A Prospective Data-Oriented Framework for New Vessel Design

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***Abstract*— Marine vessels are highly customizable solutions, designed to perform multiple missions in shifting environments for many years. The successful utilization of sensors and relevant data in vessel design requires forward thinking and consideration of stakeholders and current design processes. While heterogeneous sources of data are available from vessels such as speed, engine performance, orientation, and slamming forces, correlation to a particular design facet requires considerable effort and design experience to create a more comprehensive picture of the context. We provide a structured approach incorporating constraints for proper data acquisition collected from active (operational/real) vessel based upon post data processing through event-based information, to become a relevant approach for practical design problems. With this approach, incorporation of stakeholder and usage information facilitate an improved design process, providing traceability between the link of data streams and design decisions.**

***Keywords*— Innovative Vessel Design, IoT, Data Stream, Telemetry, SysML, Intelligent Design**

I. Introduction

The maritime industry is and has historically been a critical factor both socially and economically. In an effort to facilitate and increase the competitiveness of the European maritime sector, lessons learned from the naval and specialized 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 [1], [2]. Through the integration of reporting and real-time tracking technologies into vessel design the amounts of data being collected and generated over the past 5-years has grown exponentially [3], [4]. Despite the increasing amount of generated data, a challenge remains in how to leverage this information in the most efficient manner during the design, maintenance phases and upgrade of maritime systems.

Addressing this challenge, the efficient use of usage-data and information requires that the relationships between data-analysis, filters and the system dependencies be well established and documented. This requires that usage information and design parameters or component attributes be considered from project conception to data collection, and design alterations. Thus allowing for the transferring of usage-data into reliable parameters, in turn facilitating the successful inclusion of data streams into marine vessel design.

Today's challenge (discussed in Section II) is not necessarily to find data to aid the design process but rather how to define the right parameters necessary for assuring the quality of the data behind the parameters is useful to designers and engineers. To leverage innovation and data in an effective and meaningful way, to this point the necessary engineering effort required has increased, which can present obstacles. Owing to a lack of research into the systematic transfer of usage-data such as sensor data or usage-feedback into vessel design, this paper aims to present a preliminary framework that allows incorporation of usage-data to throughout the design process. This would allow for traceability between data streams and design decisions, which assures the quality of the data used throughout the design process.

Sensor monitoring data and Product Usage Information (PUI) requires the setup of related analysis capabilities, such as filters on the one hand and the identification of dependencies between usage-related parameters and design parameters or component attributes on the other. In addition, usage-information is usually acquired from instances (e.g. fuel-consumption of each car), while design information is usually based upon product classes (e.g. fuel-consumption of new "model of brand x") [5]. It can be possible to develop vessels faster (according to material and design parameters) with improved decision-making via ability to transfer PUI and real-time data into knowledge, thus allowing new vessels and different product generations, as well as to distinguish between relevant systems and components, which may be different from those under consideration.

II. Previous Work for Vessel Design & Engineering

This section addresses the background of maritime vessel design, as well as the relationship between design, data and PUI. In addition, this section outlines some of the processes involved in the integration and utilization of data streams for current and future vessel design and development, as well as challenges faced by designers and engineers.

A. Approach to Vessel Design

Vessel design is a complex, iterative and multifaceted process, influenced by a number of factors (both internal and external) [6]. Depending on the vision or 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 [7]. 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 undertaken from conception to delivery. Historically, new vessels base themselves on existing designs that integrate minor breakthrough innovations, which dates back to when ship design was often determined based on experience. This prescriptive practice allows for a design process that is proven to be quick and straightforward to apply for 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 [8]. Despite the obvious benefits presented by this approach, it can be difficult to incorporate new innovative solutions due to the restrictiveness of the design space [9]. In addition, the established approach to this design limits the disruptive innovative steps (e.g., boat speeds beyond the expected association rules have demand for new verification means).

B. Maritime Design Process

This section addresses the background of vessel design, to provide insights in the processes of design and illustrate how each phase of design can be pursued. In this regard, this section outlines efforts currently undertaken to facilitate the integration and utilization of technological advancements for current and future vessel design and development. Regardless of the design process, a vessel is a complex multi-domain dynamics system comprised of many components, which are designed to achieve a common objective or mission within a complex and aggressive environment. Additionally, the type, size and complexity determine the development time of the design processes.

