest value-added delivery.

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