Currently, there are different methodologies used to develop a vessels design, however a common design methodology used is the design spiral [10], [11]. The design spiral is a conceptual model for maritime vessel design that considers performance, economics and time through a sequential and iterative design process [10], [12], [13]. Following the design spiral, the ship design process is divided into 4 stages:

- Concept Design and feasibility study: Focuses on requirements definition to define the main technical ship characteristics. The results of this steps will influence the largest portion of the lifecycle cost of the ship and a design approach cored on set-based concept gives a more optimal global solution [14]
- Preliminary Design—Second to Fourth Iteration Loop: The objective of this step is to improve and elaborate the main ship characteristics partly addressed in the previous phase. The main features and coefficients of the ship, such as length, beam, horsepower deadweight etc. are defined in detail to satisfy the established requirements and obtain a technical and economically feasible solution.
- Contract Design—Fifth Iteration Loop: During this stage, the ship features are calculated and described more precisely such as hull form, powering, seakeeping and maneuvering, ship's auxiliary/supply networks, structural details and materials, spacing and precise estimation of the individual ship weight components.
- Detailed Design: Is the last phase of the design, a detailed design of all ship structural elements is provided considering the technical specifications for the ship's construction and the equipment requirements. In general, on this stage, the engineers must provide enough information to the shipyard to allow the ship construction.

Through such a series of design-phases the requirements, process, and solutions are meticulously set, culminating in a design ready for authorization and subsequent production.

C. Data for Vessel Design

The incorporation of data from sensor and PUI data is limited in the use of vessel design and vessel optimization efforts [15], [16]. Despite limited exploitation, there are several examples of vessels being produced that have shown small improvement related to fuel efficiency [16]. According to [16]–[18], PUI data related to how vessels are being used is limited, however it has demonstrated the potential for designers and shipyards to incorporate this data into their designs. This 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 to ensure that relevant, accurate and reliable data is articulated to those involved, particularly due to the relative newness of integrating data streams into vessel design decision [18] and also particularly related to the volume and variety of data, which continues to increase daily. This means that additional generated data beyond weather and geo-location can provide designers with not only performance data but also structural and mechanical loads data, which in relation to design and vessel development increases the ability for designers to be able to analyse and reuse, in short and even in real-time [19], [20].

III. Research Approach

The research approach bases itself on the previous works (Section II) to develop a comprehensive foundation for addressing maritime vessels design approaches and utilization of generated and available data from the vessels. The LINCOLN project focuses precisely on this aim.

Three industrial cases within the project are boat builders from Norway, Greece and Spain working to develop three new vessel concept:

- Multi-platform Catamaran: Service crew vessel and multipurpose survey vessel, optimized for ocean energy and Aquaculture.

- Module Based High Speed Patrol Boat Platform: Reconfigurable vessel capable of being easily adaptable for multiple missions.
- Emergency Response and Recovery Vessel: Developed for coastal recovery.

Within the projects, technology partners focusing on R&D and academic partners along with the industrial ones work to focus on two areas:

1. Development of support for vessel designers and builders, researchers and digital developers in their joint daily activities through sustainable lean development methodology.
2. Facilitation of vessel operators to serve operational activities effectively by connecting specialized vessels to an IoT Platform [21].

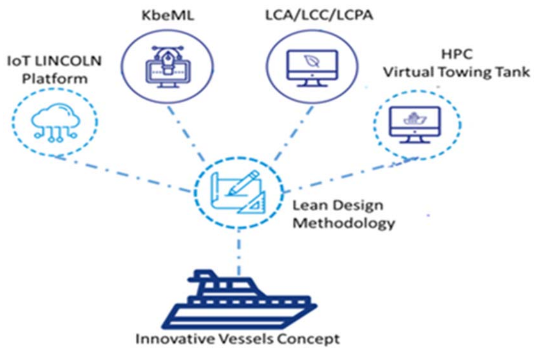

Fig. 1. LINCOLN Vessel Approach with its Components

Each vessel within LINCOLN, utilizes some of the main components mentioned in Fig.1, like the IoT Platform, KbeML, LCA/C/PA (Life Cycle Analysis/Cost) and HPC (High Performance Computing) for simulations etc. in order to increase competitiveness and coordination of real data usage in decision-making for design processes and operational support. The upcoming section illustrates usage of some of the components for a data-oriented approach to vessel design.

IV. Creating a Data-Oriented Design Framework

The design framework is an approach to support vessel designers, shipbuilders and digital developers involved in vessel and maritime design. As discussed in Section II, the traditional approach and steps involved intend to reduce risk while leveraging experience and knowledge.

Through the proposed framework and in line with the safety centric design approach of the industry, a data-oriented approach is introduced that 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. The framework has been developed to integrate with a Customizable Lean Design Methodology, and traditional maritime vessel process to support the development of a structured data oriented decision-making process.

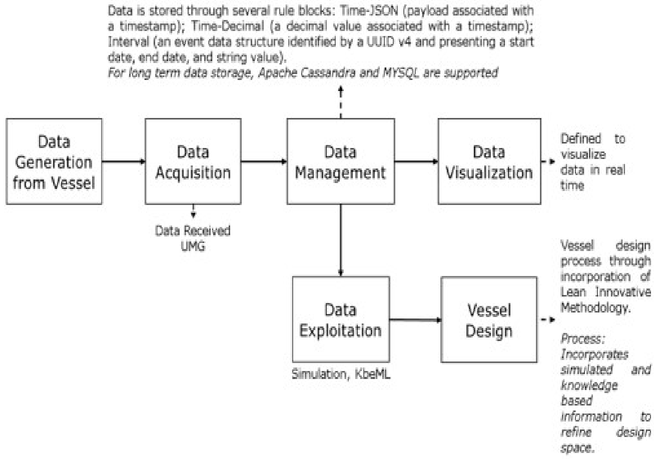

Fig. 2. Data Oriented Design Structure (data visualization representative of real-time feedback interface)

Through the utilization of three vessels which serve as the sources for data and information. Each vessel has been equipped with an on-board IoT based technology and digitalization platform to allow for profile data (equipment) and PUI data to be collected in a manner pursuant to the framework. Fig. 2 provides an overview of the framework with its main attributes discussed in detail subsequently.

In accordance to stakeholder's specifications, (Fig. 3) the vessel designer will have access to the vessel data based upon the established data types specified for the vessel. This collected 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 within the data management structure (Fig 2, Fig 3).

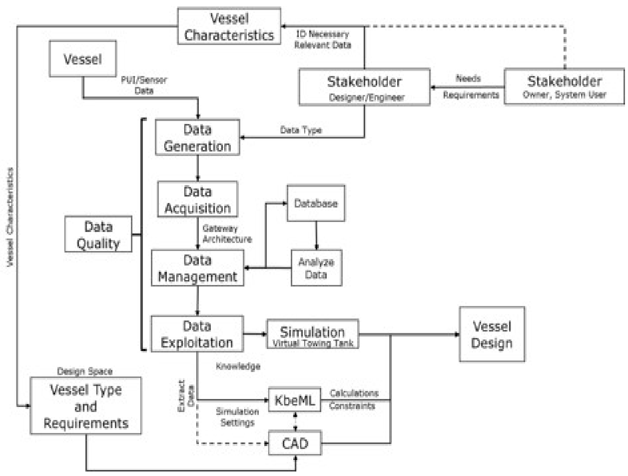

Fig. 3. Data-Oriented Vessel Design Framework Block Diagram

Through consideration of the framework (Fig 3), information and processes pursuant to vessel design are considered based upon a multitude of choices and iterations used in decision-making activities. When considering the necessary processes for data to be converted into knowledge, from real vessels, whether it be PUI or sensor-generated data the following challenges related to the process are considered:

- Data Quality: Is the determination of the appropriateness of data source in relation to design parameters and application. The challenge is to effectively combining large amounts of data from different sources, with the experience and inherent (tacit) knowledge among current designers and other key personnel in the organizations. Thereby insuring that the data is relevant and related to parameters and/or analysis being performed. The quality of information that is 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.

- Data Generation: Specification and identification of data types to be generated from onboard systems (sensor & embedded devices), pursuant to vessel and stakeholder specifications.
- Data Acquisition: Process for the collection of information from different on-board systems. A lack of reliability in the acquisition system intersects with data quality. Particularly due to the possibility that if the solution falters, belief in the truthiness of data, and thus of the whole systems is impacted.
- Data Management: Process of storage, processing and management of the vessel data. Requiring that the data be available to all personnel involved in the design process, whilst respecting privacy and delivering data security to vessel stakeholders.
- Data Exploitation: interfacing PUI and sensor generated data into analytics and product development related applications (e.g. CAD) for decision-making and design improvement. Facilitating the establishment of the direct transfer from data to knowledge and support of design and development related decisions to allow e.g., comparisons between simulated vessel behaviors and physical tests.

As discussed subsequently, the framework considers not only specialty vessels but also different product generations (a pilot product and its successors), which could extend the usefulness of the data and information gathered from each real case, facilitating relevant components to be assessed, ensuring integration compatibility, performance, and their ability to fulfill stakeholder requirements. This, for instance, could relate to speed data, which during the usage phase is captured from the engine (or GPS sensor), but in the design phase of the vessel serves as a required value for calculations referring e.g. to the shape of the hull.

A. Data Generation

According to vessel characteristics and stakeholder requirements, the specification of data types is established, and transmission capabilities verified. This process considers:

- 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;
- Beneficiary of the data (designer, engineer, or another stakeholder).

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

B. 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. Interest by boat and sailing enthusiasts to collect such data from their boats and obtain a complete overview of the voyages they make is increasing. Prominent open-source projects provide software and hardware that collects various data streams from boat's networks, and present the owner with visualizations of the data on their smartphones and send the data of the boat to cloud services for persistent storage.

Data acquisition occurs through both a single board computer (open-source or proprietary hardware) and physical connectors to the NMEA networks. The single board computer saves information to a database with timestamps. This provides a good 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. For instance, impacts on the hull due to higher speeds and waves requires specific sensors and more effort to integrate the data, which the many acquisition systems do not provide in "off-the-shelf" cases. Subsequent sections provide detailed information on the data acquisition aspect through the Universal Marine Gateway solution. It is also important to understand during the data acquisition phase for different data streams, where exactly the sensors installation takes place within the vessels. Appropriate installation of sensors within the vessel add more context to the data streams. Verification and analyses of such contextual data streams adds more value as the data is now utilizable for vessel designers/ engineers for short- and long-term planning.

Positioning and calibration of sensor nodes is vital to provide accurate information as well as adding more context to the dataset during data collection phase. An example of obtaining the orientation of the vessel as well as the impacts on the critical section like hull of the vessel is achievable by using IMU (Inertial Measurement Unit) sensors.

IMU are digital sensors that utilize the magnetic and gravitational fields of the surrounding environment and provide information such as linear acceleration, G-Force and orientation in three-dimensions. Information like acceleration at certain points of interest are utilized during design phase in order to understand the response of the vessel when impacted with strong waves. A practical use-case is an IMU sensor placement in the hull of the vessel where it can measure the orientation as well as acceleration that the vessel experiences during voyages or sea-trials. The next phases of the vessel design utilize this collected information. During deployment phase, calibration of the IMU provides accurate orientation and acceleration values according to the surrounding (hull).

This provides accurate information relevant for the data acquisition phase but cannot address the issue of how this information is relevant for a designer for further usage.

A solution to resolve this issue to align the sensor during installation according to the geometrical parameters such as the keel-line or the waterline of the vessel. Such theoretical information can be used in conjunction with the data acquisition phase and provide datasets which can be handled not just for data-analytics but also future design/engineering usage. Fig. 4 provides an illustration of how a sensor placed parallel to the waterline can in fact, provide inclination (pitch) values that is observable on a qualitative level and not just quantitatively in terms of a large dataset.

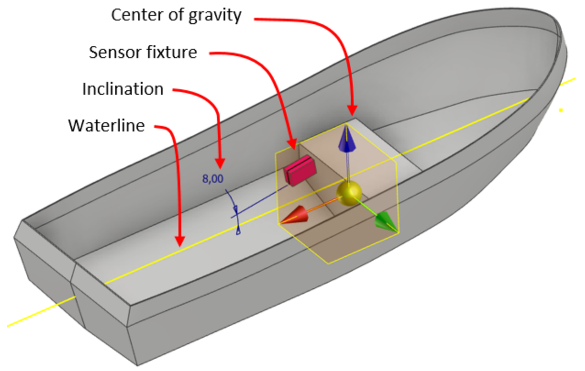

Fig. 4. Positioning of IMU sensor with respect to Water-Line of Vessel

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 centre of gravity has to be identified and provided for the mesh-model (spatial model) used for the CFD calculations. While a "theoretical" centre of gravity can be calculated by CAD systems (indicated by coordinate origin in Fig. 4), the centre of gravity under operating conditions can differ.

C. *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 is 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.

Support via persistent technologies & databases provide long-term data storage facility. To store data, several rule blocks are provided, supporting different databases and storage forms (Fig. 2):

- Time-JSON (JavaScript Object Notation): generic JSON payload, with timestamp;
- Time-Decimal: a decimal value associated with a timestamp;
- Interval: an event data structure, identified by a UUID (Universally Unique Identification) and presenting a start date, an end date and a string value.

Data visualization within the framework is the process to store received data through a GUI pipeline. This concept potentially allow for the binding of several instances across multiple environments: For example, generated low-level data is sent for processing or aggregation in real-time. A critical task of obtaining dedicated information from different parts of the vessel is data acquisition and management. A sophisticated data acquisition considers the requirements of integrating different types of sensors and transferring information in a predefined way. This is achievable via UMG.

The Universal Marine Gateway (UMG) is a data acquisition system that has been developed previously over previously EC-funded research projects "BOMA-Boat Management" (EU FP7, 12/2011 – 11/2013), "ThroughLife" (EU FP7, 04/2011 – 03/2014) and "Fortissimo – HighSea Experiment" (EU FP7, 10/2014-12/2016) that has the ability to meet the aforementioned requirements of integrating different sensors and on-board systems. It provides a wide range of hardware and software interfaces that facilitate the integration of different analogue and digital data sources like sensors and on-board systems. Fig 5 illustrates the architectural overview of the UMG. It consists of a Gateway Core, which is an industrial grade Single Board Computer (SBC) with a custom operating system. It is capable of storing persistent information from data sources into a Time-Series Database (TSDB). The TSDB comprises of measurements successively added to it through various data sources and validated through timestamps during acquisition.

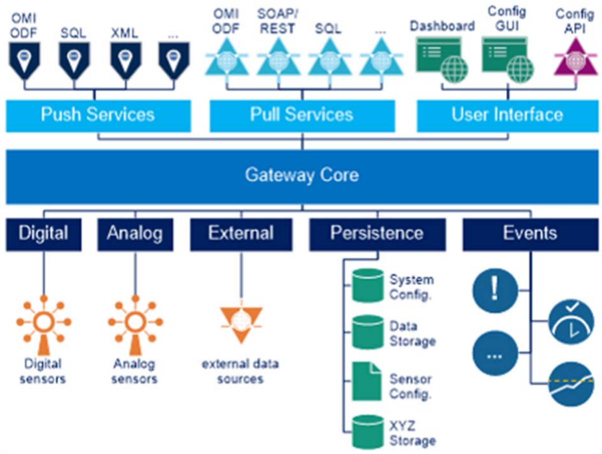

Fig. 5. Universal Marine Gateway Architecture Diagram

The UMG leverages the power supply from the vessel for its operation and has the ability to form an Ethernet network with the so-called UMG Nodes through a Power-over-Ethernet switch. The UMG Nodes are sensor nodes comprising of a small microcontroller and the ability to interface digital and analog sensors directly to them through standard interfaces. These nodes then pre-process the data from the sensors and send the information to the UMG, which in turn saves the information to the TSDB. A finite number of such nodes with the UMG form a sensor network that is deployable on the vessel. The challenge for providing power supply to each of the sensor nodes individually is overcome using the Power-over-Ethernet (PoE) switch. PoE also provides plug-and-play networking abilities for easier integration of multiple UMG Nodes on the same network making placement more flexible at desirable locations of the vessel. Fig. 6 provides a block diagram of the UMG network that is formed using UMG Nodes and other Ethernet compatible devices. As opposed to other open-source data acquisition boxes like Signal K [22], the UMG and Nodes provide data sources that can be more critical and desirable for vessel design as opposed to only on-board systems like NMEA2000 or NMEA0183.

The UMG Nodes for the LINCOLN project comprise of IMU (Inertial Measurement Units) sensors integrated into them, which provide vector measurements in three-dimensions (X, Y, Z directions). These sensors include a magnetometer, accelerometer and gyroscope which provide orientation of the boat i.e. Yaw, Pitch, Roll (Euler Angles) at the point of installation. Installation of such UMG Nodes within the vessel at specific points are important from design or test perspective in order to obtain large sets of orientation as well as acceleration data, which can be post-processed to obtain concrete results or inferences during vessel sea trials / voyages.

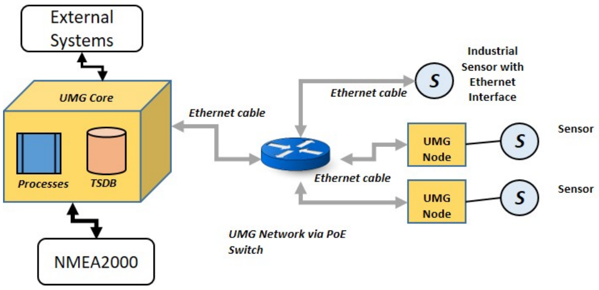

Fig. 6. A Typical UMG Network Setup Block Diagram

As illustrated in Fig. 6, industrial sensors with universal interfaces like CAN or Ethernet allow for serviceability and optimized integration. Within LINCOLN, a Laser Deflection sensor deployment is used to monitor the effects of waves hitting sensitive parts of the hull and the data collection was possible over a sea-trial through the UMG network.

D. 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. As outlined below the information can be exploited "automatically" by incorporating a coupling to Knowledge Based Engineering (KBE) solutions. This provides value to both engineers and designers, but also can be of great value for suppliers or third-party affiliates e.g., charter companies or classification societies.

1) Knowledge Based Engineering

The approach for the coupling of PUI and sensor generated data to KBE solutions is based on KbeML. Originally, the approach has been developed as a formal extension of SysML, to facilitate a formal and neutral representation of engineering knowledge independent from any KBE related framework. KbeML aims to capture codified knowledge, such as rules and equations [23], [24]. KbeML objectives are:

- 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 [23], [25]. These elements support the idea that usage related information can be mapped directly to design related elements such as equations or rules. Since KbeML serves to facilitate the codification of design & engineering knowledge in a graphical way, the different element types are represented with their own unique appearance, based on the inherent type of knowledge (PUI or engineering) and thus allowing easy recognition by the domain experts.

The validation of the KbeML approach has been related to the early-design calculations for a Multi-Platform Catamaran concept. For this purpose LINCOLN partner Techno Pro provided spreadsheet files showing calculation procedures as being used for their vessel design which originate in standard and rules of ABS [26]. In Fig. 7, a sample is provided with a block containing some Vessel characteristics and a Constraint-Block representing the Block Coefficient according to section 3.1.1 of ABS (Fig. 7). The *block coefficient* of a ship is the ratio of the underwater volume of ship to the volume of a rectangular block having the same overall length.

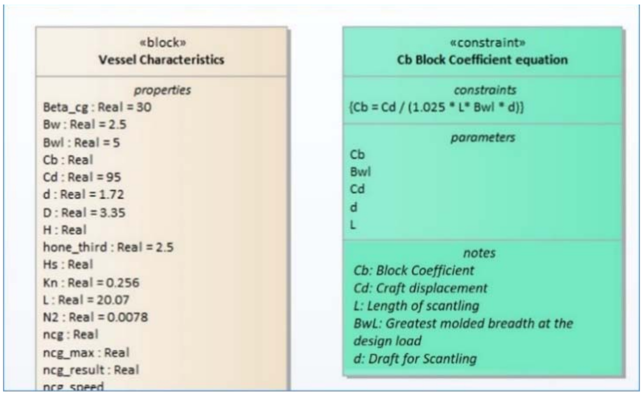

Fig. 7. Definition of Block Coefficients

For the assignment between the "concrete" Vessel parameters and the Block Coefficient equation, a parametric diagram is defined. As illustrated in Fig. 8 the parameters of the equation are linked with the inherited parameters of the Constraint-Block (which are placed as "Mini"-Blocks inside).

The "equal" connectors define the concrete linkage and enable a semantic interpretation of the diagrams.

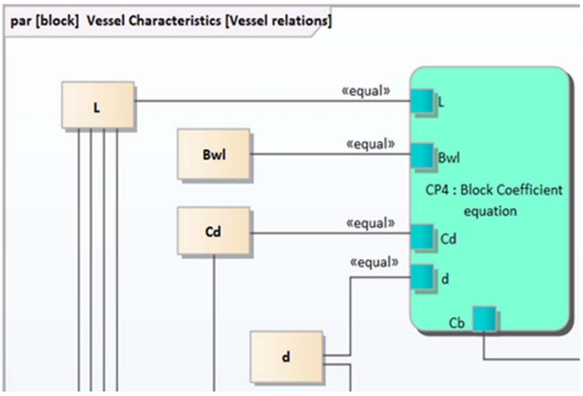

Fig. 8. Block Coefficients Equations defined in a Parametric Diagram

Following these principles, usage parameters can be linked to the calculations as well enable the direct link between usage and design related parameters. 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 also be extracted from the usage phase and provided to the vessel designers. As outlined in Fig. 9 the craft speed can be linked to a dataset referring to measured speed over water values to provide an average speed as being set by the static rule. If max, mean or similar aspects are to be considered the dependencies can be represented without further effort simply by changing the corresponding KbeML element (so-called statistical element) as being described in more detail in Fig 9.

Accordingly, the sample indicates that if engineering knowledge (equations and rules) is captured in KbeML/SysML it gets directly "linkable" to the PUI. This leads to another aspect in KbeML, which aims at transparency in terms of what kind of usage data analysis has been conducted for which part and/or step of the design process.

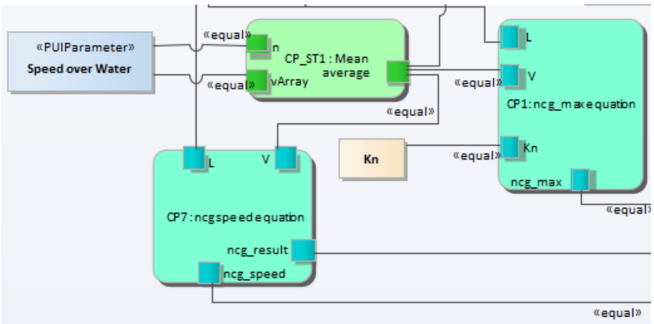

Fig. 9. PUI Parameter: Engine Speed Used for NCG Equations

KbeML allows a broad range of calculations to be linked to PUI and sensor generated data. Corresponding use cases can e.g. cover the impact of varying hull materials, based on NMEA-captured engine parameters that will be gathered from the real vessels as well as the determination of the appropriate thickness of shells and related hull components in relation to real vessel data (and in relation to a given material).

Further, the formal notation and its underlying semantic meaning allow the post-processing and linkage to the design and development related application. Exemplarily, Fig. 10 shows the initial proposal for a linkage of KbeML models to the virtual towing tank application LINCOSIM [27] by usage of KbeML elements; which represent the LINCOSIM input parameters. In the given sample, the *Wave Height* parameter is in relation to a corresponding equation of the ABS rules.

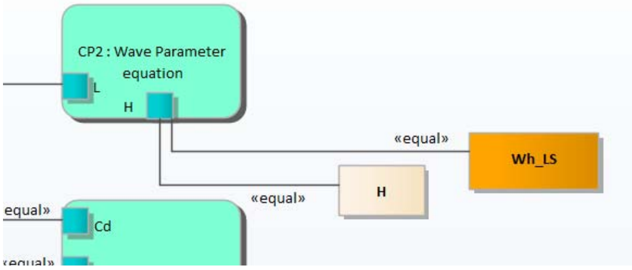

Fig. 10. Draft for a Predefined HPC Element in KbeML Notation

Finalization of KbeML is to be determined based on the successfulness of the codified knowledges used as inputs for HPC computations. Providing a support structure for future automated knowledge transfer into programs beyond CAD (HPC virtual towing tank, LINCOSIM (according to Fig. 1).

2) Traceability of Usage Data

The KbeML models allow transparency in terms of what kind of usage data analysis has been conducted for which part and/or step of the design process. The analysis of the way the data is processed in terms of if a mean or max or min value (or other statistical functions) has been used to feed design information influences the overall calculation.

To illustrate the requirement to model explicitly the usage data analysis among with the rest of the calculations the acceleration and directions captured in Fig. 8, 9, 10, with the UMG may serve as an example. If for instance one would like to know the average acceleration values per trip, there can be different ways to calculate the average acceleration:

- Each direction is captured as a dataset, the average per period is calculated and a mean of the direction-related part of the acceleration is provided. Afterwards the acceleration is calculated based on the three mean partial accelerations as the length of a 3D vector.
- For each entry triple of the dataset, the acceleration is calculated per timestamp. Afterwards the mean among the acceleration per timestamp is calculated.

Since both ways lead to slightly different results, the traceability of the data processing is a pre-condition to share a common understanding among the development teams for vessel design and in addition provides valuable support for classification and certification.

V. Conclusion

This paper is part of a greater combined research effort represents preliminary and ongoing work related to the LINCOLN project. Based on research approach introduced in Section II, the LINCOLN Design Approach aims to support and improve the vessel design process of specialized vessels through a sustainable, cost advantageous manner.

A. Limitations

Keeping in mind the requirements of the stakeholders of the vessels, it becomes eminent that not all information is directly available from various on-board systems and sensors. Since there is no *a priori* knowledge of the needs for the vessel design, challenges to find sensors that can measure parameters directly or indirectly can impede the framework usage. Such a limitation could require considerable amount of effort and resources in order to achieve the mapping between the requirements and real data collected from the vessels.

Further transferability and mapping of parameters between different product generations are crucial since the structural characteristics might change, as data from one generation may not be suitable for the next generation of products e.g., data from sea-trials becomes unreliable due to disruptive radical hull structure changes (mono design to catamaran).

B. Concluding Remarks

The preliminary framework and phases discussed in this paper therefore aim to address the inherent challenge related to the incorporation of data streams in the design process, in order to provide valuable information to designer, engineers and potentially other stakeholders in the maritime industry.

Different design options have been considered, to evaluate datasets coming from real-time data to extract and select the best concept and improve the quality of the resulting vessel. The data currently gathered through PUI and sensors is being analysed and processed to verify conformity and compatibility with software and stakeholder needs, such as designers, shipbuilders, suppliers and maintenance companies and so on. Based on preliminary results and previous research, the use of PUI and sensor data in the decision-making process can be utilized to validate simulation models for boat hull behaviour [28]. The current state of the data integration approach has demonstrated strong potential with sea-trials currently underway to measure data accuracy and data processing capabilities. However, there are further refinements and details expected to be made between the statuses presented in this paper to the final project implementation. Validation of the framework occurs through the industrial partners (boat manufacturers). The experts from the sector will test the different components of the LINCOLN Design Approach forming a closed-loop validation system.

C. Future Works

We are currently working to verify the framework and establish KPI's to measure the efficacy of data incorporation into the design process. Simultaneously, we are integrating the UMG and PUI data with the HPC "LINCOSIM" system. Additional efforts in collaboration with industrial partners are underway to confirm the reliability and relevance of the data, and its ability to integrate with existing protocols. Through these ongoing efforts we aim to create a concrete framework that incorporates feedback from the usage phase for design adaptions, improvements, and optimization.

ACKNOWLEDGMENT

This research is part of the LINCOLN project (EU H2020 Grant No. 727982). The authors wish to acknowledge the European Commission and all LINCOLN project partners for their collaboration.

REFERENCES

[1] R. Luglietti, S. Wurst, C. Sassanelli, S. Terzi, and C. M. Martín, "Towards the definition of specialized vessels ' model," in 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), 2018.

[2] H. Thanopoulou and S. P. Strandenes, "A theoretical framework for analysing long-term uncertainty in shipping," Case Stud. Transp. Policy, vol. 5, no. 2, 2017

[3] M. Mirović, M. Miličević, and I. Obradović, "Big Data in the Maritime Industry," Naše More - Int. J. Marit. Sci. Technol., vol. 65, no. 1, pp. 56–62, 2018.

[4] IHS Markit, "Five trends shaping the global maritime industry," 2016.

[5] Lützenberger, Johannes, Patrick Klein, and Klaus-Dieter Thoben. 'Successful Exploitation of Product Usage Information for the Design of Product Service Systems Using the Capabilities of a Formal SysML&UML Extension.' Procedia CIRP IPSS 2016 (2016).

[6] C. Vossen, R. Kleppe, and S. Randi, "Ship Design and System Integration," no. September, 2013.

[7] A. F. Molland, The Maritime Engineering Reference Book, 1st ed. Butterworth-Heinemann, 2008.

[8] R. Hamann and J. Peschmann, "Goal-Based Standards and Risk-Based Design," Sh. Technol. Res., vol. 60, no. 2, pp. 46–56, 2013.

[9] A. Papanikolaou, Risk-Based Ship Design: Methods, Tools and Applications. Springer, 2009.

[10] J. Evans, "Basic Design Concepts," Nav. Eng. J., pp. 671–678, 1959

[11] F. Mistree, W. F. Smith, B. A. Bras, J. K. Allen, and D. Muster, "Decision-Based Design: A Contemporary Paradigm for Ship Design," Soc. Nav. Archit. Mar. Eng. Annu. Meet., vol. seminar, p. seminar, 1990

[12] I. L. Buxton, Engineering Economics and Ship Design, 2nd ed. British Ship Research Association, 1976.

[13] D. Andrews, Creative Ship Design. RINA, 1981.

[14] H. L. Brinati, O. B. Augusto, and M. B. De Conti, "Learning Aspects of Procedures for Ship Conceptual Design Based on First Principles," Int. Conf. Eng. Educ., no. June, pp. 3–7, 2007.

[15] N. L. Trivyza, A. Rentizelas, and G. Theotokatos, "The influence of ship operational profile in the sustainability of ship energy systems," in International Conference of Maritime Safety and Operations 2016, 2016.

[16] P. Pakkanen and E. Henttinen, "How Data Is Shaping the Future of Vessel Design , Navigation and How Data Is Shaping the Future of Vessel Design , Navigation and," in Smart Ship Technology, 2016, no. January.

[17] C. C. Røstad and B. Henriksen, "ECO-Boat MOL Capturing Data from Real Use of the Product," in PLM 2012, IFIP AICT 388, 2012, pp. 99–110.

[18] H. M. Gaspar, "Data-Driven Ship Design Data-Driven Ship Design," no. May, 2018.

[19] M. E. Porter and J. E. Heppelmann, "How Smart, Connected Products Are Transforming Competition," Harv. Bus. Rev., no. November, 2014.

[20] Y. Raptodimos, I. Lazakis, G. Theotokatos, T. Varelas, and L. Drikos, "Ship sensors data collection & analysis for condition monitoring of ship structures & machinery systems," RINA, R. Inst. Nav. Archit. - Smart Sh. Technol. 2016, Pap., no. January, pp. 77–86, 2016.

[21] B. P. Sullivan, M. Rossi, C. Sassanelli, R. Luglietti, L. Ramundo, and S. Terzi, "LINCOLN Integrated Solution Supporting the Design of Specialized Connected Vessels," in XXIII Summer School "Francesco Turco" – Industrial Systems Engineering LINCOLN, 2018, pp. 250–256.

[22] Signal K Project Website. https://signalk.org Accessed on: 14/04/2019

[23] P. Klein, J. Lützenberger, and K.-D. Thoben, "A Proposal for Knowledge Formalization in Product Development Processes," in INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15, 2015, no. July, pp. 1–12.

[24] P. Klein, D. Pugliese, J. Lützenberger, G. Colombo, and K. D. Thoben, "Exchange of knowledge in customized product development processes," 24th CIRP Des. Conf., vol. 21, no. May 2015, pp. 99–104, 2014.

[25] J. Lützenberger, P. Klein, K. Hribernik, and K. D. Thoben, "Improving Product-Service Systems by Exploiting Information from the Usage Phase. A Case Study," Procedia CIRP, vol. 47, no. December, pp. 376–381, 2016.

[26] A. B. of S. ABS, . "High-Speed Craft. Rules for Building and Classing," 2012.

[27] Ponzini, R., & Salvadore, F. (2018). LincoSim: a web based HPC-cloud platform for automatic virtual towing tank analysis. arXiv preprint arXiv:1810.09830.

[28] M. von Stietencron, K. A. Hribernik, C. C. Røstad, B. Henriksen, and K.-D. Thoben, "Applying Closed-Loop Product Lifecycle Management to Enable Fact Based Design of Boats," 2017, pp. 522–531.